DEVELOPMENT OF PUSHBROOM AIRBORNE CAMERA SYSTEM USING MULTISPECTRUM LINE SCAN INDUSTRIAL CAMERA

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Abstract. One of the steps on mastery the remote sensing technology (*inderaja*) for satellite was the development of aerial camera prototype that could be an alternative for LAPAN light cargo aircraft mission (LAPAN Surveillance Aircraft, LSA-01). This system was expected could be operated to fulfill the emptiness or change the remote sensing data of optical satellite as the observer of vegetation covered by cloud. On this research, it was developed a prototype of pushbroom airborne camera 4-channels spectrum with very high resolution that worked on wavelength range seem near infra-red/ NIR used simple components that were available in the commercial market (commercial off-the-shelf/ COTS components). This research also developed georeference imagery software module used method of direct georeference rigorous model that had been applied on SPOT satellite. For this one, it was installed supported sensory for GPS and IMU as the writer of location coordinate and camera behavior while doing the imagery exposure or acquisition. The testing result gave confirmation that COTS components, such as industry camera LQ-200CL, and lower class GPS and IMU could be integrated became a cheaper remote sensing system, which its imagery product could be corrected systematically. The corrected data product showed images with GSD 0.4m still had positioning mistakes on average 157m (400 pixel) from the original position on GoogleEarth. On spectro-radiomatic aspect, the used camera had much higher sensitivity of NIR channel than the looked-channel so it caused bored faster. On the future, this system needed to be fixed by increasing the rate of GPS/ IMU data updates, and increased enough time resolution system so that the synchronization process and the availability supported data for completing more accurate georeference process. Besides, the sensitivity of NIR channel needed to be lower down to make it balance to the looked-channel.

Keywords: *airborne camera, industry camera, multispectrum, pushbroom*

1 INTRODUCTION

Airborne photography was one of remote sensing technique forms that had been well-known for a long time. On 1858, Nadar proposed the creation of topography mapping from “birth’s eyes” image of Paris that was got from lifted camera for some fifty meters above the groundused tied- air balloon. He was succeeded getting images of Petit Bicetre area and identified the houses very clearly (Reeves 1975). The usage of airborne images and technology that were used developed until today, for both military and civilian purposes.

Today the digital imagery, for both from satellite and airborne imagery, multispectrum or hiperspectrum, had been accepted well. Great challenges became inseparable parts in developing the camera system to produce images that met the remote sensing needs, for both interpretative analysis and precise photogrammetric purposes (Sandau et al. 2000). For example, to observe the vegetation, the remote sensing photography sensory at least needed to be able recording objects in two different spectrum tapes, red and infra-red that was highly sensitive to the changes of leaves condition (Jones & Vaughan 2010). Whereas to measure how wide and where was the location, those data needed to be completed by positioning data and camera behavior to do the result of imagery rectification into the map coordinate with the accuracy level that could be accepted. Nowadays, there had been numerous imagery system with the consumer-based camera that was designed for remote sensing purposes (Zhang *et al.,* 2016), (Yang *et al.*, 2014), (Papale *et al.,* 2008), most of them used still camera or area scan camera; there was not many that used line scan camera or pushbroom camera.

Daily, the line scan camera was hugely used in manufacture industries as part of quality control mechanism. The camera was pointed on running- track conveyor to bring materials or products from a section, mark imperfect or defected product to be sorted before continuing to the next section or production process. One of the reasons of its usage was because of more efficient and simpler lighting.

On the remote sensing imagery, the line scan technology was mostly applied on the satellite than airborne remote sensing. One of the factors that became a reason for this was a matter of vehicle stability. The spacecraft generally was much more stable than airborne vehicles due to the lack of fluctuation and turbulence by surrounding substance flow medium. For now, the application trends for line scan technology or pushbroom on remote sensing satellite was higher. Remote sensing Landsat satellite these days applied whiskbroom scanning technology (TM Landsat 1 up to ETM+ Landsat 7) had changed now to be pushbroom technology (OLI/Landsat 8) (USGS 2016), continued by SPOT satellite series that had been applied since SPOT-1. Different from whiskbroom technology that forced the availability of components or parts that mechanically moved continuously (oscillating mirror and scan line corrector on ETM Landsat sensory), the pushbroom technology got rid of those mechanism so it appeared simpler, reliable, compact, light, and durable.

