Assessment of Low Cost Small Format Aerial Photogrammetry for Cadastral Mapping (Case Study in Klaten Regency, Central Java, Indonesia)

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Key words: Small Format Aerial Photogrammetry (SFAPm), low cost technology, cadastral mapping, map accuracy

SUMMARY

In region with rapid growing economic and population, such as Klaten Regency, Central Java, Indonesia, availability of cadastral infrastructure plays important role in land management. It is also useful to anticipate conflict due to parcel ownership and parcel usage in future. Commonly, in Indonesia, production of cadastral and parcel data utilizes terrestrial mapping or standard aerial photogrammetric mapping. Terrestrial mapping using Total Station has exellent accuracy, but it is expensive and time consuming. Standard aerial photogrammetric mapping is suitable for moderate area and has good accuracy, but it needs expensive equipment, for instance: aerial metric camera. For limited area coverage, about 1.000 hectare, Small Format Aerial Photogrammetry (SFAPm) has advantage in low cost equipment and its operational, efficient, and rapid photo acquisition. This technology is efficient since it utilizes amateur digital camera or non metric digital camera equipped on ultra light aeroplane. This non metric digital camera is widely available on market.

This paper elaborates utilization of low cost SFAPm for cadastral mapping in Klaten Regency, Central Java, Indonesia. The study was carried out in 7 stages, i.e. developing Ground Control Points (GCP), aerial photography survey, interior orientation for each photo, aerial triangulation for entire block photos, performed orthophoto and mosicking, interpretation and delineation of land parcel, and finally evaluation.

Research shows developing premark and coordinate adjustment for GCP and photogrammetric processing consumed a lot of time, but duration for set up digital camera on ultra light aeroplane was about 2 hours and less than an hour for taking 310 aerial photos in flight. Measured parcel's area by on screen digitizing and by terrestrial is almost similar on clear area. And, small format aerial photogrammetry is able to speed up parcel indentification and measurement, but it still needs to be verified by in-situ investigation

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1. INTRODUCTION

Development of Land Information System needs georeferenced spatial data in order to identify position of registered or certified parcels on field and also their attribute data, such as parcel ownership, kind of right, and parcel usage. Both data, spatial and attribute data, have implication on law assurance. In this case, law assurance covers certainty of subject, object, and relation between subject and object of the parcel.

Law assurance due to object (parcel) relates to its area, position, border, and shape. In Indonesia, in order to guarantee law assurance, parcel must be able to be measured and mapped on Land Registration Map (*Peta Pendaftaran Tanah*). Land registration can be carried out in 2 ways, sporadic or systematic.

For parcels that distributed in separate location, sporadic land registration is chosen. Unfortunatelly, this method can cause flying parcel. Flying parcel refers to parcel which has been registered but it could not be mapped, so it was difficult to be identified on a map. In future, existence of flying parcel can cause double certificate, overlapping parcel, and parcel border dispute.

Mapping of flying parcels need identification of these parcels on field and development of Technical Base Point (TDT) for unification of land parcels on Land Registration Map. Small Format Aerial Photography (SFAP) which consists of processed photos using photogrammetric methodology and called as Small Format Aerial Photogrammetry (SFAPm), can be utilized to recognize, identify, and interpret land parcel on photos visually. This method can reduce field work, and of course, budget. SFAPm also can be used for systematic land registration, which parcels' border are coincided in same region. SFAPm was expected to be low cost, rapid, and efficient techology for cadastral mapping.

This paper elaborates utilization of low cost SFAPm for cadastral mapping in Klaten Regency, Central Java, Indonesia.

