Dark-Image Modeling Analysis of LAPAN-A3 Satellite Imager

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Abstract: To produce a high quality image, raw image produced by LAPAN-A3 satellites imager must be systematically corrected, both in geometric and radiometric aspect. One important variable that is used in radiometric correction process is dark-image, which is an image produced when the camera is closed, thus the camera does not receive any light source. Ideally, the dark-image is acquired directly in orbit just before image acquisition period, but it cannot be done since LAPAN-A3 satellite does not have auto-calibration mechanism or referenced detector. This research aims to model the dark-image of both LAPAN-A3 imagers as a function of several imager intrinsic parameters and period of imager operation, using least-square linear regression method. The resulted model is then used to estimate the dark-image value which is subsequently used in systematic radiometric correction calculation. Experiments and calculation that have been done show that matrix imager has constant dark-image during entire acquisition period, and can be accurately modeled using simple equation as a function of camera parameter only. Meanwhile, multispectral imager has an increasing monotonic dark-image response during acquisition period, which is caused by significant detector temperature increase. Dark-image of multispectral imager can be modeled using linear equation as function of operating-time only, but the model could only produce good estimation for specific camera parameter. All of these results can be used as references in processing raw data of LAPAN-A3 satellites imager, so that the final image produced will have a high radiometric quality.
Key Words: radiometric correction, dark-image, least-square, intrinsic parameter, temperature

Nomenclature

DN	:	Digital number of detector
T_X	:	Camera exposure time
G_D	:	PGA gain amplifier
G_A	:	ADC circuit amplifier
O_A	:	ADC circuit offset
L	:	Incoming radiance
D	:	Dark voltage of detector

1. Introduction

As an experimental micro-satellite with earth surveillance and remote sensing mission, LAPAN-A3 satellite has two optical payloads, which are multispectral imager and digital matrix camera. The multispectral imager is a push-broom (line-scanner) type of imager which has four color channels, i.e.: red, green, blue and near-infrared (NIR), with 15 meter spatial resolution and approximately 120 km swath width. Meanwhile, the digital matrix camera uses a RGB-Bayer filter as color filter array (CFA), with 3 meter spatial resolution and around 6x6 km coverage area at nadir. To produce high quality images and free from systematic distortions, several stages of radiometric and geometric correction have to be done to raw images that are generated by both imagers. Systematic geometric correction is necessary so that the image produced has a shape, position and orientation similar to the actual object on the earth surface. Several studies related to systematic geometric correction of LAPAN-A3 imager have been carried out[1,2], which essentially seeks to minimize the geometric distortion of multispectral imager that is caused by satellite instability, based on ancillary data of satellite position and orientation that come from GPS and star tracker sensor (STS).

Meanwhile, systematic radiometric correction is needed so that satellite images produced have a uniform intensity response between pixels, and to derive the radiance value of each pixel. Several studies related to systematic radiometric correction of LAPAN-A3 imager have also been carried out, among others, are vignetting effect of the matrix imager[3], and demosaicing process of matrix imager RGB-Bayer filter[4]. Generally, radiometric correction requires several information of the camera used, some of them are detector sensitivity and detector dark-current, or commonly known as dark-image. These data can be

obtained through a series of experiments and calibration in the laboratory before the satellite is launched, and then the results are validated once the satellite is in orbit using the vicarious calibration method[5)].
However, LAPAN-A3 satellite does not have auto-calibration mechanism nor detectors that can be used as references, so that the determination of dark-image data in orbit is not easy to do, and more importantly, because it does not guarantee the accurate results. Therefore, the process of determining dark-image data that is used in systematic radiometric correction must be done accurately in the laboratory before the launch. Dark-image is defined as the image produced when camera system does not receive any light source, which can be technically accomplished by closing the camera shutter completely[6)]. Dark-image data is largely dependent on the temperature of the detector at the time of the observation took place, and indirectly also affected by some intrinsic parameters of camera[7)]. General radiometric model of LAPAN-A3 matrix camera has been previously developed[3,8)], which describes the value of camera digital number (*DN*) as a function of the amount of incoming radiance and camera intrinsic parameters. This model has been used in relative radiometric calibration of LAPAN-A3 matrix imager[3)], which is based on radiometric calibration standard using integrating sphere as uniform light-source[9,10,11)].
Based on this model, this paper aims to model dark-image of LAPAN-A3 satellite multispectral imager and digital matrix camera, as a function of several camera intrinsic parameters and the length of observation time, which might be affected by detector temperature. The camera intrinsic parameters used in this research are camera exposure time and analog-to-digital (ADC) circuit parameter, i.e.: gain and offset. Based on observation data taken in several camera parameter combinations, linear least-squares regression method is then used to produce the dark-image equation model with camera parameters and operation time-length as independent variables. The equation model produced is then validated using a series of other observation image data that is not used during the regression process. Finally, dark-image calculated from the validated model is used in relative radiometric correction to minimize radiometric distortions on distorted images.

