

Band co-registration modeling of LAPAN-A3/IPB multispectral imager based on satellite attitude

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Abstract. One of significant geometric distortion on images of LAPAN-A3/IPB multispectral imager is co-registration error between each color channel detector. Band co-registration distortion usually can be corrected by using several approaches, which are manual method, image matching algorithm, or sensor modeling and calibration approach. This paper develops another approach to minimize band co-registration distortion on LAPAN-A3/IPB multispectral image by using supervised modeling of image matching with respect to satellite attitude. Modeling results show that band co-registration error in across-track axis is strongly influenced by yaw angle, while error in along-track axis is fairly influenced by both pitch and roll angle. Accuracy of the models obtained is pretty good, which lies between 1-3 pixels error for each axis of each pair of band co-registration. This mean that the model can be used to correct the distorted images without the need of slower image matching algorithm, nor the laborious effort needed in manual approach and sensor calibration. Since the calculation can be executed in order of seconds, this approach can be used in real time quick-look image processing in ground station or even in satellite on-board image processing.

1. Introduction

LAPAN-A3/IPB satellite is third Indonesian micro-satellite with earth observation and remote sensing missions, with 4-bands multispectral pushbroom imager, which are blue, green, red and near-infrared (NIR), as main payload. The images produced have 16 bit radiometric resolution with 15 meter ground sampling resolution and 120 km swath-width [1]. Same as other multispectral satellite images, raw images captured from LAPAN-A3/IPB satellite multispectral imager suffer from both geometric and radiometric distortion which should be systematically corrected. There are several distortions which commonly occur on satellite multispectral images, most importantly are radiometric vignetting distortion [2] and geometric distortion due to satellite movement instability while imaging [3][4]. Another significant geometric distortion which also occurs on LAPAN-A3/IPB multispectral images is band co-registration distortion, which is caused by position and orientation differences of band detectors respect to lens center [5]. The distortion causes an object in four channel images are not align each other, therefore the composite image produced seems being blurred since same object in different channel image have different position and orientation within the image.

Band co-registration can be corrected using several methods, which are manual approach, rigorous sensor modeling and image matching method. Every approach has its own different advantages and disadvantages. Manual approach is done by producing many ground control points (GCP) for each channel image, which is referenced to referenced image. The referenced image could be a validated



referenced map or one of the multispectral channel images which is chosen as reference. This manual approach could produce an accurate result if done very carefully by the expert, but it needs laborious efforts and time consuming. Another approach to correct band co-registration distortion is rigorous sensor modeling which will directly calculate the distortion parameters based on known and validated satellite and imager parameters, both intrinsic and extrinsic ones [6]. However, this approach needs accurate satellite and sensor geometry to produce an accurate result.

Currently, band co-registration distortions occur on LAPAN-A3/IPB multispectral images are corrected using image matching approach, in which NIR, green and blue channel image is referenced to red channel image. The approach divides each channel image into many sub-images and then utilizes Canny edge detection algorithm to pre-process the image before applying cross-correlation based image matching [7][8][9]. This method can be executed autonomously without knowing any satellite and imager characteristics, and based on numerous LAPAN-A3/IPB images which have been processed, this approach is able to produce quite accurate result. However the algorithm still needs time to process the images, which is around 4-5 minutes in average for one image. While the time needed is still considered acceptable in most application, it clearly cannot be used in real time satellite image processing, for example in quick-look application on real time acquisition mode.

This research aims to develop a simple approach which is able to calculate band co-registration that occurs on LAPAN-A3/IPB multispectral images, based on satellite attitude data provided by star tracker sensor (STS). In this approach, the influence of various satellite attitudes when imaging to band co-registration error produced by image matching algorithm is deeply investigated based on numerous actual LAPAN-A3/IPB multispectral images which are captured under various attitudes. The method works entirely based on image matching approach which is used on current setup, however the manner in which the calculation is done is significantly simplified. The main idea of this approach is to find the relationship between satellite attitude while imaging and band co-registration distortion characteristics produced by image matching calculation on LAPAN-A3 multispectral images. Once the band co-registration models have been established, they can be used to calculate band co-registration parameters in no time with similar accuracy compare to image matching approach used in standard processing.

2. Methodology

Based on rigorous sensor modeling theory, band co-registration distortion is influenced by satellite attitude while imaging. The calculation of band co-registration distortion on more than 150 images of LAPAN-A3/IPB imager by using image matching approach, which is composed of Canny edge detection and Fast Fourier Transform (FFT), also shows this characteristics. Nadir observation tends to produce small band co-registration distortion while off-nadir observation often produces significant distortion. The model of this relationship however, is still unknown, therefore needs to be determined for each pair of band co-registration.