2. METHODOLOGY

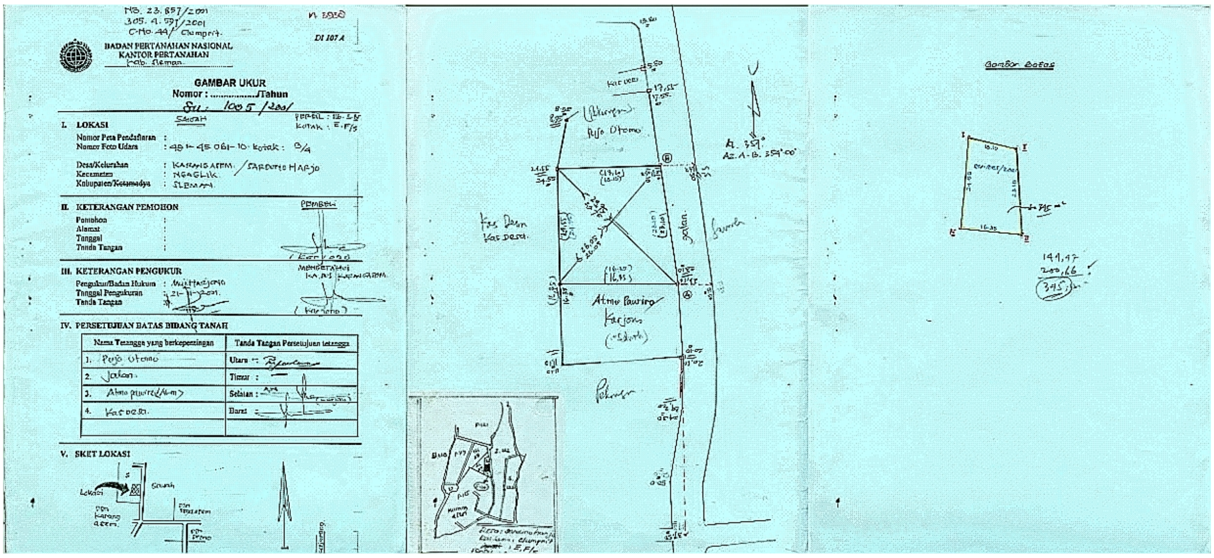
2.1 Theoretical Background

2.1.1 Land Registration Mapping

Basic principle of land parcel measurement for land registration must fulfill technical specification of land measurement and mapping, so the border and position can be identified clearly on map. Practically, land measurement can be carried out in 2 ways, sporadic or systematic. Systematic land measurement is measurement of massive and clustered parcels on a village or more for land registration. Sporadic land measurement is measurement of one or some parcels which the position are separately in a village.

In order to guarantee law assurance for object of land parcel that will be registered, the parcel must be able to be observed and mapped on land registration map. Before parcel measurement conducted, parcel border needs to be determined by person in charge based on agreement among adjacent parcel owners. Agreement of border determination usually called as principle of *Contradictoire Delimitatie* (Hermanses, 1965 in Yuwono, et al., 2008).

In Indonesia, parcel measurement must be recorded on standard BPN's measurement form (*GU- Gambar Ukur*, see Figure 1). On GU document, all of measurement quantities, such as: distance, angle, azimuth, sketch of both parcel and its surrounding, are recorded. Notes on GU document must be able to reconstruct parcel's location and its border. This is very useful, for instance, in case the border's monuments can not be found in field. A GU document can be used to record data of some parcels.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BADAN PERTANAHAN NASIONAL
KANTOR PERTANAHAN
GAMBAR UKUR
Nomor : ..../Tahun
I. LOKASI
Nomor Peta Pendaftaran :
Nomor Foto Udara :
Desa/Kelurahan :
Kecamatan :
Kabupaten/Kotamadya :
II. KETERANGAN PEMOHON
Pemohon :
Alamat :
Tanggal :
Tanda Tangan :
III. KETERANGAN PENGUKUR
Pengukur/Badan Hukum :
Tanggal Pengukuran :
Tanda Tangan :
IV. PERSETUJUAN BATAS BIDANG TANAH

Nama Tetangga yang berkepentingan	Tanda Tangan Persetujuan tetangga
1.	Utara :
2.	Timur :
3.	Selatan :
4.	Barat :

V. SKET LOKASI

Figure 1. An example of Indonesian GU or measurement form (Yuwono, et. al, 2008)

Land registration map, a kind of thematic map, is a map which inform about shape, borders, location, and number of each land parcel and it can be used to record the parcel. Land registration map is georeferenced in specific map coordinate system and composed on specific map's lay out. Specific map coordinate system means land registration map is formatted on local or national coordinate system. Entire parcels which covered on map must be able to be reconstructed on field. Specific map's lay out means land registration map needs to follow specific map's lay out which determined by Indonesian National Land Agency (BPN, Badan Pertanahan Nasional).

2.1.2. Small Format Aerial Photogrammetry

Warner, et. al (1996) stated Small Format Aerial Photography (SFAP) is aerial photo which acquired using 24 mm x 36 mm camera frame and has lenght of focus about 35 mm. Lens system of the camera is not designed for mapping purposes, so their interior orientation parameters, such as coordinate of fiducial marks, calibrated focal length, pinciple points, and distortion parameters are unknown. This camere could be analog or digital. SFAP or SFAPm has advantages, i.e. widely available of amateur digital camera on market, low cost equipment and its operational, and data or photo is up to date. Unfortunately, this technology is not designed for mapping application, due to inaccuracy and instability of camera system, which in photogrammetry community is ussualy recognized as interior orientation parameter (IOP). Utilization of ultra light aeroplane also contibutes to instability of position and orientation of camera exposure center (Harintaka, et.al, 2009). For large area coverage and height spatial accuracy intended, standard metric aerial photogrammetry is still effective and efficient technology.

Theoretical background or mathematical models of SFAPm is exactly similar with analytical photogrammetry. In order to obtain precise spatial information, processing of photos acquired using SFPm follows standard photogrammetric procedure, i.e. interior orientation, relative orientation, and bundle adjustment or aerial triangulation.