2. Research Methodology

This research consist of five steps, first is deriving general dark-image model, second is conducting several observation under varying camera parameters, third is fitting the observation data into the model used, fourth is validating the fitted dark-image model and last one is conducting radiometric correction. Fig. 2.1. shows the flowchart of methodology used in this research.

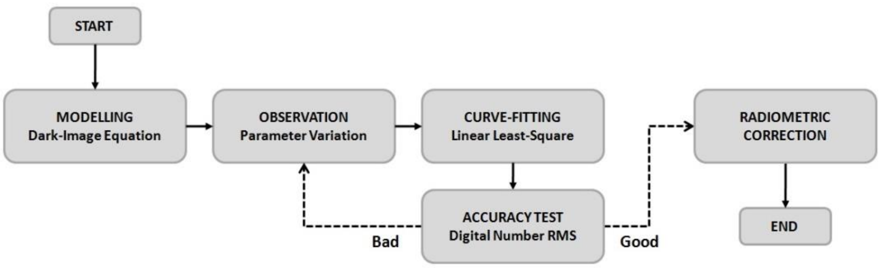

Fig. 2.1. Flowchart of methodology used in this research

2.1. Dark-Image Equation

Although have a quite different structure, but basically LAPAN-A3 multispectral imager and matrix camera have similar radiometric model. In general, the incoming light passing through the lens system will experience several geometric and radiometric distortions, such as radial-tangential distortion and lens vignetting effect. The light is then received by the detector system, which will transform the physical light quantity (radiance) into electrical quantities. Each detector has different sensitivity and noise level, so each detector could generates different response to uniform light source. The electrical output signal from detector system is then amplified by analog-to-digital converter (ADC) circuit, and finally the output is sampled to generate digital data number (*DN*) for each pixel. Fig. 2.1.1. explains the radiometric model used in this research, which can be applied to both camera matrix and multispectral imager of LAPAN-A3 satellite.

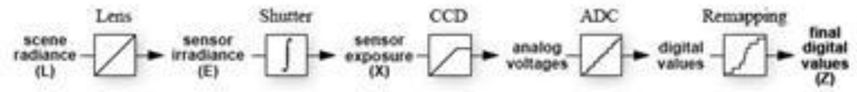

Fig. 2.1.1. General radiometric model of optical system[3,6)]

There is one difference between radiometric model of camera matrix and multispectral imager, i.e.: camera matrix has additional PGA amplifier circuit. In matrix camera, detector electrical output signal will be amplified twice by PGA and ADC circuit, while in multispectral imager the signal will only be amplified once. For matrix camera, the radiometric model for each detector have the following general equation[3,6)]:

$$DN = K_1 G_A G_D T_X L + K_2 G_A G_D D + K_3 G_A O_A \tag{1.}$$

Where *DN* is digital number of each pixel of generated images, *L* is an incoming radiance that enters the camera, T_X is camera exposure time, G_D is PGA gain amplifier, while G_A and O_A are gain and offset of ADC circuit. Meanwhile, *D* is detector dark-voltage that depends on detector temperature. Constants K_1, K_2, and K_3 on the equation is a combination of several parameters which is generally constant in a general optical system. The above equation model can also be used for multispectral imager, ignoring PGA amplifier G_D, because there is no PGA in multispectral imager. In addition, the ADC parameter value of G_A and O_A for each color channel in multispectral imager has different values from each other.