As with any other modeling, this research starts with tabulating all variables which will be modeled, both for dependent and independent variables. In this modeling, dependent variables consist of band co-registration parameters of each pair of channel images. These parameters essentially determine translational difference of two channel images both in vertical and horizontal direction. These dependent variables are produced by image matching algorithm which is used in current setup of LAPAN-A3/IPB multispectral image pre-processing. In the other hands, independent variables in this modeling consist of satellite attitude of yaw, pitch and roll angle when the imager capturing the image. These satellite attitudes when imaging are derived from star tracker sensor (STS) data and by using SGP-4 orbit model [10].

After all dependent and independent variables are gathered, modeling of band co-registration distortion for each band with respect to satellite attitude can be done by using least-square regression method. Since the number of observation data is much higher than model parameters which will be determined, pseudo-inverse approach will be used in this regression process [11]. There are six models that will be developed, consisting two models for each pair of band co-registration. Then the accuracy

of each models produced is evaluated. Finally, actual image correction using the resulted band co-registration models is done to validate the results visually. Figure 1 shows general flowchart that is used in this research.

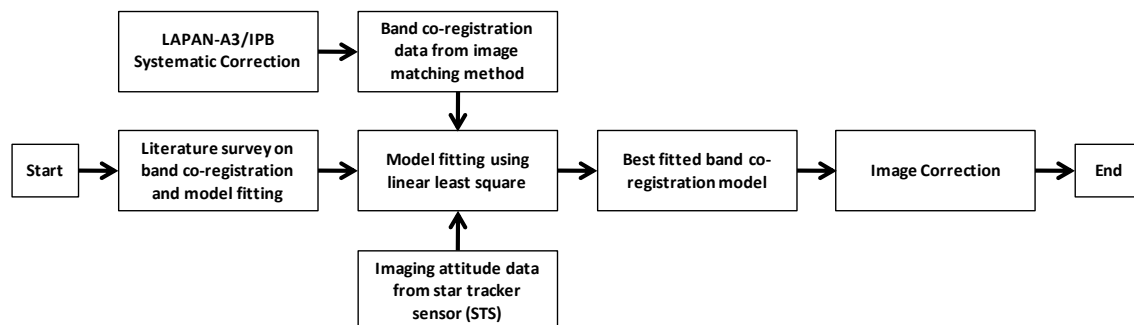


Figure 1. General flowchart used in this research.

3. Modeling Result and Analysis

As explained earlier, the modeling process is based on image pre-processing that has been done on numerous actual LAPAN-A3/IPB multispectral images. Figure 2 shows several examples of band co-registration distortion on parts of LAPAN-A3/IPB multispectral images in NRG composite format, which clearly showing that each color-channel is not aligned to each other.

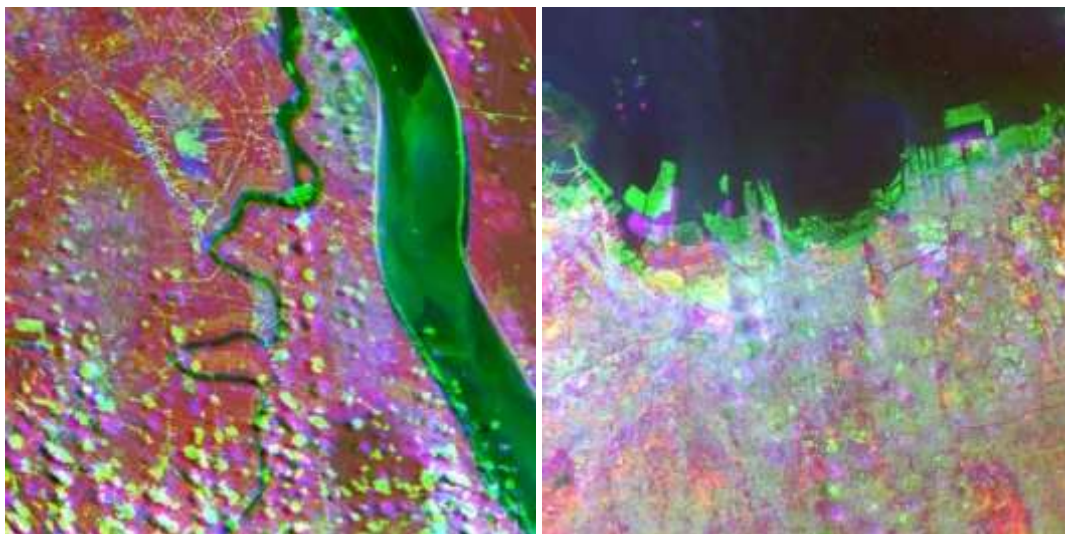


Figure 2. Examples of band co-registration distortion on LAPAN-A3/IPB multispectral images.