In analytical photogrammetry, there is 3 coordinate systems, i.e. photo coordinate system, relative or model coordinate system, and absolute or ground coordinate system. Photo coordinate system is two dimensional cooordinate system which its origin is cross of perpendicular lines from fiducial mark or photo corner. Aerial photo acquired using non-metric digital camera has image coordinate system which its origin on the top left of image. To conduct photogrammetric process, image coordinate system needs to be transformed onto photo coordinate system. This coordinate transformation is called interior orientation and performed using two dimensional affine transformation (equation 1). To solve equation (1), minimum 3 corners position of image are required and least squares estimation is performed.

$$x = a_1 + a_2 u + a_3 v$$
$$y = a_4 + a_5 u + a_6 v \qquad (1)$$

where,

x, y : photo coordinate system
u, v : image or pixel coordinate system
$a_1, \ldots, a_6$: affine's parameter transformation

Geometric relationship between photo coordinate system and ground coordinate system is expressed by bundle ray (Figure 2). Point P (on the ground), p (on photo), and o (projection center) lies on straight line or bundle ray. Based on this principle, mathematical model can be developed and known as 3D conformal transformation (equation 2).

$$\begin{pmatrix} X_p \\ Y_p \\ Z_p \end{pmatrix}_{Ground} = \begin{pmatrix} X_o \\ Y_o \\ Z_o \end{pmatrix} + \lambda R \begin{pmatrix} x_p \\ y_p \\ f \end{pmatrix}_{Photo} \qquad (2)$$

where,

X_p, Y_p, Z_p : position of P point on ground coordinate system
X_o, Y_o, Z_o : position of camera projection center
x_p, y_p, z_p : position of p point on photo coordinate system
λ : scale factor
f : focus

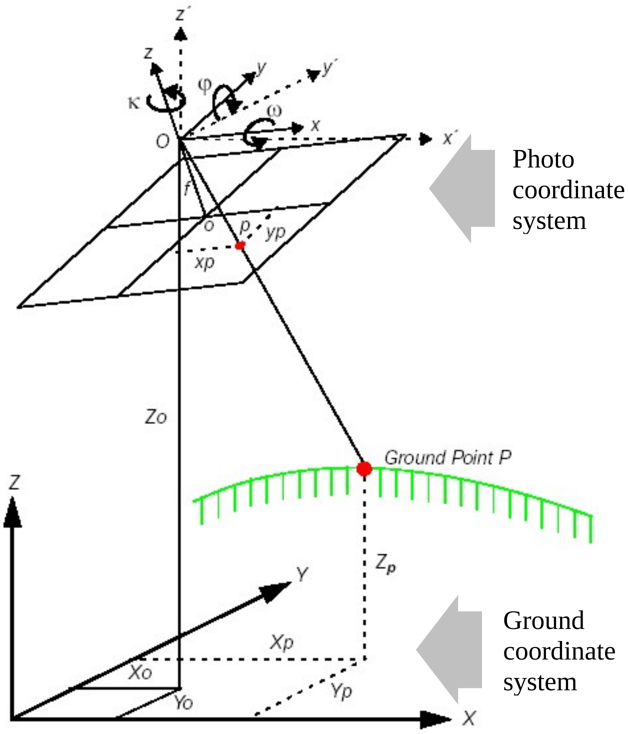


Figure 2. Relationship between photo coordinate system with ground coordinate system (Leica Geosystem, 2005)

Inversion of equation (2) is equation (3). In equation (3), photo coordinate is a function of ground coordinate. In this case, r_{11}, …, r_{33} are elements of rotation matrix R^T and function of roll, pitch, and yaw.

$$\begin{pmatrix} x_p \\ y_p \\ -f \end{pmatrix} = \frac{1}{\lambda} \begin{pmatrix} r_{11} & r_{21} & r_{31} \\ r_{12} & r_{22} & r_{32} \\ r_{13} & r_{23} & r_{33} \end{pmatrix} \begin{pmatrix} X_p - X_o \\ Y_p - Y_o \\ Z_p - Z_o \end{pmatrix} \quad \text{——— (3)}$$

Based on equation (3), if first row and second row are divided with third row, collinear equation is obtained (equation 4).

$$x_p = -f \frac{(r_{11}(X_p - X_o) + r_{21}(Y_p - Y_o) + r_{31}(Z_p - Z_o))}{(r_{13}(X_p - X_o) + r_{23}(Y_p - Y_o) + r_{33}(Z_p - Z_o))}$$
$$y_p = -f \frac{(r_{12}(X_i - X_o) + r_{22}(Y_i - Y_o) + r_{32}(Z_i - Z_o))}{(r_{13}(X_i - X_o) + r_{23}(Y_i - Y_o) + r_{33}(Z_i - Z_o))} \quad \text{——— (4)}$$

Equation (4) express that point on the ground, on photo, and projection center lies on straight line (Figure 2). This collinear equation has 6 unknown parameters, i.e. ω, φ, κ, X_o,

Y_o, Z_o for each photo. To obtain these parameters, equation (4) has to be linearized to each parameter using Taylor series' as shown on equation (5).