Based on previous definition, dark-image is an image that is generated when the camera is closed and does not receive any incoming light. Based on Eq. (1), the equation dark-image can be derived by adjusting the radiance *L* to zero, as following equation:

$$DN = K_2 G_A G_D D + K_3 G_A O_A \tag{2.}$$

From Eq. (2), the dark-image is affected by both ADC circuit parameters and dark-voltage detector, beyond the constant parameters of optical systems used. ADC parameter consists of an offset and gain amplifier, and PGA gain amplifier for camera matrix, while dark-voltage is a variable that is always changing depending on the temperature of the detector at the time of observation. This research will use these variables as independent variables in estimating dark-image equation model.

2.2. Iterative Linear Least-Square Regression

Based on previous dark-image model, it seems that the equation model is non-linear since it has multiplication of independent variables such as $G_A G_D D$ on first term and $G_A O_A$ on second terms. However, in data regression perspective, such equation model is still considered linear system as each term of these multiplications can be treated as single independent variable. For example, $G_A G_D D$ can be treated as new independent variable X_1 and $G_A O_A$ can be treated as X_2. As a result, a new set of linear equations can be obtained for each detector from *N*-observation:

$$\begin{bmatrix} DN_1 \\ DN_2 \\ DN_3 \\ \vdots \\ DN_N \end{bmatrix} = \begin{bmatrix} X_{11} & X_{21} & 1 \\ X_{11} & X_{22} & 1 \\ X_{11} & X_{23} & 1 \\ \vdots & \vdots & \vdots \\ X_{11} & X_{2N} & 1 \end{bmatrix} \begin{bmatrix} K_2 \\ K_3 \\ e \end{bmatrix} \tag{3.}$$

Variable X_{1i}, X_{2i} and DN_i in Eq. (3) are new independent variables and the captured camera digital number, respectively. To determine the value of constants K_2, K_3 and *e*, this set of linear equations then can be solved by using following pseudo-inverse method[12)]:

$$\begin{bmatrix} K_2 \\ K_3 \\ e \end{bmatrix} = (\mathbf{X}^T \mathbf{X})^{-1} \mathbf{X}^T DN \tag{4.}$$

Matrix **X** is a regression matrix which is composed from a set of new independent variables. By solving the equation, constant K_2, K_3, and e can be determined. By evaluating all equations from each detector (pixel), then 2048x2048 sets of constant for matrix camera and 4x8002 sets of constant for multispectral imager, are produced. However the calculation is impractical when there are a lot of observation data to be processed at once, especially with more than four million equations to be solved in case of matrix camera. It will take a massive memory usage as well as quite long computation. Therefore, iterative-type of calculation is needed to reduce computational complexity, but without affecting the computational accuracy. In this research, regression matrix **X** is first calculated, and then constant K_2, K_3 and e are iteratively updated for each subsequent observation data.

2.3. Experiment Procedure

To solve the above linear equation, a set of measurement needs to be done. First experiment is conducted to determine dark-image model of LAPAN-A3 matrix camera, while second experiment is done for multispectral imager. There is no significant difference procedure between them, except that there will be four model constructed for each multispectral imager color channel. Theoretically since there are three new independent variables, three observation are enough to solve the equation, however to minimize the effect of measurement noise, the number observation needed should be much higher. In this research, at least 80 observations with different intrinsic camera parameter to each other were done for each experiment.

Each observation is simply done by taking a picture of shutter-closed camera, and then captured image data are saved in computer. In the same time, several intrinsic camera parameters and detector temperature are also saved manually. Each observation is done around 30 seconds after another, so it accommodates the transition condition that might be occurs after changing some parameters. With this setup, each observation will have digital number data, all the needed intrinsic parameters, and also detector temperature. To simplify the procedure, all parameter changes should be planned beforehand, so there is no need to save telemetry data from the camera for each observation. Fig. 2.3.1. shows the experiment procedure used for each set of observation, which can be used for both imagers.