It can be seen on these two example raw images that co-registration distortion occurs on many objects across the image, such as cloud, river, road and other human-made structure. The distortion appears on every LAPAN-A3/IPB multispectral images, however the magnitude of co-registration which occurs between images varies depending on satellite attitude when the imager capturing the image on each particular day.

3.1. Observation Data

Table 1 shows example of several data which relate band co-registration distortion produced by image matching algorithm and satellite attitude while imaging, only for NIR to red pair of co-registration. These sampled data are obtained from images taken by LAPAN-A3/IPB multispectral imager during

August 2017. Band co-registration values on the table represent both horizontal and vertical pixel differences between two channel images, which further divided into three sampled region of image, which are left and right side as well as center region of the image. Meanwhile, satellite attitude values on the table represent average satellite attitude while imaging in each yaw, pitch and roll axis.

Table 1. Example of observation data used in the modeling.

Image Data		Satellite Attitude			NIR-Red Co-registration Values					
					Horizontal			Vertical		
Date	Target	Yaw	Pitch	Roll	Left	Mid	Right	Left	Mid	Right
20170801	Muntok-Lampung	4	-7.4	-1.9	-49	0.3	33	-71	-81	-113
20170802	Ciledug-Kalipucang	5.1	-1.5	-1.5	-48	-0.1	32	-69	-79	-112
20170803	Sipitang-Tinotuhan Kalteng	6.7	-2	-2.4	-51	-3.4	27	-70	-79	-111
20170809	J P Coen Peak-Kimaam Papua	5.3	-5.5	-2.7	-51	-2.7	28	-70	-80	-113
20170810	Waikabubak NTT	10	-6.6	-7	-55	-6.2	23	-70	-81	-116
20170811	Maluku Utara	10	-9.4	-6.5	-55	-7.3	23	-70	-81	-116
20170812	Pangkalpinang-Ujungkulon	4.8	-3.6	-11	-48	0.3	32	-69	-80	-115
20170813	Nangatayap Kalbar	9.3	-5.8	-1.8	-54	-6.4	23	-70	-79	-111
20170815	Lombang-Somba Sulbar	0.5	-12	0.5	-46	4.4	40	-72	-81	-114
20170816	Salongo-Banggai Sulawesi	2.3	-3.9	-3.2	-46	3.4	38	-69	-78	-110
20170817	Kepri-Jambi	5.6	1.3	-0.3	-49	-0.1	32	-68	-77	-110
20170819	Brunei-Nangaipinoh Kalbar	0.2	13	-2.7	-42	5	36	-71	-82	-116
20170820	Senggi-Okaba Papua	2.5	15	1.7	-44	2.7	32	-74	-84	-117
20170823	Merak	0.1	0.5	1.5	-42	6.3	40	-69	-78	-109
20170824	Ambarawa-Purworejo	-0.7	-0.7	2.5	-43	5.9	40	-69	-78	-108
20170825	Kaltim-Kalsel	-1.4	-3.2	1.4	-43	5.6	40	-69	-78	-109
20170826	Palu-Polewali	1.7	-4	2.5	-43	5.6	39	-69	-78	-108
20170827	Manado-P Masoni Sulawesi	-2.1	-3.9	5.8	-40	9.1	45	-70	-78	-109
20170828	Palembang-Martapura	0.7	-7.6	-8.6	-41	7.7	44	-70	-80	-114
20170830	Tuban-Blitar	-0	1.3	0.1	-42	6.1	40	-69	-78	-109

Based on attitude filtered data used in this modeling, Figure 3 shows example of strong relationship between satellite attitudes in yaw axis to NIR-red band co-registration values in horizontal direction, while the values of band co-registration in vertical axis has fairly good relationship with pitch and roll angle. The co-registration values in Figure 3 are the values obtained from center part of the image.