$$x_p = (x_p)_o + \frac{\delta x_p}{\delta x_o}\delta x_o + \frac{\delta x_p}{\delta y_o}\delta y_o + \frac{\delta x_p}{\delta z_o}\delta z_o + \frac{\delta x_p}{\delta \omega}\delta \omega + \frac{\delta x_p}{\delta \varphi}\delta \varphi + \frac{\delta x_p}{\delta \kappa}\delta \kappa$$

$$y_p = (y_p)_o + \frac{\delta y_p}{\delta x_o}\delta x_o + \frac{\delta y_p}{\delta y_o}\delta y_o + \frac{\delta y_p}{\delta z_o}\delta z_o + \frac{\delta y_p}{\delta \omega}\delta \omega + \frac{\delta y_p}{\delta \varphi}\delta \varphi + \frac{\delta y_p}{\delta \kappa}\delta \kappa \qquad (5)$$

where,

$(x_p)_o$: initial value for x
$(y_p)_o$: initial value for y

In aerial photogrammetry, number of GCP is limited. Theoretically, GCP is distributed for 4-6 basis. To densification GCP can be utilized aerial traingulation (AT). Densification of GCP uses tie point (TP) which appears on overlap area between adjacent 2 photos or more. Traditionally, number of TP between adjacent photo is 6 points and well known as von Gruber point. In computation, all of GCP and TP are adjusted simultaneously using equation (5) and expanded with coordinate of point P, so equation (5) becomes equation (6). This equation is standard equation for AT or AT without AP (Additional Parameter).

$$x_p = (x_p)_o + \frac{\delta x_p}{\delta x_o}\delta x_o + \frac{\delta x_p}{\delta y_o}\delta y_o + \frac{\delta x_p}{\delta z_o}\delta z_o + \frac{\delta x_p}{\delta \omega}\delta \omega + \frac{\delta x_p}{\delta \varphi}\delta \varphi + \frac{\delta x_p}{\delta \kappa}\delta \kappa + \frac{\delta x_p}{\delta x_p}\delta x_p + \frac{\delta x_p}{\delta y_p}\delta y_p + \frac{\delta x_p}{\delta z_p}\delta z_p$$

$$y_p = (y_p)_o + \frac{\delta y_p}{\delta x_o}\delta x_o + \frac{\delta y_p}{\delta y_o}\delta y_o + \frac{\delta y_p}{\delta z_o}\delta z_o + \frac{\delta y_p}{\delta \omega}\delta \omega + \frac{\delta y_p}{\delta \varphi}\delta \varphi + \frac{\delta y_p}{\delta \kappa}\delta \kappa + \frac{\delta y_p}{\delta x_p}\delta x_p + \frac{\delta y_p}{\delta y_p}\delta y_p + \frac{\delta y_p}{\delta z_p}\delta z_p \qquad (6)$$

Aerial triangulation (AT) based on equation (6) can be used to compute:

a. Exterior orientation parameters (ω, φ, κ, X_o, Y_o, Z_o) for each photo on a block.
b. Ground coordinate (X, Y, Z) for each tie point.

All parameters computed from AT process can be used to:

a. develop stereo model by utilizing interior and exterior orientation each photo,
b. establish height accuracy point positioning,
c. extract DTM (*digital terrain model*)
d. perform orthorectification to produce orthophoto

2.2. Data and Equipment

This research utilized 116 photos which divided into 6 flight paths (Figure 3). These photos was acquired using Nixon D2X non-metric digital camera on September 27, 2008. Figure 4.a,b,c show equipping the camera and gyro stabilizer on ultra-light aeroplane. Study area is located at Klaten Regency, Central Java, Indonesia. This research also utilized 34 Premark

Points as GCP (Ground Control Point) and ICP (Independent Check Point) which observed using high precision Total Station (Figure 4.d,e).

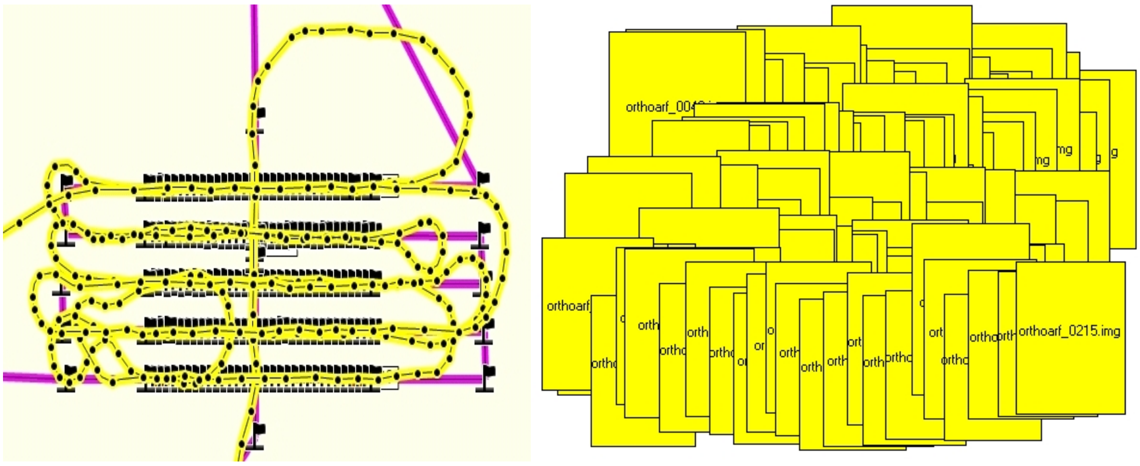


Figure 3. Flight plan (left) and a block of SFAPm (right)

