Performance of thermal imager on LAPAN-A3/IPB satellite compare with thermal band Landsat imager

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Abstract. LAPAN-A3/IPB Satellite is 3rd generation experimental satellite of LAPAN. This satellite has been launched in June 2016 and orbited on altitude 510km with sun synchronous orbit. One of the payloads of this satellite is experimental thermal imager camera, called micro-bolometer with 8-12 um band spectral. At first, micro-bolometer is used as horizon sensor, but also can be used for monitoring of earth surface temperature. The aim of this research is to validate image data of micro-bolometer based on Landsat infrared band image data. The method used in this research is to find the correlation between digital number (DN) of micro-bolometer camera of LAPAN-A3/IPB with the temperature that has been calculated and obtained from image of Landsat satellite. The result of this research shows that the data from micro-bolometer LAPAN-A3/IPB has characteristics that are close to Landsat infrared band image data. Moreover, the data of micro-bolometer camera has also been validated with multispectral camera of LAPAN-A3/IPB satellite both in coverage swath-width and visual identification.

1. Introduction
LAPAN-A3/IPB is a 3rd generation of experimental microsatellite of LAPAN, this satellite was launched by using Indian PSVL on 22th of June 2016[1]. This satellite has main mission to support the program of national food security. This satellite has a collaboration with Bogor Agricultural Institute (IPB). IPB as an academic institution is specialist in agricultural science and technology, so all payloads requirement are defined by IPB as a partner.

The first payload is Multispectral Imager (MSI). The MSI is also known as Line Imager Space Application (LISA), a push broom 4-band imager with 300mm lens to produce ground resolution 15m and swath width 123 km [2]. The second payload is Digital Space Camera (DCS). This camera is same as with LAPAN-A2, this payload capable to produce resolution around of 4m. The third payload is Automatic Identification System (AIS) receiver for monitoring ship traffic, and the last payload is experimental thermal imager which is called as micro-bolometer. The thermal imager is provided by FLIR. The resolution of thermal imager is 640x320 with using 60mm lens and it can produces swath width is around 92km. Beside, this thermal imager has wavelength 8-12μm with temperature range is around -40 until 80°C. The output of this thermal camera is an analogue video with 14 bits, but camera on-board data processing automatically converts it to 8 bits [3].

The processing of video data thermal imager into mosaicking images and classification object were done in previous paper [4]. As a continuation of the development of a systematic data processing system
for thermal imager LAPAN A3 satellite, this research will try to calculate land surface temperature of micro-bolometer by utilizing its data digital number (DN) and assisted by the value of DN and Land Surface Temperature (LST) of LANDSAT-8 Thermal Infrared Sensor (TIRS). TIRS senses the TIR radiance at a spatial resolution of 100m using two bands located in the atmospheric window between 10 and 12 μm[6,7]. The technique presented in this paper is by estimating the LST of a given Landsat8 image with the input of the red band as band4 (0.64–0.67μm), near infrared band (NIR) as band5 (0.85–0.88μm), and thermal infrared band10 (TIR) (10.60–11.19μm). Following the instructions of United States Geological Survey (USGS) January 6, 2014, of not using TIRS band 11 due to its larger calibration unreliability, only band 10 was considered in the technique.

The paper will be organized as follows, Section II will describes the methodology used in this research, shows brief concept and algorithm to calculate value of LST from band10 of Landsat8. Section III will discuss about observation data between microbolometer LAPAN-A3 satellite and band10 Landsat satellite for finding DN, and utilize of multispectral camera LAPAN-A3/IPB for identification object. Section IV will discusses about result of analysis comparison of data from micro-bolometer of LAPAN-A3/IPB and Landsat infrared band image data. Moreover, the data of micro-bolometer camera will also been validated with multispectral camera of LAPAN-A3/IPB satellite both in coverage swath width and visual identification fitting. Finally, some research conclusions are presented in section V.