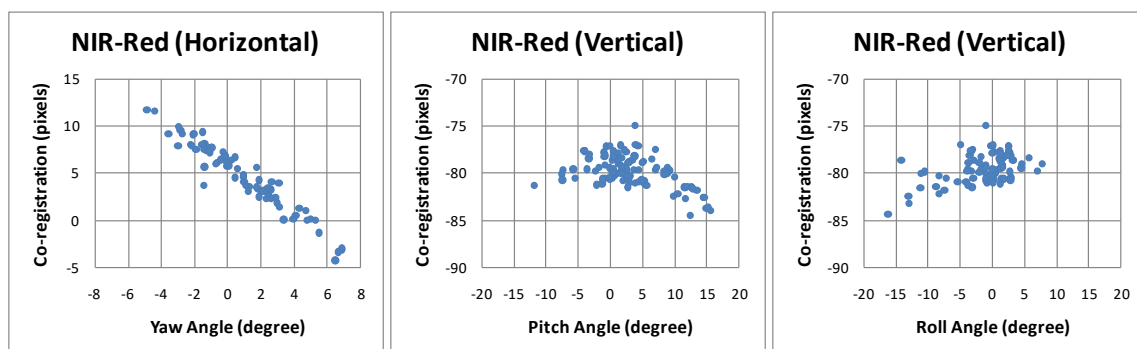


Figure 3. Strong relationship between satellite attitudes to NIR-red band co-registration values.

3.2. Linear Least Square Regression

As can be seen from Figure 3, yaw angle has a strong influence to horizontal co-registration value, while pitch and roll angle has fairly influence to vertical co-registration value. However, type and magnitude of the relationship still need to be determined. Therefore, modeling band co-registration as

a function of satellite attitude is conducted by using linear least square approach. The model of each band co-registration in both directions could be linear or nonlinear, first order or second order, as well as could be sinusoidal or exponential. Initially, trial and error approach is used to determine the best approximation for each co-registration model, where all potential candidate models are evaluated. Model with the smallest error is chosen as the best model for that particular co-registration model. Table 2 shows sample of list of models which are evaluated for NIR-Red band co-registration in vertical axis, producing second order cosine model with pitch and roll couplings as the best model.

Table 2. The best model determination of vertical NIR-Red co-registration.

No	Vertical NIR-Red Co-registration Model	Model Error (Pixels)			
		Left	Mid	Right	Mean
1	$K_1 \sin(\text{Yaw}) + K_2$	1,75	2,25	4,08	2,69
2	$K_1 \cos(\text{Yaw}) + K_2$	1,77	2,12	3,79	2,56
3	$K_1 \cos(\text{Pitch}) + K_2$	1,32	1,74	3,52	2,19
4	$K_1 \cos^2(\text{Pitch}) + K_2 \cos(\text{Pitch}) + K_3$	1,17	1,52	3,12	1,94
5	$K_1 \cos(\text{Pitch}) \cos(\text{Roll}) + K_2$	1,36	1,39	2,42	1,73
6	$K_1 \cos^2(\text{Pitch}) \cos^2(\text{Roll}) + K_2 \cos(\text{Pitch}) \cos(\text{Roll}) + K_3$	1,21	1,19	2,15	1,51

3.3. Regression Result and Analysis

The same approach is used to find the best model of all pair of band co-registration in both horizontal and vertical direction. Table 3 shows the best model obtained for each band co-registration. It can be seen that all band co-registration in particular direction has the same type of model, although the magnitude might not be the same.

Table 3. The best model of each pair of band co-registration.

Band	Co-registration Model	Model Error (Pixels)			
		Left	Mid	Right	Mean
N2R (H)	$K_1 \sin(\text{Yaw}) + K_2$	1,85	1,22	3,08	2,05
N2R (V)	$K_1 \cos^2(\text{Pitch}) \cos^2(\text{Roll}) + K_2 \cos(\text{Pitch}) \cos(\text{Roll}) + K_3$	1,21	1,19	2,15	1,51
G2R (H)	$K_1 \sin(\text{Yaw}) + K_2$	1,56	1,33	1,97	1,62
G2R (V)	$K_1 \cos^2(\text{Pitch}) \cos^2(\text{Roll}) + K_2 \cos(\text{Pitch}) \cos(\text{Roll}) + K_3$	1,48	1,35	2,38	1,74
B2G (H)	$K_1 \sin(\text{Yaw}) + K_2$	0,37	0,30	0,46	0,38
B2G (V)	$K_1 \cos^2(\text{Pitch}) \cos^2(\text{Roll}) + K_2 \cos(\text{Pitch}) \cos(\text{Roll}) + K_3$	0,42	0,15	1,72	0,76

Based on regression results obtained, it can be concluded that band co-registration value in horizontal axis is strongly influenced by yaw satellite angle, which can be modeled as first order of sine function. Meanwhile band co-registration value in vertical axis is influenced by both pitch and roll satellite angle, which can be modeled as second order of couplings cosine function.