In airborne remote sensing, ADS40 from DLR/LH system was the first professional airborne camera that applied pushbroom technology, and then followed by Starlmager from Starlabo Corporation, Japan. Pushbroom airborne mostly was created to fulfill the stereo mapping needs (through three-line-scanner/TLS approach, with wider wipes, high resolution and accuracy of radiometric and geometric (Sandau *et al.*, 2000), (Petrie 2005), (Zhang *et al.*, 2016). That's why the pushbroom airborne camera needed GPS and IMU with the new higher data accuracy and frequency.

This paper talked about prototype development of multispectrum pushbroom airborne camera in LAPAN Technology and Data Center used COTS components that were expected would be fit properly to be operated together with aircraft LSA-01 LAPAN. Besides, to complete data variety of available remote sensing, occupation also became one of steps on remote sensing development program for satellite in LAPAN.

2 METHODOLOGY

2.1 Principle of imagery acquisition pn pushbroom camera

On geometry acquisition context, pushbroom sensory could be described simply as a lens system on its focus field was applied the linear array detector (such as CCD) as imagery optic recorder from the objects that were seen by the lens system. Because of the detector contained of a set of cells that formed a linear, so the images or pictures that were produced by expose was just in form of a linear image with certain wide that could be stated as 1 Dimension Imagery and it was still difficult to be interpreted. 2 Dimension Imagery would be formed if the camera was shifted regularly and exactly every time the exposure was based on the wide size of image lines that had been given.

Pushbroom word was a terminology that was existed to describe the way getting those images as required, which could be analogized by numerous small brooms and arranged in a row to fulfill the road's width and then be pushed upfront to clean up the road that was passed by. Each broom individually took data (energy from optical imagery) for certain time that had been customized to its speed for passing by the track. That's the reason why this technique was also called as along track scan due to each small broom was like downloading in every track starting from back to upfront. Whereas the word of line scan was existed because of a set of brooms were arranged in line to create the straight line that was located across the moving directions.

To get the right and in a row imagery lines, so it was needed the proper synchronization of the shooting rate with camera- shifting rate and they needed to be kept the steadiness. In the photogrammetric discourse, each imagery line was associated with an expose station that needed to be written of its data of location and orientation.

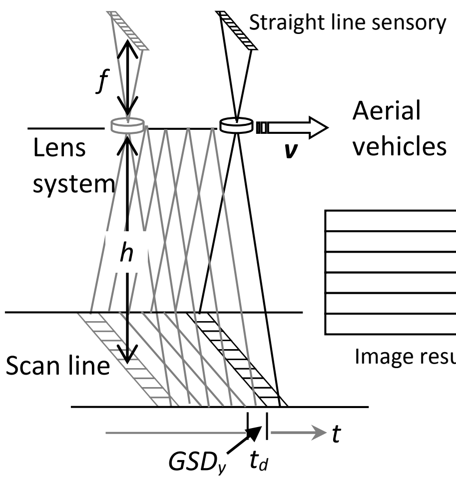

Figure 2-1: Principle of 2 Dimension imagery creations by pushbroom scanning technique (modified from (Poli 2005))

2.2 Important Parameter

As seen on Figure 2-1, two imagery lines chronologically would be in a series if the acquisition break, L, was managed on the right value as same as the detector's dwell time, td, was the time that was needed by detector to shift for GSDy in the earth's surface (Sabins 2007), (Poli 2005) and (ITC 2009).

$$t_d = \frac{GSD_y}{v} \qquad (2\text{-}1)$$

$$GSD_y = \frac{p_y}{f} h \qquad (2\text{-}2)$$

GSD_y = camera spatial resolution (ground sampling distance on y direction), v = aircraft's velocity in the earth's surface, py = px = pixel pitch, f = length of lens focus.

The imagery elements of acquisition result would exactly be in a row if it was managed Lr = td. If Lr< td the imagery elements would stick each other on the patch, if Lr>td would exist the gap between two imagery elements that were in sequence. On the uncorrected condition, for Lr < td the images would seem longer than it should be (stretch) while for Lr> td images seem shorter than it should be (wrinkle).

Besides the in row imagery lines, td also became limitation factor of shelf time or integration time that could be applied. On all moving images, tint ≤ td to avoid the pixel mixtures. Because of tint was compared directly to the radiant energy total that was compiled for shelf process, so td was also early indicator of the brightness level of imagery exposure of a camera.

2.3 Basic Principle of Direct Georeferencing pushbroom

Direct georeference with the physical model or flat model basically was method for deciding the imagery pixel location based on detector orientation inside the internal orientation that had been transformed to a set of external orientation, which connected camera to the reference system that was centered on earth's center.