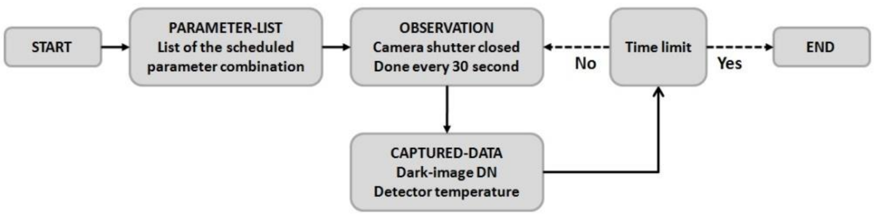

Fig. 2.3.1. Observation procedure for single experiment

3. Results and Analysis

Although both LAPAN-A3 matrix camera and multispectral imager have similar radiometric model and experiment procedure, but they produce significant different observation result, and thus also have different analysis. This section will explain all observation results, with their data regression process and analysis, for both satellite payloads.

3.1. Matrix Camera

To be able to model the dark-image accurately, a set of observation with different camera parameter are needed. For LAPAN-A3 camera matrix, there are four intrinsic parameters that can be adjusted that contribute to dark-image, i.e.: camera exposure time, PGA amplifier, as well as gain and offset of ADC. Theoretically, a good estimation model can be produced when the variation of each parameter is spread out within the parameter domain, but the number of observation needed can be pretty high. To reduce the number of observation needed, each parameter domain is limited to the value that might occur when the satellite is in orbit. In addition of reducing the number of observation needed, the limited domain will have more stable estimation compare to original domain, due to possibility of non-linear response in some parts of domain. For example, the camera exposure time value can be set anywhere from 0,25 ms to 6 seconds, but for LAPAN-A3 satellite, camera exposure time cannot be set that high, it is limited by image resolution constraint. Table 3.1.1. shows each original parameter domain, the limited domain chosen, and the actual parameter value that are used in this research. There are two experiments that have been conducted for matrix camera modeling, the first one uses wide-range of parameter domain while second experiment uses narrow-range of parameter domain, specific to most-probable parameter value in orbit. Each parameter in will have three different values, so combination of four parameters will produce 81 observations.

Table 3.1.1. Intrinsic parameter combinations that are used for matrix camera experiments

Parameter	**Original Domain**		**Limited Domain**		**Experiment-1**			**Experiment-2**		
	Min	**max**	**min**	**max**	**#1**	**#2**	**#3**	**#1**	**#2**	**#3**
Exposure Time	1	6000	10	90	10	50	90	27	29	31
PGA Amplifier	0	3	1	3	1	2	3	1	2	3
ADC Gain	0	63	0	60	0	30	60	55	57	59
ADC Offset	-16000	16000	0	1000	0	500	1000	-220	-120	-20

After doing these experiments in two different time and condition, it is found out that detector temperature does not change at all from the start to the end, which is 30 degree Celcius. This fact shows that dark-image of matrix camera is independent from operating-time variable, i.e.: given the same values of intrinsic camera parameter, the dark-image value will always be the same. However, the dark-image still might be affected by detector temperature changes. Unfortunately, this research conducts all observations at the same ambient temperature, it does not use thermal chamber to accommodate temperature effect on dark-image value. Therefore, all data produced here are under condition the same ambient temperature, which is 25 degree Celcius. Table 3.1.2. shows sampled observation results of first experiment, showing only observation under combination of minimum and maximum value of each parameter. Dark-image values shown are averaged digital number from all pixels of each color channel.

Table 3.1.2. Sampled observation data of matrix camera, using only min-max of limited domain

Intrinsic Camera Parameter				**Dark-Image (Averaged-*DN*)**		
Exposure	**Offset**	**PGA**	**Gain**	**Green**	**Red**	**Blue**
10	0	1	0	280.1	280.11	280.08
10	0	1	60	306.48	306.56	305.03
10	0	3	0	280.18	280.19	280.15
10	0	3	60	309.96	310.09	308.42
10	1000	1	0	1280.1	1280.1	1280.1
10	1000	1	60	1302.6	1302.7	1301.1
10	1000	3	0	1280.2	1280.2	1280.1
10	1000	3	60	1306.2	1306.3	1304.7
90	0	1	0	280.11	280.12	280.09
90	0	1	60	302.37	302.48	300.83
90	0	3	0	280.17	280.18	280.14
90	0	3	60	305.73	305.86	304.4
90	1000	1	0	1280.1	1280.1	1280.1
90	1000	1	60	1304.7	1304.8	1303.2
90	1000	3	0	1280.2	1280.2	1280.1
90	1000	3	60	1310.1	1310.3	1308.8