2. Method
The approach of the proposed work is to validate image between thermal imager of LAPAN-A3/IPB satellite and Landsat 8 that is shown in the figure 1. Figure 1 shows that there are two main processes in this research. First process is capturing image by using thermal camera or micro-bolometer of LAPAN-A3/IPB satellite. There are several steps to do, such as determine the target or area that will be analysed. In this research, there are two sample areas, which are Bandung, West Java at 2nd October 2018 and Krakatau in Sunda Strait at 14th September 2018. Next step is mosaicking image process, followed by image registration process using Ground Control Point (GCP) [5]. The last step is to determine DN value from thermal camera. In determining DN value, it defines the object classification of two image targets such as clouds, vegetation, habitation, sea, lake and others.

The second process is the processing image of Landsat8 Satellite. The target for this process is same as the target at thermal camera of LAPAN-A3/IPB and the capturing image time also should be close to. In this research, band10 is used to estimate brightness temperature and bands 4 and 5 are used to calculate Normal Difference Vegetation Index (NDVI). The steps involved in the proposed work are detailed in the following literature.

The last process is validating data of the images. In this research, there are several validations that must be done, such as DN thermal imager with DN Landsat8 Satellite, DN thermal imager with LST Landsat8 Satellite temperature and swath width comparison to LAPAN Image Space Application (LISA).
2.1 Top of atmospheric spectral radiance

The Landsat8 satellite data products were geometrically corrected data set. The metadata of the satellite images were presented in table 1. The first step of the proposed work is to convert the DN values of band10 to the sensor spectral radiance using the following equation below [9,10,11].

\[ L_\lambda = M_L \cdot Q_{cal} + A_L \]  

(1)

Where,
- \( L_\lambda \) = Top of Atmosphere spectral radiance (Watts/(m²*srad*μm))
- \( M_L \) = Band-specific multiplicative rescaling factor from the metadata
- \( A_L \) = Band-specific additive rescaling factor from the metadata
- \( Q_{CAL} \) = Quantized and calibrated standard product pixel values (DN)
Table 1. Metadata of the satellite image.

| Variable | Description            | Unit    |
|----------|------------------------|---------|
| K1       | Thermal Constanta      | 774.8853|
| K2       | Thermal Constanta      | 1321.0789|
| AL       | Radiance Add Band      | 0.1     |
| ML       | Radiance Multi Band    | 0.0003342|

2.2. Conversion of radiance to at sensor temperature
After converting DN values to the sensor spectral radiance, the TIRS band data should be converted to Brightness Temperature (BT) using the thermal constants given in metadata file and the following equation [8]:

\[
BT = \frac{K_2}{\ln\left(\frac{K_1 L_\lambda}{L_1}\right)+1} - 273.15
\]  

(2)

Where K1 and K2 is the thermal constants of TIR band10 which can be identified in the metadata file associated with the satellite image. For having the results in Celsius, it is necessary to revise by adding absolute zero which is approximately equal to -273.15. Since the atmosphere in our research area is comparatively dry, therefore, the range of water vapour values is relatively small, the atmospheric effect is not taken into consideration in retrieving the LST.

2.3. NDVI method for emissivity correction

2.3.1. Calculating NDVI
Landsat visible and near-infrared bands were used for calculating the Normal Difference Vegetation Index (NDVI). The importance of estimating the NDVI is essential since the amount of vegetation present is an important factor and NDVI can be used to infer general vegetation condition [12]. The calculation of the NDVI is important because, afterward, the proportion of the vegetation (Pv) should be calculated, and they are highly related with the NDVI, and emissivity (\(\varepsilon\)) should be calculated, which is related to the Pv.

\[
NDVI = \frac{(NIR\ Band5 - RED\ Band4)}{(NIR\ Band5 + RED\ Band4)}
\]  

(3)

2.3.2. Calculating the proportion of vegetation
Spatial variation in the radiometric temperature of surfaces is related to variations of the soil-water concentration vertically and surface greenness detailed by the Pv. The variations of detailed explanations of FVC are utilized by remote sensing and modelling, be that as it may, can prompt an error between what is utilized as part of a model and what is estimated utilizing remote sensing. Hence, the formula as described in [13] was used in deriving the Pv from the NDVI image as shown in equation 4

\[
Pv = \left[\frac{NDVI - NDVI_{\text{min}}}{NDVI_{\text{max}} - NDVI_{\text{min}}}\right]^2
\]  