On Figure 2-2, $\vec{s}$, $\vec{g}$, and $\hat{\boldsymbol{\imath}}$ was vector on the same coordinate system, which was earth coordinate system. For this condition, it could be written (Korechoff *et al.,* 1999):

$$\vec{g} = \vec{s} + \mu\hat{\boldsymbol{\imath}} \qquad (2\text{-}3)$$

With $\vec{s}$was the vector of vehicles position, read from GPS, $\vec{g}$ was the vector of earth pixel position that would be counted, and $\hat{\boldsymbol{\imath}}$ was unit vector that represented the detector of observation direction to the pair pixel in earth's surface, G was cut point of vector $\hat{\boldsymbol{\imath}}$ on reference earth's ellipsoid.

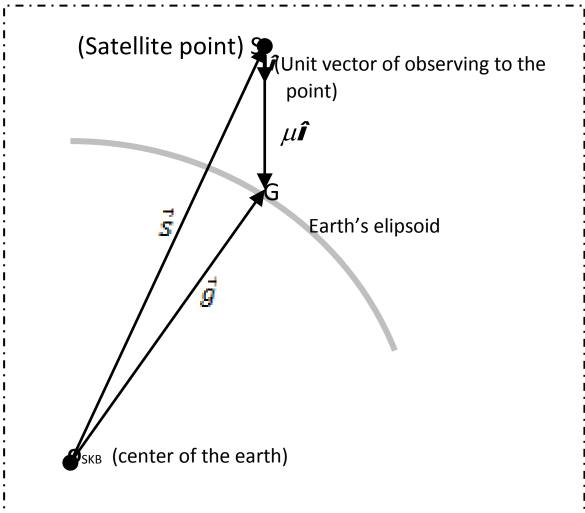

Figure 2-2: Vector relation of vehicles position and observation point in earth at the time of doing the expose

For the straight lined camera with pixel amount of N_p,inner orientation or pixel observation vector to v for the paired pixel in object room,$\vec{\imath_k}$, could be stated with (Maryanto 2012):

$$\vec{\imath_k} = \begin{bmatrix} 0 \\ \left(\frac{N_p}{2} - v\right) y_p \\ -f \end{bmatrix} \qquad (2\text{-}4)$$

With $y_p$was the individual measure of detector cell on y direction, and f was the lenght of lens focus. On a simpler system where the coordinate system of camera was identified in row with the vehicles coordinate system, unit vector$\vec{\imath_k}$ was the result of a set transformation vector on terms of plane reference (system of vehicles coordinate, SKW/ T1) and then to the terms of local reference that moved along together with the vehicles (system of local coordinate, SKL/ T2), and then terms of earth reference (system of geocentris coordinate, SKB/ T3). For the off- camera that was installed on the vehicles, so T1 had the characteristic of constant and simple, it also happened to T3. More complicated rotational transformation happened on T2 that delivered the observation vector on the terms of local reference. This transformation had characteristic of rotational due to phisically dependent vehicles system loosely to the terms of local reference. The data of angular orientation changes (roll, yaw, and pitch) that were written byIMU sensory on this transformation.

The scale of factor value on equation (3) could be counted from the cut vector to the curved elliptical earth by using ABC formula (Riazanoff 2004), (Kwoh et al. 2012), which would give two different values (because of teoritically the camera observation vector would cut off the elliptical earth in two spots). From that result, it was chosen the small value and then inserted to the equation (3) to get vector position that represented coordinate of imagery pixel location on the system of geocentris eart coordinate. With this geolocation data, so the over all of imagery pixels could be placed on its each position based on the adopted projection map model.

3 DESIGN AND IMPLEMENTATION

System that had been developed was multispectrum airborne pushbroom that had been completed by still camera as supporter. This prototype was built using the available components and easy to get in commercial market. Especially for line scan camera, the main consideration was its potency to be applied on the vegetation mission, and for this was chosen camera LQ200CL (4- band @ 2048 pixel, 14um pixel pitch) from JAI that was operated on the range of wave lenght (400 – 1000) nm with the color separation technique of dichroic prism technology, which guaranteed the pixel simultanity between channels. Meanwhile for supporter, it was used camera Nikon D800E.

For location identification and camera behaviour at the time of doing expose, it was used Garmin GPS18 as geolocation sensory and IMU HMR3000 as behavioural sensory.Scematically, the system of diagram block was shown on this following Figure 3-1.

3.1 Acquisition of Imagery Data

To handle the acquisition devices for imagery data, it was developed two separated modules s/w, module to control and handle the pushbroom camera data, and module to control and handle still camera data.