Based on Eq. (2) and observation data from Table 3.1.2., it can be concluded that camera exposure time does not affect the dark-image value. Meanwhile, ADC offset seems to have unity influence to dark-image data, although Eq. (2) shows that there is coupling effect between ADC gains and offset to the value of dark-image. Based on these facts, in this research LAPAN-A3 matrix camera will have following general model, where K_4 is added to accommodate any other factor that does not included in this model:

$$DN = K_2 G_A G_D + K_3 O_A + K_4 \tag{5.}$$

There are several ways to construct the dark-image model from above data. First, either the model is applied to single color channel or to all channels. Second, either the model is applied to single detector or to all detectors. There are some approaches that are used in this research. In first approach, a single model is applied to all color channel and all detectors. In second approach there are four models, each one is applied to all detector of each color channel, where green channel has two models since the camera has a GRBG Bayer filter. In third approach, 2048x2048 models are applied to each detector. Note that two parameter value, PGA amplifier and ADC gain, need to be converted to their physical quantities before applying them into regression process, using calibration data. Each experiment then further divided into several models correspond to the calibration data used. Table 3.1.3. and Table 3.1.4. shows regression result of each experiment, showing estimated coefficients, model-error, and cross-error. Model-error is produced when validating the model using its corresponding regression data, while cross-error is produced when using another set of data.

Table 3.1.3. Regression result of first experiment with wider parameter domain

Dark-Image Model	**Estimated Coefficient**			**Model-Error**		**Cross-Error**	
	K_2	K_3	K_4	*DN*	**NSR**	*DN*	**NSR**
Model-1: There is only one equation describing all detectors response							
Model 1 (average)	1,6634	0,99993	278,22	3,2180	0,57582	5,2683	4,2106
Model 1 (red-command)	1,6917	0,99993	278,20	3,2206	0,57630	5,2289	4,1787
Model 1 (green-command)	1,6680	0,99993	278,21	3,2190	0,57601	5,2550	4,1998
Model 1 (blue-command)	1,5696	0,99993	278,33	3,2099	0,57426	5,4439	4,3529
Model-2: There are four equations, one for each channel using different channel-command							
Model 2-Green	1,7123	0,99992	278,17	3,2230	0,57623	5,4138	4,3177
Model 2-Red	1,7439	0,99992	278,16	3,2180	0,57554	5,4230	4,3254
Model 2-Blue	1,5200	0,99993	278,37	3,1907	0,57129	5,2262	4,1885
Model 2-Green	1,6249	0,99993	278,25	3,1946	0,57201	5,0875	4,0732
Model-3: There are four million equations, each one describes each detector response							
Model 3 (average)	1,6636	0,99993	278,22	1,8355	0,33322	6,3335	5,0355
Model 3 (red-command)	1,6919	0,99993	278,20	1,8394	0,33394	6,2956	5,0049
Model 3 (green-command)	1,6681	0,99993	278,21	1,8363	0,33337	6,3201	5,0246
Model 3 (blue-command)	1,5698	0,99993	278,33	1,8228	0,33083	6,4913	5,1626
Model-4: There are four million equations, by using corresponding channel-command							
Model 4-Green	1,7124	0,99993	278,17	1,8495	0,33532	6,4752	5,1344
Model 4-Red	1,7443	0,99993	278,15	1,8556	0,33646	6,4444	5,1127
Model 4-Blue	1,5199	0,99993	278,37	1,8090	0,32877	6,3218	5,0400
Model 4-Green	1,6252	0,99993	278,25	1,8221	0,33119	6,1767	4,9227

Table 3.1.4. Regression result of second experiment, using narrow-specific of parameter domain