(a). set up equipment on fixed wing ultralight (b). gyrostabilizer (c). Nikon D2X digital camera (d). Nikon Total Station (e). Target for premark

Figure 4. Equipment for aerial photography survey

Based on flight plan, execution of aerial photography survey conducted on 6 flight paths (figure 3). As shown on figure 3, flight plan is in pink and the realization is in yellow. At the time of photo exposure, position of camera was recorded in camera's internal memory. Observation of camera position was utilized a hand held GPS which equipped on ultralight aeroplane. However hand held GPS has accuracy about 2 – 6 m, this information was very useful for identification of each photo position on a flight, and also for initial value in aerial triangulation process. If height accuracy expected, for instance to conduct direct georeferencing, hand held GPS must be replaced by RTK GPS.

2.3. Research Method

Research method can be seen on Figure 5. The reseach was carried out in 7 stages, i.e. developing Ground Control Points (GCP), aerial photography survey, interior orientation for each photo, aerial triangulation for entire block photos, performed orthophoto, interpretation and delineation of land parcel, and finally evaluation.

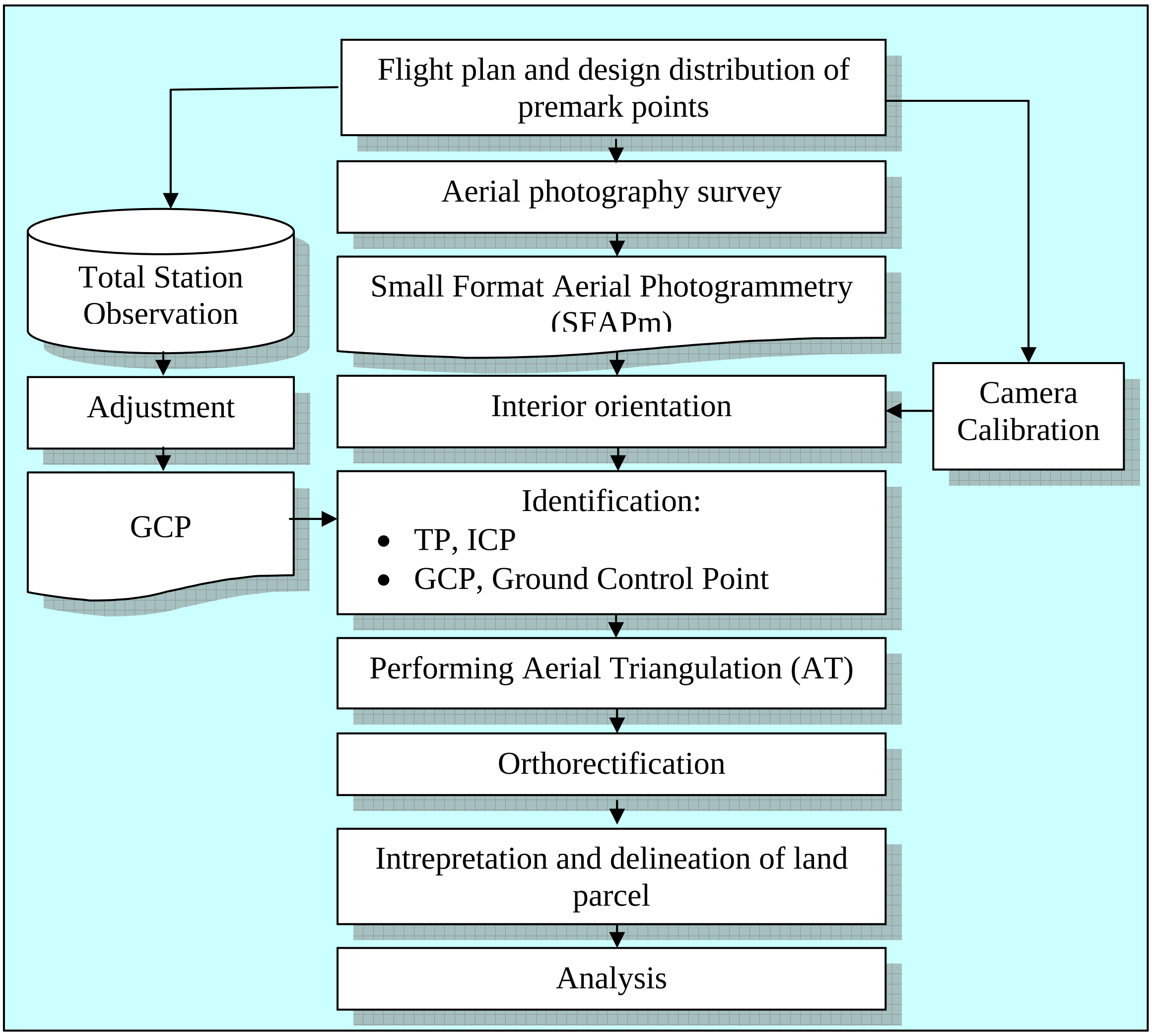


Figure 5. Research method

3. RESULT AND DISCUSSION

In order to obtain height accuracy for aerial triangulation, ground control points must has height accuracy and be able to be identified clearly by established premark target (figure 4.e) before aerial photography survey conducted. In this research, position of premarks were surveyed using Total Station Nikon DTM 352.