The main function of both modules was to give the start order for acquisition simultaneously, gave instruction for the data taken from camera on each storage directory, and gave file names for recorded data sistematically. For control module and data tabulation of pushbroom camera, module was also completed by function of real time display (live) data as result of perfile acquisition that contained of 500 scan lines.

Module was developed by basic module that was enclosed by camera factory and grablink card by customization based on defined needs.

3.2 Module of Supporting Data Acquisition (GPS/IMU)

GPS (location sensory) and IMU (behavioural sensory) was needed to remark location of geographycal coordinate and orientation of external camera (pitch, yaw, roll) on every expose station. This data was needed at the time of imagery georeference procces, for both from line scan camera and still camera. Because of the still camera wiped off the ride moves in the same direction was a way wider than the line scan camera (7360 pixel compared to 1 pixel) every time doing the expose and it mean the rate of expose repetition a way rare than the line scan camera, so generally the needs of proper supporting data could be fulfilled from the sensory devices i.e. GPS and IMU, although it came from a class of low grade devices.

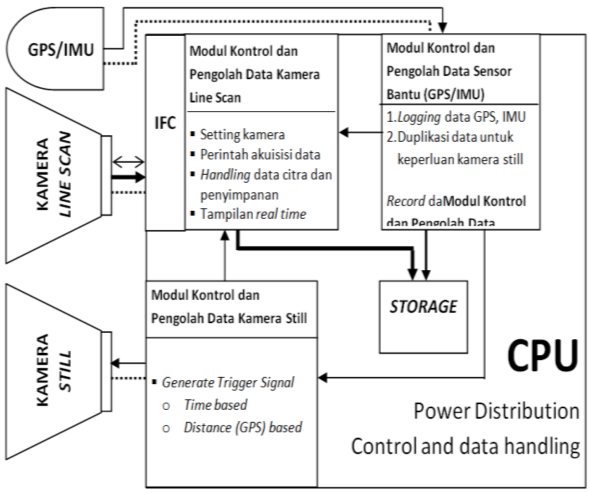

Figure 3-1: System diagram block of multispectrum airborne pushbroom that was developed. ___ control track .... energy track imagery data track ▬▬ supporting data track

On the developed system, GPS and IMU data was saved on one separate file that was available on each data row inside and it was given the time stamp as a sign of when the position data and those behaviour were got. Besides, the supporting data flow also was paralleled to be taken and added on every file of line scan camera imagery and still camera shortly after the creation process of imagery file had done.

3.3 Mechanical Interface

Based on the outline, the mechanical interface was mechanical connector device that bridged the component of camera system with 3 chambers that had been supplied for it on LSA LAPAN, which was the chamber of carrying pod, cockpit chamber (dashboard control and monitor for the operator) and luggage chamber on the plane's tail (to put the system of voltage source/DC power supply). That's why it was designed the mechanical interface to consider limitation of spatial dimension, or weight and temperature as the main input. The mechanical interface was designed to give maximal protection and guaranteed the performance of components inside to keep on their best performance. Besides, it was also designed to ease the instalation process and deinstallation of carrier vehicles with sturdy and strong physical link, but push down the vibration as low as possible as stated by barrier to the brought camera system.

Schematically, the main box design and component positioning was seen on Figure 3-2. Box was designed following the eggshell concept where the box's cover or wall was also in function as a structure to keep the rigidity system to guarantee the absence of defletion in camera view direction.

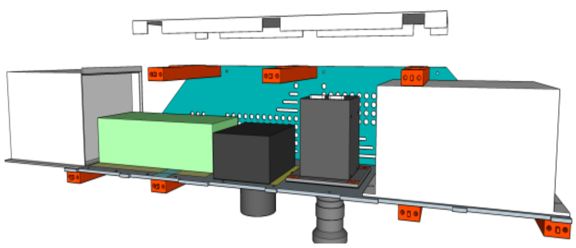

Figure 3-2: Main components structure and positioning of multispectrum airborne pushbroom that was developed. (1) The main camera (LQ – 200CL), (2) supporting camera (Nikon D800E), (3) behavioural sensory (IMU), (4) control unit and data tabulation (PC), (5) power supply (DC 12V 40Ah)

4 RESULTS AND DISCUSSION

4.1 Basic System Feature

System integration result as seen on Figure 4-1. Refer to specifications of components or subsystem that was used, camera was developed having some characteristics:

- Fit to fly with LSA-01 and able to work for 6 hours continuously.
- Physical dimension : 888 mm x 234 mm x 195 mm.
- Overall weight < 35 kg.
- Power supply : 12VDC, 40AH.
- Imaging abilities:
  - *4-channel visible- nir pushbroom camera using dichroic prism spectral splitting technology*
- *Band 1 : (392 – 486) nm*
- *Band 2 : (490 – 574) nm*
- *Band 3 : (580 – 674) nm*
- *Band 4 : (762 – 914) nm*
  - *Pixel number/ channel : 2048*
  - *Pixel pitch: 14μm.*
  - *Focal lenght : 3 mm → gsd: ~73 cm, gswath: ~1.4km at 6000fts alt.*
  - *Adjustable focal number : 2.8 – 22.*
  - *Programmable line scan rate up to 19000 lines/ second.*
  - *Programmable integration time.*

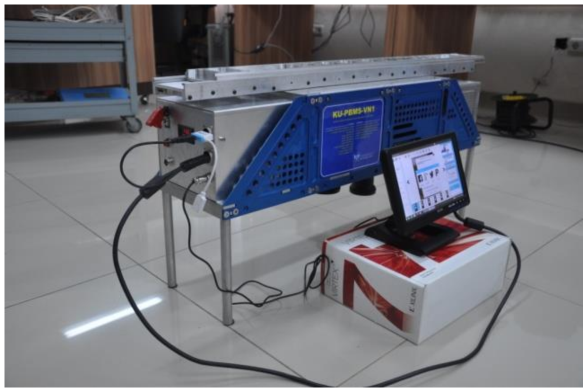

Figure 4-1: Multispectrum Pushbroom airborne camera system visible- nir version_1 (KU–PBMSVN1) Technology and Data center

From the aspects of physical dimension, the spatial dimension and total weight of the camera were still below maximum capacity of load permits per basket carrier, i.e. 70 kilograms. That's the reason why power supply placement became one inherent part in the camera system that was developed and estimated would not shift the center of mass vehiclesextremely so it was expected would not smuggle the distorsion to the image result. On the capability aspect of imagery acquisition, the acquisition rate of scan lines, Lr, so 19000 lines/ second gave potency of camera application to do the acquisition to the high resolution data until 40 cm GSD on satellite devices of LEO with the speed assumption in eart vg = 7000 m/s. This potency was not yet confirmed from spectroradiometric aspect related to very short haven time, which was (1/19000) second or about 52 µs.

From the spectroradiometric aspect, camera promised the potency of vegetation application to the ability of producing the vegetation index information remembering its spectrum tape, which contained of red tape and near infra red (NIR). However, the test result of vegetation object expose showed that the NIR channel was much more sensitive than the red channel. On a condition where optimal red channel (DN ~ 1/ 2 DN maximum), the NIR channel had reached the saturated condition so the data was not worth the information. It became a reminder or challenge that the industry camera usage like this for outdoor application needed additional treatment to make the promised potency could be increased to the efficient reality.

4.2 Trials

The trials were done in two developmental phases. Earlier trial was done before the component was assembled/ integrated and the flight test after the component was getting assembled to be one unified system.

4.2.1 Pre-integration trials

Test of pre- integrated acquisition was mean to test the function system on the whole, including the acquisition function of *image,* acquisition of navigation data support (GPS and IMU), *recording* data function (*image* and support data), before done the assembly into one system of airborne camera. The field trials with car as the vehicle was done in office environment of LAPAN Aeronautic Technology Center (*Pustekbang – LAPAN*), Rumpin, Bogor on August 14th 2014, to observe the performance system of supporting data acquisition, especially IMU sensory and the battery life.

The test result that was shown on Figure 4-2 showed that behavioural sensory and s/w module of behavioural sensory data reader ran well. With the 1 Hz recitation rate, there was no lost data. For recording duration of 35 seconds, the behavioural data that was shown on Figure 4-2 was seen that the head value (yaw, Figure 4-2c) changed seamlessly based on the characteristic of steering maneuvers while turned to follow the track. But on the nod value (pitch, Figure 4-2d) seem the oscillations and very strong oscillations that described the uneven road contour on the longitudinal direction and the braking mechanism that caused the vehicle to be upside-down or crashed at the time of sharp bends. While the oscillation on roll data showed that the ruggedness of road contour was also happen in the transvere direction.

Besides the field test, the acquisition test was also done in Remote Sensing Laboratory – Technology and Data Center on August 21st 2014 at 12 pm with the way of pointing the camera to the out of the window to photograph the vegetation object that existed around the building. The main purpose of this test was observe the spectroradiometric camera that was the partial result was shown on Figure 4-3.