Dark-Image Model	**Estimated Coefficient**			**Model-Error**		**Pixel-Error**	
	K_2	K_3	K_4	*DN*	**NSR**	*DN*	**NSR**
Model-1: There is only one equation describing all detectors response							
Model 1 (average)	1,2111	0,99953	278,07	3,1580	2,4657	4,2661	0,73978
Model 1 (red-command)	1,2320	0,99953	278,09	3,1586	2,4661	4,2370	0,73454
Model 1 (green-command)	1,2141	0,99953	278,07	3,1576	2,4652	4,2612	0,73889
Model 1 (blue-command)	1,1429	0,99953	277,98	3,1569	2,4652	4,3944	0,76290
Model-2: There are four equations, one for each channel using different channel-command							
Model 2-Green	1,2475	0,99952	277,97	3,2062	2,4950	4,3864	0,75982
Model 2-Red	1,2819	0,99951	277,86	3,2243	2,5097	4,4284	0,76733
Model 2-Blue	1,0950	0,99957	278,22	3,0711	2,4075	4,1725	0,72537
Model 2-Green	1,1818	0,99956	278,17	3,0977	2,4258	4,1198	0,71558
Model-3: There are four million equations, each one describes each detector response							
Model 3 (average)	1,2110	0,99954	278,07	2,2221	1,7290	5,9584	0,99547
Model 3 (red-command)	1,2320	0,99954	278,09	2,2233	1,7297	5,9478	0,99364
Model 3 (green-command)	1,2140	0,99954	278,07	2,2216	1,7286	5,9542	0,99473
Model 3 (blue-command)	1,1428	0,99954	277,98	2,2206	1,7284	6,0060	1,0039
Model-4: There are four million equations, by using corresponding channel-command							
Model 4-Green	1,2476	0,99952	277,97	2,2578	1,7514	6,0953	1,0182
Model 4-Red	1,2820	0,99951	277,86	2,2720	1,7624	6,1024	1,0208
Model 4-Blue	1,0950	0,99957	278,22	2,1709	1,6955	5,8343	0,97378
Model 4-Green	1,1819	0,99955	278,17	2,1868	1,7063	5,8218	0,97260

From these results, it can be concluded that different calibrated data that are used in regression does not influence the model accuracy significantly, as can be seen in several model-1 and model-3 for each experiments. Although using different calibrated data, the models produce quite similar results, both in estimated coefficient and model accuracy. Furthermore, different model for each color-channel also does not influence the model accuracy significantly, although there are slight differences in estimated coefficient, especially for K_2 value. These two findings show that color-channel of each detector can be neglected when developing the model, thus the model can only use single calibrated data as well as single model to represent all color-channel accurately. However, four millions models that are used in model-3 and model-4 produce different result when compared to model-1 and model-2, especially in accuracy point of view. From both tables above, model-3 gives much better model-accuracy compare to model-1, but model-1 has slight better cross-accuracy.

The trade-off between model-accuracy and cross-accuracy should be further analyzed to determine the best model that will be used to describe the whole matrix camera detector response. In general, one single as in model-1 has better accuracy when the model is developed from a set of observation which does not specifically predict the actual parameter value. For example, when the condition in orbit is somewhat hard to predicted, thus the value of each parameter cannot be predicted accurately, then the model-1 will give better model. In other hand, if parameter value in orbit can be predicted accurately, then model-3 is much better than model-1. When the parameter domain can be accurately predicted, cross-accuracy analysis will be irrelevant since the other set of data does not describe the condition of observation accurately.

Obviously, it can be seen that cross-model accuracy has higher *DN*-error since they are tested using another set of data, unlike the other one where the model are tested using their own data. However, Table 3.1.3. and Table 3.1.4. also show that even though the errors produced are bigger, the value of error themselves are still acceptable, which are under 5% of dark-image nominal value. This means that both experiments could produce accurate model, they have been validated using another set of data which have not used in their regression calculation. Furthermore, although model-3 gives better accuracy compare to model-1 in specific parameter domain, model-1 has far more simple form, it has only single equation for entire pixel detectors. Therefore, the dark-image value of entire LAPAN-A3 matrix camera detector can be modeled quite accurately using one simple model, for example DN=1,6634G_AG_D+0,99993O_A+278,22, as produced by model-1 from experiment-1. Finally, the single estimated dark-image value produced by this simple equation then was used for relative radiometric correction algorithm. The corrected image produced by using the estimated dark-images does not have significant differences from the corrected image produced by using the real or actual dark-image. This shows that the proposed dark-image model of LAPAN-A3 matrix camera is good enough for relative radiometric correction purpose.