Data observed by Total Station was raw data which composed of electronic distance, horizontal angle, vertical angle, and helling. The data needs to be post processed by least squares adjustment to obtain 3D position of premark points. Based on observation, 37 premark points and 50 additional points could be calculated. Positional accuracy obtained was vary between 4.9 mm – 137 mm for abscissa (X), 4,7 mm – 153 mm for ordinate (Y), and 0.3 mm – 7.9 mm for vertical (Z). Developing premark and coordinate adjustment for GCP and photogrammetric processing consumed a lot of time, it was approximately 2 weeks for field campaign and post processing the data.

Aerial photography survey covered 4 villages, i.e. Banyuripan, Beluk, Nengahan, and Jarum, which located in Bayat subdistrict, Klaten regency, Central Java, Indonesia. Execution of aerial photography survey conducted on 6 flight paths. Each flight path had 25-35 photos. Each photo composed by 4.288 x 2.848 pixels with CMOS size equalled to 5.5 micron, so in the ground it was equivalent to 720 m x 420 m and 20 cm for GSD (ground sample distance). One of useful feature of the camera was ability to record detail metadata, such as: camera setting, and GPS data on exif format. Duration for set up digital camera on ultra light aeroplane was about 2 hours and less than an hour for taking 310 aerial photos in 6 flights.

Due to instability of the non-metric digital camera, determination of interior orientation parameter or instrinsic parameters was conducted using insitu camera calibration. For this purpose, it was conducted 5 times flight exposures that covered 10-15 premark points for each photo.

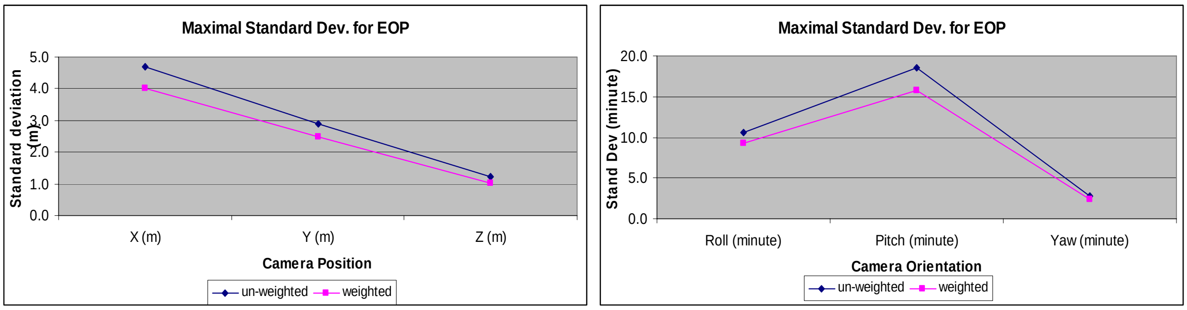
Instrinsic parameters and systematic distortions were corrected for each photo in interior orientation stage. Systematic distortions which involved in this computation were refraction and earth curvature. Computation showed parameter transformation for each photo had the same value, and the residual value varied between $2x10^{-6}$ mm - $15x10^{-6}$ mm.

Aerial triangulation was performed to compute exterior orientation parameter or EOP (ω, φ, κ, X_o, Y_o, Z_o) for each photo on a block and ground coordinate for each tie point. So far, there were 2 kinds of AT, i.e. standard AT and AT with additional parameter. AT with additional paremeter could be divided into 5 models, i.e. Brown, Bauer, Ebner, Jacobsen, and lens distortion. In this case, AT with lens distortion parameter was chosen since this method had superior performance rather than the others (Harintaka, et al, 2009). AT was performed for 116 photos simultaneously.