The histogram data on Figure 4-3a, b, c showed that a group of NIR channel data population for the object of vegetation image (which was considered as homogen), radiated far enough from the seen channels showed that NIR channel was more sensitive than the seen channels. If the range of dynamic image quantitation could be stated on percent (225 = 100%) so the nearest edge distance to the seen data group with the NIR data group were on approximately 45%, counted by disaccording the mean value plus deviation standard of seen channel with the mean value minus deviation standard of NIR channel. By assuming that digital number (DN) was representation of detector reaction for received radiant energy, so the spout distance of 45% could be assumed as indication that sensitivity of NIR channel was 45% higher than the seen channel, especially for leaves object (vegetation). If camera could be expected as the measuring instrument of the light energy, so very striking difference of sensitivity was less ideal, so it was needed special treatment, which pushed down the sensitivity of NIR channel to create harmony with the other channels (seen channel) because of the whole spectrum channels used the same collecting tools (camera system with single lens).

4.2.2 Flight test

The flight test was conducted on June 10th 2016 at 1.22 pm up to 2.50 pm with a plane of LSA-01 LAPAN above the training area of Budiarto airport, Curug, Tangerang, Banten.

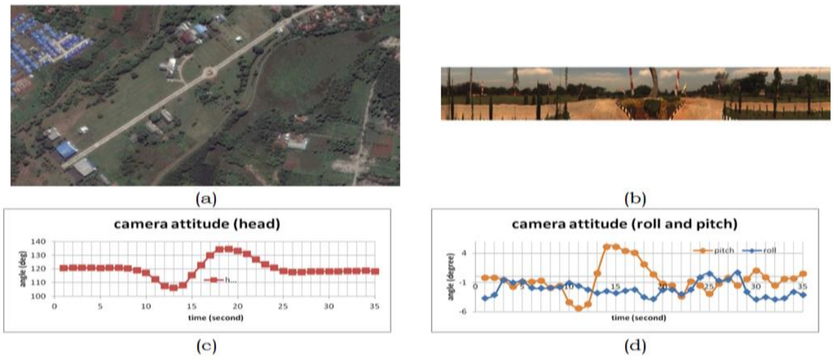

Figure 4-2: The pre-integration ground testing using car. (a) track, (b) image result, (c) and camera behavior recording for 35 seconds this car was running on the track that was marked by red color on Figure a