3.2. Multispectral Imager

Based on several dark-image observation of LAPAN-A3 multispectral imager, the most important thing that can be pointed out is that detector temperature of the camera keep increasing during period of observation. This makes the value of dark-image captured also increases as time goes, given the same intrinsic parameter value. Fig 3.2.1. shows averaged digital number of dark-image for each color channel, which also shows that each color-channel gives quite different dark-image response to others. Note that this observation was done in around 40 minutes with fixed intrinsic camera parameter.

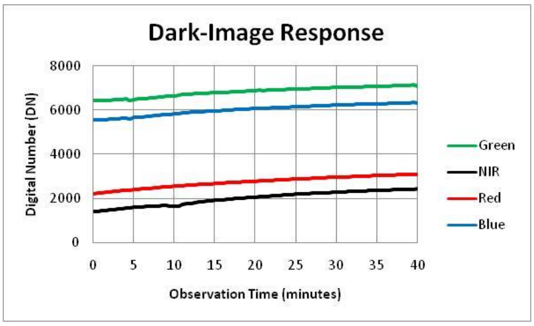

Fig. 3.2.1. Dark-image observation of each color-channel of LAPAN-A3 multispectral imager

Since the detector temperature increases over time during observation, which cause dark-image also increases even when all camera parameter are fixed, this research will only models the dark-image of multispectral imager as a function of operation-time period only. Table 3.2.1. shows regression results based on observation data shown in Fig. 3.2.1.

Table 3.2.1. Dark-image regression result of each color-channel of LAPAN-A3 multispectral imager

Color-channel (band)	Equation Model (Linear)
Green	$DN = 18{,}22t + 6459$
NIR	$DN = 26{,}43t + 1463$
Red	$DN = 21{,}20t + 2308$
Blue	$DN = 20{,}25t + 5603$

Although above models could only give a good estimation in particular ambient temperature and some fixed camera parameters, at least they can give moderate understanding how the dark-image will behave during each observation period. In general, the direct consequence of dark-image increasing during observation time, is that composite image produced will have different brightness in different parts of image, i.e.: earlier lines of image that are captured at the start of observation will be darker compare to later lines of images, which are captured after few minutes of observation. The difference, however, might be insignificant to human eyes, but obviously it still can be detected and differentiated by computer. With the proposed model above, the correction algorithm could estimate the difference between dark-image on the start and on the end of observation, and then subtract these values to their corresponding real-images. The images produced after correction, in theory, will have more uniform brightness across entire parts of image, compare to raw image.

3.3. Payload Comparison Analysis

As summary, dark-image produced by of LAPAN-A3 matrix camera has following characteristics: 1) the detector temperature does not change at all during entire observation periods, but the value of dark-image still might be affected by ambient temperature difference, 2) camera exposure time does not affect the dark-image value, and ADC offset seems to have unity influence to dark-image data, 3) color-channel of each detector can be neglected when developing the model, and 4) if parameter value in orbit can be predicted accurately, then model-3 with four million equations is much better than model-1, and vice versa. Meanwhile, dark-image of LAPAN-A3 multispectral imager has following characteristics: 1) detector temperature changes significantly during observation, 2) ADC offset has coupling effect with ADC gain parameter, 3) color-channel might have slight influence to the model, although this still need to be investigated further, and 4) the dark-image model could only developed as a function of operating-time only, since it is hard to model both temperature and camera parameter changes simultaneously. Table 3.3.1. shows the comparison of dark-image characteristics between LAPAN-A3 camera matrix and multispectral imager.