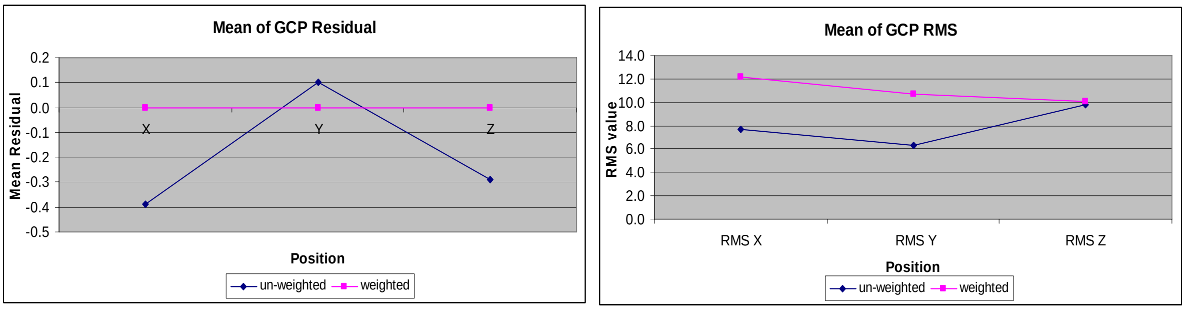
In order to improve accuracy, all of observation data was added by weight. Weight referred to assign degree of accuracy or standard deviation for each observation/measurement. In this case, point measurement on photo coordinate system assigned with weight equal to 1/3 pixel and 10 cm for GCP. Figure 6 shows accuracy indicator for AT with weight and without weight. As seen on figure 6, small value indicates better accuracy. All graphic show AT with weight has superior accuracy.

EOP which obtained by AT in a block of photos could be used to compute 3D ground coordinate of entire point in overlap area. Mathematical model which used to compute 3D ground was referred as space intersection. In a block or strip, as far as overlap area was exist, DEM (Digital Terrain Model) could be extracted.

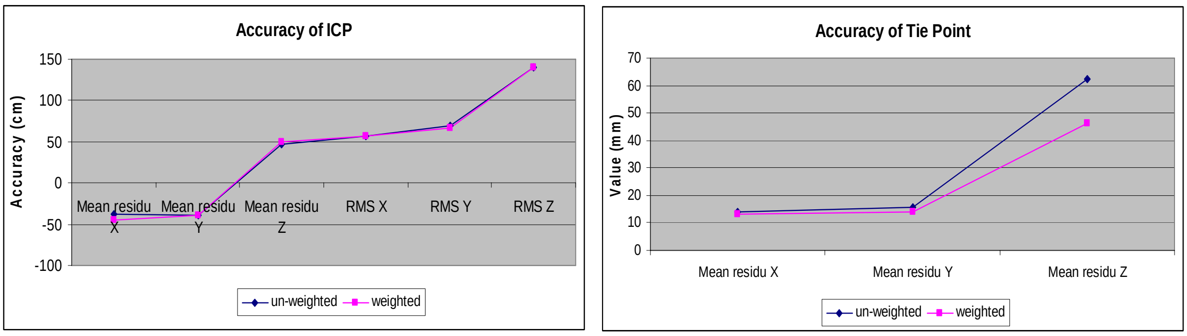
The way to generate DEM from 2 photos or more could be manual or automatic. Manual method needs a stereo viewing so an operator can see stereo model on screen and manually digits object directly. This method consumes a lot time and needs well trained operator. Automatic method used cross corelation between adjacent photos to identify similar object, for instance: cross way intersection on the left and the right photo. This method is very fast to compute ground coordinate of extracted objects, but it needs correction since the product is DSM (Digital Surface Model), not DEM. Appearance of tree, bush, and bulding on stereo photos would be extracted their height, so it need to be filtered to obtain DEM.



(a). Maximal standard deviation for EOP



(b). Mean for residual (left) and root mean square for GCP (right)



(c). ICP Accuracy (left) and tie point accuracy (right)

Figure 6. Comparison between weighted AT with AP (pink) and un-weighted AT with AP (blue)

Based on computed EOP and extracted DEM, orthophoto could be generated for each photo. Orthophoto has orthogonal projection, equal scale in entire photo, and vertical air photo, so reliable measurement can be done directly on orthophoto. Orthophoto also has been georerefenced, so it was very useful for mosaicing.
Visual interpretation and delineation for 70 parcels have been conducted on orthophotos separately. By utilizing CAD software, dimension and area of each parcel could be computed. To verify dimension and area of extracted parcels, terrestrial measurement was conducted using Total Station.

Terrestrial measurement for 70 parcels showed minimal area was 12.5 m^2, maximal area was 1,272 m^2 and 292 m^2 for average area. Discrepancies parcel's area between on screen measurement and terrestrial measurement were 0.2 m^2 for minimal, 35 m^2 for average, and 197 m^2 for maximal. Figure 7 shows samples of digitized parcels (left) and the overlay on orthophoto (right).