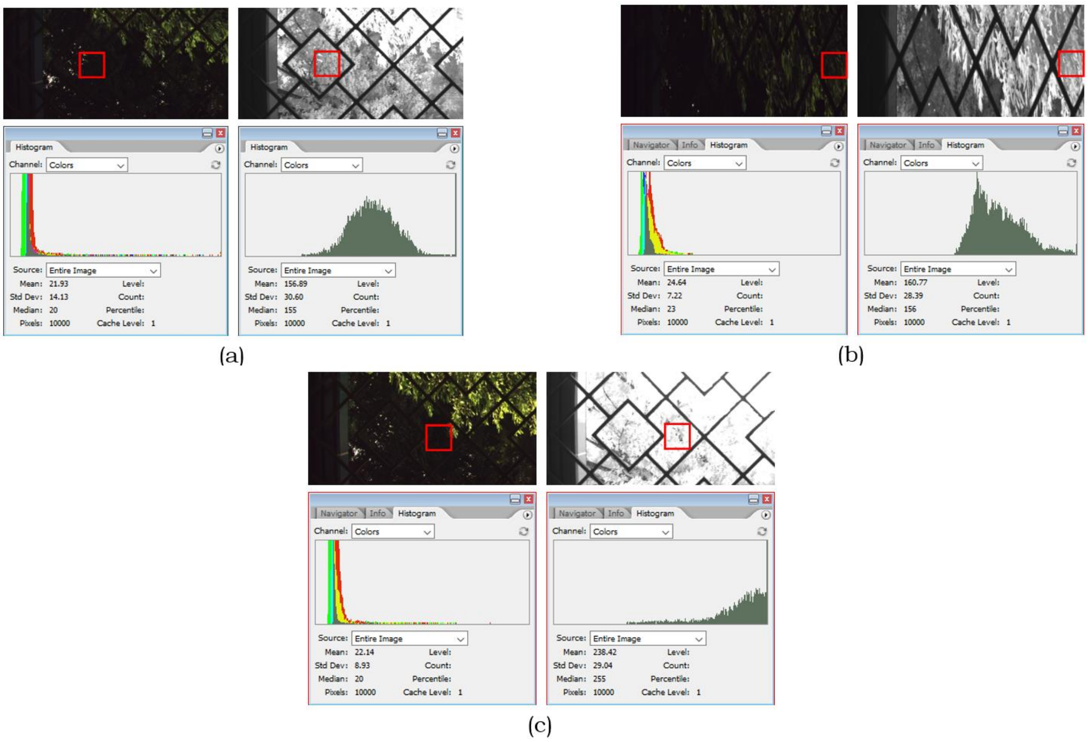

Figure 4-3: The result image of acquisition test in laboratory and shareable pattern of data for limited area by red box. The left lane was image of the seen channel (RGB), the right lane was image of the right NIR. (a) and (c) were exposed by the rate of line acquisition = dwelling time detector (b) was exposed by the rate of line acquisition = ½ of dwelling time detector

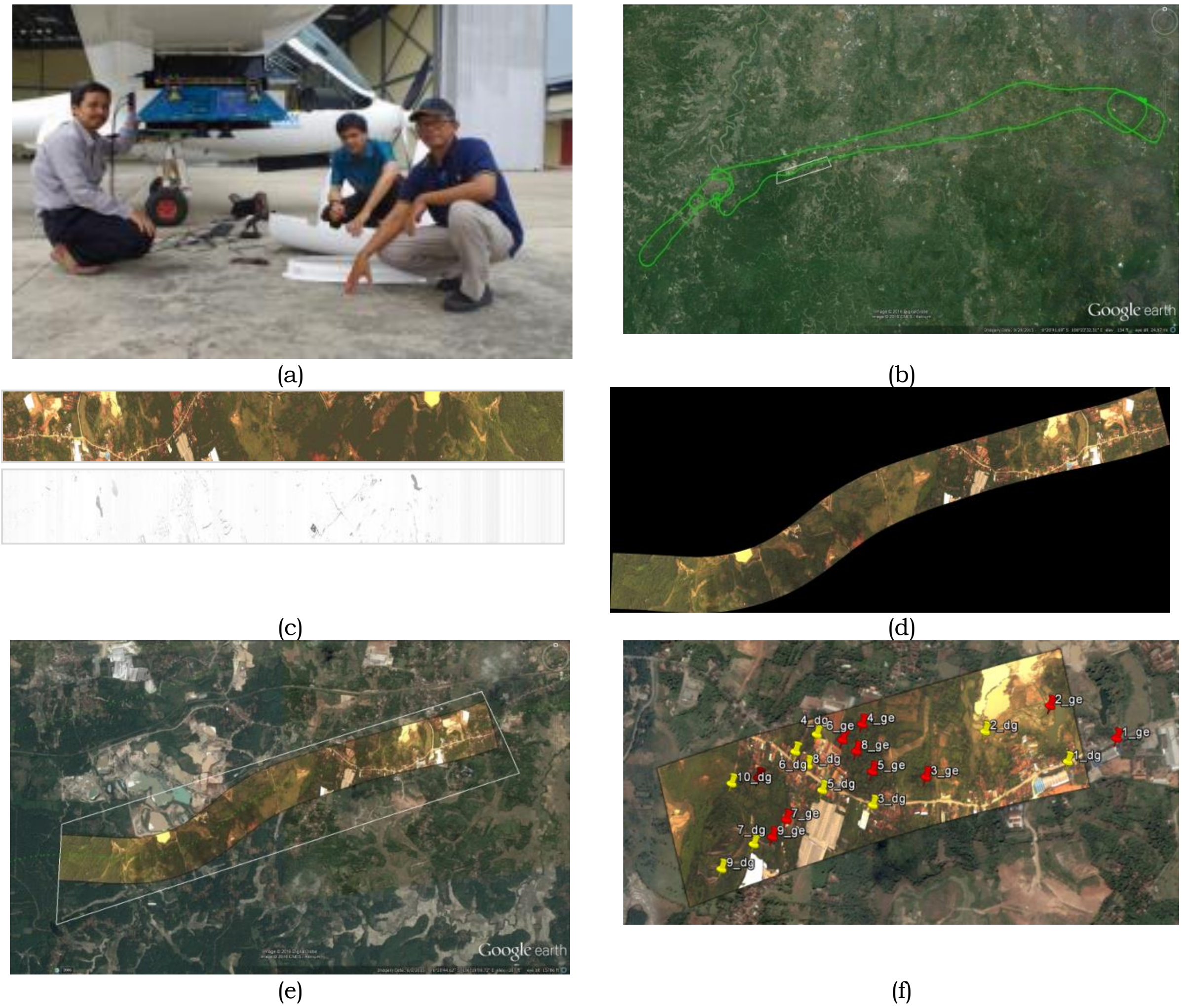

Figure 4-4:The flight test for prototype of airborne camera Pustekdata-1 and image sample that was resulted. (a) Instalation on LSA-01 LAPAN, (b) flight route, (c) raw data sample that was resulted (file 2151-2220) RBG channel (above) and NIR channel (below), (d) the data sample after geometric tabulating, (e) the overlaying of tabulated data on google map, (f) validation of 10 image points that were tabulated by google map (google earth) reference