(4)

2.3.3. Calculating land surface emissivity
LSE is a proportionality factor that scales blackbody radiance (Planck’s law) to predict emitted radiance, and it is the efficiency of transmitting thermal energy across the surface into the atmosphere[14]. In this sense, LSE must be known in order to estimate land-surface temperature accurately from radiance measurements. We used the USGS equality to calculate for the LSE. This equality uses the NDVI Normalized Difference, the formula is shown in equation 5

\[
\varepsilon = 0.004 \ PV + 0.986
\]  

(5)
2.4. Calculating LST

The final step is to calculate LST using BT of band10 and LSE derived from Pv and NDVI [15]. LST can be retrieved using the equation 6.

\[
LST = \frac{BT}{1 + (\lambda \times BT / \rho) \times \ln(\varepsilon)}
\]  

(6)

Where, the LST in Celsius (°C), BT is at-sensor Brightness Temperature (°C), \( \lambda \) is the average wavelength of band10 is 10.8 µm, emissivity (\( \varepsilon \)) is the calculated from equation from (5) and \( \rho \) is (h*c/s) which is equal to 1.438 x 10\(^{-2}\) mK in which, \( \sigma \) is the Boltzmann constant (1.38 x 10\(^{-23}\) J/K), \( h \) is Planck’s constant (6.626 x 10\(^{-34}\) Js) and \( c \) is the velocity of light (3 x 108 m/s).

3. Observation data

This research chooses 2 sample targets, Bandung-West Java and Krakatau-Sunda Strait, where each of them has their own characteristic. For making easy to determine the DN of the area target, the image of the micro-bolometer has to be mosaicked. Figure 2 is the mosaicking result of micro-bolometer camera of LAPAN-A3/IPB satellite and image of band10 from Landsat8 satellite.

At determining of DN value from that 2 satellites, the sample of DN value will be determined randomly for determining of the point to be analysed such as clouds, vegetation, habitation, sea, lake and mountain. For example, first target area is a habitation in Bandung, then it will be sampled 10 to 20 DN points in habitation around Bandung area from that two satellites.

Target area Bandung Jawa Barat 2 October 2018

![Figure 2](image.png)

**Figure 2.** (a) Mosaicking result of thermal imager LAPAN-A3 satellite (b) band10 Landsat8 satellite.

To make easy in identification and validation of determination DN value from thermal camera LAPAN-A3/IPB satellite, this research will use the image of LISA that has been processed[16,17]. This will help determine target especially habitation area and vegetation area [18]. Moreover, the result of LISA camera also can be used to determine comparison coverage swath width from thermal camera LAPAN-A3/IPB satellite. Figure 3 is the comparison coverage between image of micro-bolometer and image of LISA from LAPAN-A3/IPB satellite.
Target area Bandung Jawa Barat, 2 October 2018

Figure 3. Coverage image of (a) thermal imager and (b) LISAT of LAPAN-A3/IPB satellite

As mentioned previously, experimental thermal imager has resolution around 640x320 with lens about 60 mm. The altitude of the LAPAN-A3/IPB satellite is about 510 km, so this payload can have coverage about 92 km and resolution around 143m. While, multispectral imager payload uses lens about 300 mm can produce image swath width with coverage about 123 km, resolution around 4m. It means that the swath width of payload thermal imager is in swath width of LISA. So that, these two payloads can complement each other. Figure 4 is the coverage swath width of micro-bolometer, LISA of LAPAN-A3/IPB and also band10 of Landsat8 satellite.

Figure 4. Observation image thermal imager, LISA and Landsat8 satellite.
3.1 DN value approach
Pixel (picture element) is the smallest element point of satellite image. A numerical number (1 byte) from pixel is called Digital Number (DN). DN can be shown in gray color, range between white and black (gray scale), depends on the detected energy level. Pixel which is stacked in the right order will compose an image. Many of satellite images that have not been processed will be stored in gray scale, color scale from black to white with gray degree variation. In thermal imager payload, the scale is 256 shade gray scale, which 0 as black color and 255 as white color.