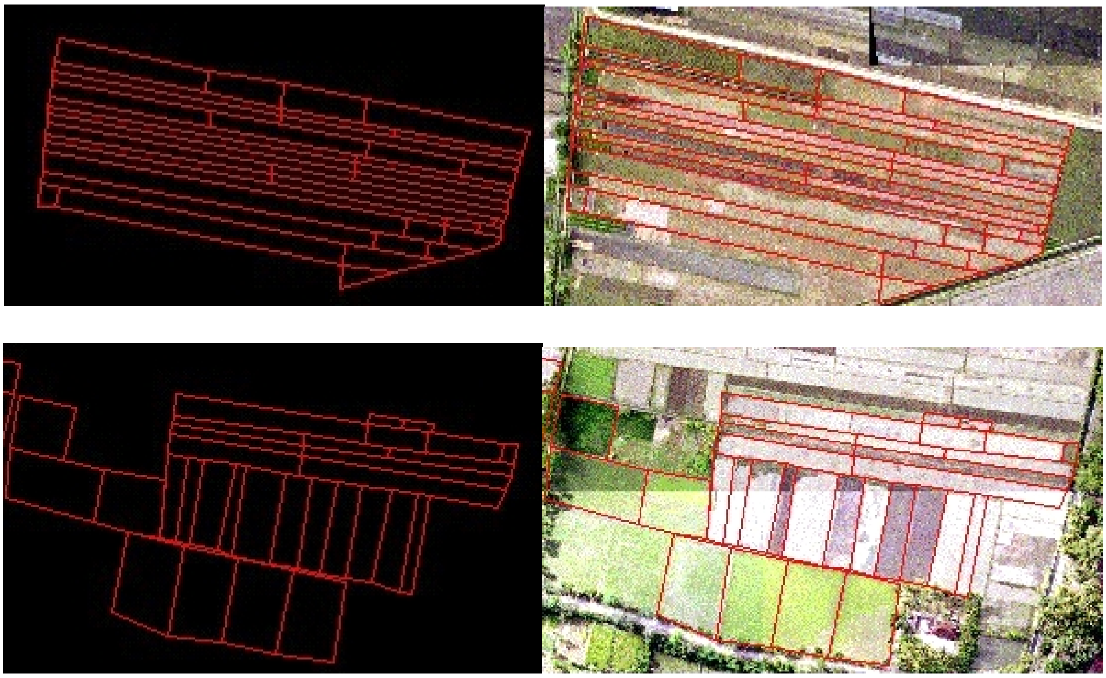


Figure 7. Samples of digitized parcels (left) and its overlay on orthophoto (right).

Figure 8 shows plotting each parcel area measured on photo and directly on field (terrestrial). Measured parcel's area by on screen digitizing and by terrestrial is almost similar. Small discrepancies are obtained on paddy field or open space. On the contrary, large discrepancies are obtained on urban area and dense vegetated area. In this case, beyond orthophoto quality, accuracy of parcel measurement on photo is depend on border interpretation and identification.

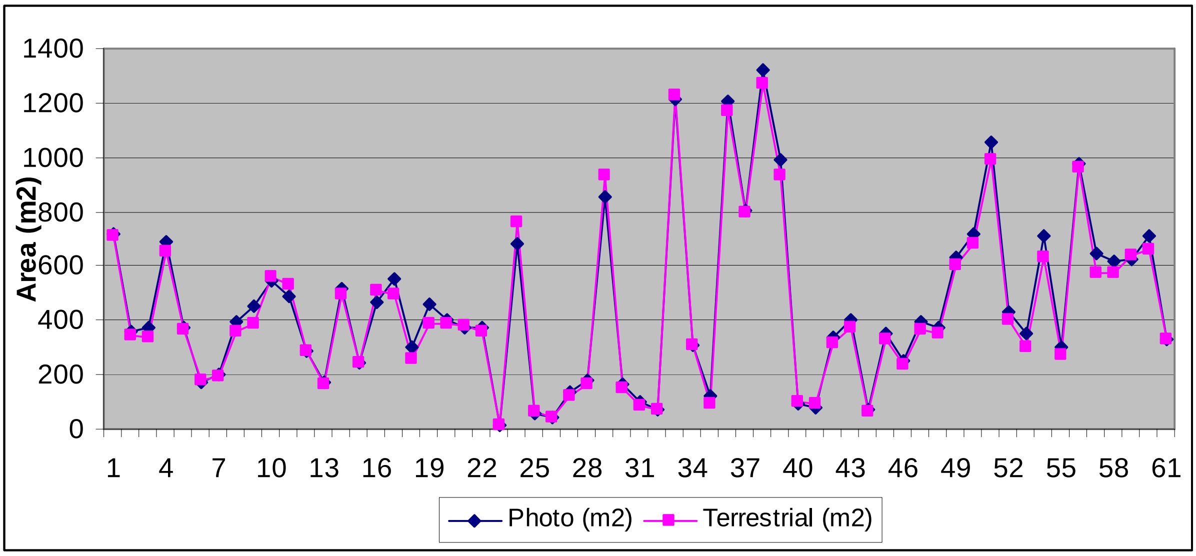


Figure 8. Plotting each parcel area measured on photo and directly on field.

4. CONCLUSION

From the result of the experiment, it can be concluded that:

1. Developing premark and coordinate adjustment for GCP and photogrammetric processing consumed a lot of time.
2. Duration for set up digital camera on ultra light aeroplane was about 2 hours and less than an hour for taking 310 aerial photos in flight.
3. Measured parcel's area by on screen digitizing and by terrestrial is almost similar on clear area.
4. Small format aerial photogrammetry is able to speed up parcel indentification and measurement, but it still needs to be verified by in-situ investigation.

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BIOGRAPHICAL NOTES

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