This test was purposed to observe the system readiness as a whole, including mechanical, electrical, and the function of imagery acquisition on various flight condition to the extreme manouver. Camera was prepared for acquisition rate of 3,75ms per scan line with the assumption of flight height 6000 feets. The result was shown on Figure 4-4.

The test result confirmed that various flight manouver, prototype system could work well and it was proven by the absence of lost data, for both imagery data and supporting data. But then, amount of supporting data that was given still far from sufficient. By the rate of supporting data acquisition 1 data per second, so to fulfill the rate of imagery data acquisition 3.75 mili second per line, each supporting data set needed to be interpolated for about 260 other picture lines that had no supporting data. Figure 4-4d-f showed data of corrected geometric using module s/ w correction of geometric autonomous development by supporting data intake as interpolation result. At a glance, the correction result could put the image pixel in accordance with the pattern of flight trajectory, but the deeper analysis showed that the position was still far deviated from it should be (refered to GoogleEarth) as well as showen on Figure 4-4f and Table 4-1 below.

Table 4-1: Distance difference (Δr) and Angular orientation (φ) image location coordinate calculation result by Direct Georeferencing and GoogleEarth reading

No	Δr (m)	φ (°)
1	162.98	64.53
2	212.75	68.61
3	182.31	62.03
4	144.73	77.49
5	163.64	69.64
6	150.80	75.21
7	121.4	52.55
8	157.19	74.21
9	184.67	57.15
10	86.48	78.34
$\overline{\Delta r}$	157	68
stdev	35	9

With GSD 0.4 m, deviation mean 157 m (equal to ~400 pixel) as shown on Table 4-1 gave description that prototype system of development result was still too far from the standard of remote sensing system. Sutanto (Sutanto 2013) illustrated that for GSD 0.4m, so the scale map, which could be lowered form that imagery was 1:4.000 with the maximum deviation standard was less than 1.2 m or 3 pixel. Concerning to enormous terror like that, there were some explanations that were expected explaining some conditions:

- Degree of irreversibility on the field of reference camera and supporting sensory reference was very low, and the calibration factor was yet to be inserted to the calculation. Generally, camera, GPS, and IMU, were on its own position and with its own orientation. To get the accurate result of georeference calculation, the coordinate transformation between these systems also needed to be counted well and inserted into used analytic formula (Poli 2002), (Mûller et al., 2002).
- Resolution of timing system was very low. The smallest timescale that was adopted on this prototype was second, and the rate of scan line acquisition was regulated on 3.75 ms, or about 266 lines per second. This condition would cause the existance of 2 steps of georeference mistakes. 1) Confusion of the timestamps ownership between 266 linescane that had been acquisied, 2) Escalation of the confuseness because of the existance of interpolation that needed to be done to fulfill 265 other linescanesthat did not have supporting data. As a result, although the georeference directly was exact analytical formula and exploreable, but because of the existance of terraced confusion like this so the calculation result would miss by a mile from the position it should be.
- The error on point 1 had the quality of systemic, confirmed from the shifting orientation of pixel location toward nearly the same direction.

5 CONCLUSION

The system prototype of airborne camera pushbroom 4-channel spectrum visible-NIR which was appropriate to LSA-01 LAPAN could be built from simple components that were available in commercial market. By the industry camera of LQ-200CL and GPS supporting sensory and low class of IMU, the prototype that was developed could give complete remote sensing data, which was enable to do the process of geometric processing to create the standard images that were connected its systematic geometric. The results of developed prototype system trials showed that that product of data connected geometric had high error, shifted about 400 pixels from refered map of GoogleEarth. On the spectroradiometric aspect, the system prototype had the opportunity to give data for vegetated application by first fixing the rensponsity of system NIR channel. System NIR channel needed to be reduced for its sensitivity up to less 50% than today's condition to make the output would not saturated fast and balance with other channels. This system needed to be calibrated the directions, besides sharpening the timing system and increasing the rate of the supporting data renewal so both in quantity and quality fulfilled the accurate georeference process.

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