Table 3.3.1. Dark-image comparison of LAPAN-A3 satellite imager

Characteristics	Matrix Camera	Multispectral Imager
Detector temperature	Constant during entire observation	Monotonically increases as time goes
ADC offset	Unity influence to dark-image	Has coupling effect with ADC gain
Color-channel model	Can be neglected in modeling	Might influence dark-image model
Uniformity	Uniform across image	Has vignette-like effect
The proposed dark-image model	Dark-image as a function of intrinsic camera parameter only	Dark-image as a function of observation-time only
Dark-image used in radiometric correction	Actual value of dark-image	Delta (increment) of dark-image

4. Conclusion

One variable that plays important role in processing raw satellite image is dark-image of the camera, which is the image produced when camera shutter is totally closed. This research aims to analyze the dark-image characteristics of both LAPAN-A3 matrix camera and multispectral imager. Dark-image of LAPAN-A3 matrix camera has simpler model compare to multispectral imager, since detector temperature does not change at all during entire observation period. However, since in this research, ambient temperature is not used as one of independent variables, the dark-image is modeled as a function of intrinsic parameter and operating-time only. Several regression results and analysis show that the dark-image of matrix imager can be modeled accurately using one single first-order linear equation that can be applied to all detectors. Further more complex model enhancements such as the use of color-channel differentiation and even the use of one equation for each detector will not increase the accuracy significantly. Meanwhile, dark-image of multispectral imager has quite different characteristics compare to dark-image of matrix camera, importantly because detector temperature increases monotonically during observation period. Since it is hard to model both varying detector temperature and camera parameter simultaneously, the dark-image of multispectral imager can only be modeled as a linear function of operation time period. Although it is not the best model estimation, but it could give some reference when calculating the dark-image of LAPAN-A3 multispectral imager during entire observation period, given particular set of intrinsic camera parameter.

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References

1) Hakim, P.R., Rahman, A., Suhermanto, and Rachim, E.: *Systematic Geometric Correction Model of Pushbroom Imager Data using Colinear Projection Method*, Journal of Aerospace Technology, Vol. 10 No. 2, 2012, pp. 121-132.
2) Hakim, P.R., Hasbi, W., and Syafrudin, A.H.: *ADCS Requirements of Lapan-A3 Satellite Based on Image Geometry Analysis*, International Conference of Aerospace and Remote Sensing Technology (ICARES), Yogyakarta, 2014.
3) Hakim, P.R., Syafrudin, A.H., and Salaswati, S.: *Analysis of Radiometric Calibration on Matrix Imager of LAPAN-A3 Satellite Payload*, International Conference of Aerospace and Remote Sensing Technology (ICARES), Bali, 2015.
4) Salaswati, S., Hakim, P.R., and Syafrudin, A.H.: *Comparative Analysis of Demosaicing Methods on Radiometric Corrected Image*, SIPTEKGAN XIX, Serpong, 2015.
5) Leigh, L., and Aarron, D.: *Absolute Radiometric Vicarious Calibration of on Orbit Imaging Satellites*, Asian Conference on Remote Sensing (ACRS), Bali, 2013.
6) Kelcey, J., and Lucieer, A.: *Sensor Correction and Radiometric Calibration of a 6-band Multispectral Imaging Sensor for UAV Remote Sensing*, International Archives of the Photogrammetry: Remote Sensing and Spatial Information Sciences Vol. XXXIX-B1, Melbourne, 2012.
7) McCluney, R.: *Introduction to Radiometry and Photometry*, Artech House, Inc., Norwood, MA, 1994.
8) Salaswati, S., and Syafrudin, A.H.: *Simulation of Radiometric Correction of CCD KLI 8023*, LAPAN Satellite Technology Scientific Book, 2016, submitted.
9) Beisl, U.: *Absolute Spectroradiometric Calibration of the ADS40 Sensor*, Proceeding of the ISPRS Commission I Symposium: From Sensor to Imagery, Paris, pp. 3-6.
10) Olsen, D., et al.: *Radiometric Calibration for AgCam*, MDPI Journal: Remote Sensing, 2010.
11) Zhang, Y., and Chen, S.: *Preflight Calibration of HY-1 Satellite 4-band CCD Camera*, 22nd Asian Conference on Remote Sensing, Singapore, 2001.
12) Ben-Israel, A., and Greville, T.N.E.: *Generalized Inverses: Theory and Application (2nd edition)*, Springer, New York, 2003.