These obtained models have an average 1-2 pixels relative accuracy compared to current image matching approach. Meanwhile, absolute accuracy of band co-registration correction currently employed on LAPAN-A3/IPB multispectral images by using image matching approach is around 2-3 pixels error [7]. Therefore, the overall accuracy of the proposed band co-registration in this research by using attitude modeling approach is around 3-5 pixels error. However, accuracy of the model obtained seems to be good only for near nadir satellite attitude, since most of the images used in this research were taken when the satellite not far away from nadir. Therefore, the band co-registration model of each band should be updated by using every new image captured in the future, to cover wider range of satellite attitude while imaging.

4. Image Correction Analysis

The band co-registration models that have been obtained are then used to produce band co-registered composite image of actual LAPAN-A3/IPB multispectral images. The models directly replaces image matching algorithm used in standard LAPAN-A3/IPB systematic image processing algorithm. Figure 4 shows image correction results in NRG composite format, showing that the models successfully correct band co-registration distortion occurs on raw satellite image.

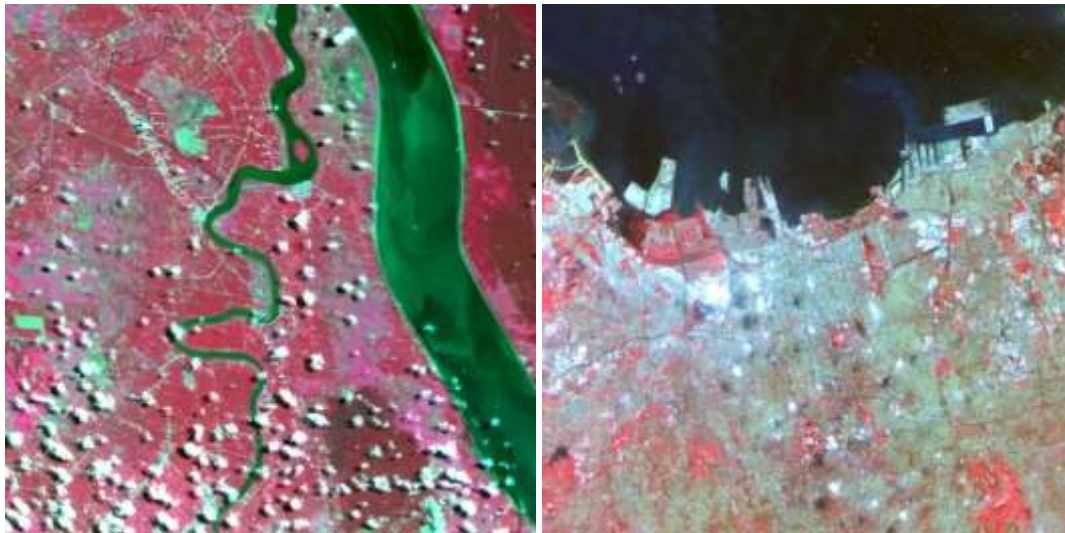


Figure 4. Systematic image correction of LAPAN-A3/IPB multispectral images.

From Figure 4, it can be seen that every object in each corrected channel image has aligned to each other, which can be seen clearly on the shape and color of clouds and river. The images have also been geo-referenced to referenced map as well as radiometric corrected for vignetting effect using pre-flight radiometric calibration data.

While the accuracy produced seems not the ideal performance to achieve, the proposed band co-registration algorithm can be executed in no time. For typical LAPAN-A3/IPB images, the algorithm can be executed averagely in 5-10 seconds, compare to 4-5 minutes needed when executing current image matching algorithm. The trade-off between band co-registration accuracy and processing time needed by the algorithm should be treated carefully, maintaining good accuracy with fast computation. Based on numerous image processed, more complex model such as non-linear sinusoidal model should always been chosen since it produces better accuracy with similar computation time.

5. Conclusions

Band co-registration of LAPAN-A3/IPB multispectral images can be corrected by using simple modeling approach, based on satellite attitude data which provided by star tracker sensor. The band co-registration distortion in horizontal axis can be modeled as yaw angle function with first order sine model, while distortion in vertical axis can be modeled as pitch and roll coupling function with second order cosine model. Accuracy of the proposed band co-registration models are around 2 pixels error compare to results produced by image matching algorithm. Meanwhile, the processing time of the proposed band co-registration algorithm is much faster compare to the other methods, allowing real time implementation. Further research should be conducted about the possibility of satellite attitude determination based on calculated co-registration values from image matching algorithm, thus greatly improves systematic image correction performance in case of the absence of satellite attitude data provided by star sensor tracker.

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