Based on the data that have been observed with comparing the data from band10 Landsat8 and DN thermal imager, DN thermal imager value from the objects like clouds is around 30-50, vegetation is around 30-90, habitation is around 100-130 and sea is around 50-70. Figure 5 shows graph of relation between DN thermal imager with DN band10 Landsat8 satellite. This graph shows the characteristics that means the DN thermal imager and DN band10 Landsat8 satellite have high correlation.

![Graph relation between DN thermal imager and band10 Landsat8](image)

**Figure 5.** Graph relation between DN thermal imager and band10 Landsat8.
4. Result

4.1 Comparison coverage
Based on the data in Bandung and Krakatau areas, it can be known the coverage swath width between LISA thermal imager of LAPAN-A3/IPB satellite is not too far. So, it makes that two payloads can complement each other to validate the data or compare the data. Table 2 is the summary of comparison of geometric characteristic parameters between payload of thermal imager and LISA from LAPAN-A3/IPB satellite.

Table 2. Comparison thermal imager and multispectral imager LAPAN-A3 satellite.

| Parameter          | Dimension | Pixel Size | Lens | GSD | Swath Width |
|--------------------|-----------|------------|------|-----|-------------|
|                    |           | H (µm)     | V (µm) | F (mm) | F# | H (m) | V (m) | H (Km) | V (Km) |
| Thermal Imager     | 640       | 512        | 17  | 17 | 300 | 60 | 1.3 | 143 | 143 | 91.6 | 73.3 |
| Multi Spectral Imager | 8000 | 1          | 9   | 9  | 300 | 60 | 1.3 | 143 | 143 | 121.2 | 970 |

4.2 Analysis of DN thermal imager to DN Landsat8
Figure 6 shows the relation between DN thermal imager of LAPAN-A3/IPB satellite with DN band10 of Landsat8 satellite that has enough correlation. By using least square regression method, the relation between DN thermal imager and DN band10 Landsat8 can be explained by order 3 polynomial equation with coefficient of determination (R²) is 0.37. The result shows that thermal imager camera of LAPAN-A3 can produce thermal image with DN characteristic similar to band10 Landsat8. But, that graph still shows that there are significant errors for low DN value. This is because thermal imager camera has auto contrast mechanism which the data that should be 14 bits become 8 bits automatically.

Figure 6. Relation DN thermal imager and DN band10 Landsat8.

4.3 Analysis of DN thermal imager to temperature Landsat8
Based on the data of DN band10 Landsat8 by using equation (1-6) in Section II, it will be obtained the temperature of LST from band10 Landsat8 satellite. Figure 7 shows the relation between DN thermal imager of LAPAN-A3/IPB satellite and the temperature for Bandung and Krakatau areas. Then, it can be known that the DN thermal imager of LAPAN-A3/IPB satellite has a quite relation with the temperature that is generated from the data calculation of band10 Landsat8 satellite. From the graph in figure 7, it can be obtained the coefficient of determination (R²) for that two areas is about 0.35. This
result shows that the thermal imager camera of LAPAN-A3/IPB satellite can determine the temperature of land surface with enough accuracy.

![Graphs showing correlation between DN thermal imager and temperature](image)

**Figure 7.** Relation between DN thermal Imager LAPAN-A3/IPB and temperature.

### 5. Conclusion

From the data of observation and analysis result, overall the thermal imager camera of LAPAN-A3/IPB satellite has good enough performance. This thermal camera has been success to be calibrated toward band10 Landsat8 satellite which the DN thermal imager value has enough high correlation to the DN and Land Surface temperature (LST) of band10 Landsat8. Besides that, this thermal camera has been success to be compared with LISA payload which from the observation and analysis result this thermal camera has same coverage. So, with that result, these two cameras can complement each other to do the mission.

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