Acquisition performance of LAPAN-A3/IPB multispectral imager in real-time mode of operation

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Abstract. LAPAN-A3/IPB satellite was launched in June 2016 and its multispectral imager has been producing Indonesian coverage images. In order to improve its support for remote sensing application, the imager should produce images with high quality and quantity. To improve the quantity of LAPAN-A3/IPB multispectral image captured, image acquisition could be executed in real-time mode from LAPAN ground station in Bogor when the satellite passes west Indonesia region. This research analyses the performance of LAPAN-A3/IPB multispectral imager acquisition in real-time mode, in terms of image quality and quantity, under assumption of several on-board and ground segment limitations. Results show that with real-time operation mode, LAPAN-A3/IPB multispectral imager could produce twice as much as image coverage compare to recorded mode. However, the images produced in real-time mode will have slightly degraded quality due to image compression process involved. Based on several analyses that have been done in this research, it is recommended to use real-time acquisition mode whenever it possible, unless for some circumstances that strictly not allow any quality degradation of the images produced.

1. Introduction
LAPAN-A3/IPB satellite is an experimental remote sensing satellite which brings a multispectral pushbroom imager as main payload. The imager has four color channels of blue, green, red, and near-infrared (NIR) with 15 meters ground sampling resolution and swath-width of 120 km [1]. The imager has been continuously producing images which cover all Indonesia regions with 5 GB of daily image produced. Currently, LAPAN-A3/IPB multispectral image acquisition is done by using recorded mode where the satellite records the image captured in on-board memory and then downloads the images later in the day from polar ground station. Limitation of satellite on-board RAM memory buffer storage limits the imager to capture the image for only around two minutes duration for single acquisition pass. Furthermore, limitation of number of the payload data downloading in polar ground station, which is once a day, also limits the size of images that can be produced daily which is a round 5 GB a day. With current setup, LAPAN-A3/IPB multispectral imager produces two images each day with averagely 700x120 km coverage area per image with revisit time of 21 days [2].

To build up national capability and independency of foreign technologies, in 2018 LAPAN will have an X-band antenna installed in Bogor ground station, which will directly replace polar ground station for downloading the payload data. In addition of this daily payload downloading, there will be an option for LAPAN-A3 multispectral imager to capture western parts of Indonesian regions in real-time acquisition mode, thus the imager will be able to observe full area within its ground-track path inside LAPAN ground station coverage. However, in real-time mode acquisition, the image captured must be
compressed on-board before transmitted to ground station since the image data rate is beyond satellite transmission rate of 105 Mbps [3]. LAPAN-A3/IPB multispectral images can be compressed by using lossless method of Differential Pulse Code Modulation (DPCM) [4][5] or lossy method of Fast Fourier Transform (FFT) [6][7].

This research will discuss about performance of LAPAN-A3/IPB multispectral imager in real-time acquisition mode of operation. The goal of this research is to determine the image coverage and image quality produced by the imager when the real-time mode is used. Image coverage analyses consist of comparison between daily Indonesia images produced by current recorded mode and the proposed real-time mode of acquisition, considering satellite on-board limitations as well as satellite transmission capability. Image compression performance which will be used in real-time operation mode will also analyzed deeply since it plays important role in both image coverage and image quality analysis. The research will utilize numerous actual LAPAN-A3/IPB multispectral images that have been captured up to recently. With careful setup, the trade-off between the coverage area and image quality can be optimized to produce optimal LAPAN-A3 multispectral imager real-time acquisition performance.

2. Methodology
This research aims to evaluate performance of real-time operation mode of LAPAN-A3 multispectral imager, in terms of image coverage and image quality. This research consists of several steps, starting by calculating average daily image coverage produced in recorded acquisition mode by using current acquisition setup. Then the average of daily image coverage produced in real-time acquisition mode supported by the addition of LAPAN X-band receiver in Bogor is calculated. The quality of image produced in real-time acquisition mode, which uses either lossless or lossy image compression, is analyzed based on numerous actual LAPAN-A3/IPB multispectral images that have been captured. Finally, the trade-off between the quantity and quality of image produced in real-time acquisition mode compare to current setup is evaluated. Figure 1 shows general flowchart used in this research.

![General flowchart of this research.](image)

The calculation of daily image coverage of LAPAN-A3/IPB multispectral imager of current setup is done based on numerous images that have been captured. In the other hands, the calculation of daily image coverage of LAPAN-A3/IPB multispectral imager in real-time mode needs the calculation of data rate of the imager, image compression ratio produced, as well as estimated of the length of satellite pass where the imager would capture the image. Table 1 shows LAPAN-A3/IPB multispectral imager and satellite operation parameter which are used in image coverage analyses.

| Parameter                   | Value       | Parameter                   | Value       |
|-----------------------------|-------------|-----------------------------|-------------|
| Color channels              | 4 bands     | RAM capacity                | 4 GB        |
| Array of detectors          | 8000 pixels | Transmission data rate      | 105 Mbps    |
| Radiometric resolution      | 16 bit      | Daily polar transmission    | ~10 minutes |
| Repetition period           | 1,9 ms      | Daily Bogor transmission    | ~15 minutes |
| Ground sampling distance    | 15 meter    | Lossless compression        | DPCM 10 bit |
| CCSDS format                | +20%        | Lossy compression           | FFT 12 bit  |
3. Image Coverage Analysis

Image coverage area by LAPAN-A3/IPB multispectral imager will be analyzed based on experience of numerous acquisitions that have been done since the satellite launch in 2016. One of limitations that limit LAPAN-A3/IPB multispectral image coverage area in current setup is 4 GB of RAM which causes the imager could only capture maximum of 4 GB image data for single pass. Another limitation is in current setup, downlink transmission is done only once a day, limiting roughly 5.6 GB daily image data that can be downloaded from satellite. Figure 2 shows the mosaic of more than 200 images captured by the imager since the satellite launch, although effectively the imager started continuously to capture the data since January 2017. The images have been systematically corrected, including radiometric correction [8][9] and geometric correction [10][11]. It can be seen that, in many cases, the imager could only capture small portion of the longest possible path in the satellite pass. Even the longest image captured often could only cover half of its potential area that should be covered.

![Figure 2. Mosaic of LAPAN-A3/IPB multispectral images on Indonesia region.](image)

With the addition of X-band receiver in Bogor ground station, there are two major fields of improvement that could be exploited, which are the ability to download more payload data and also the ability of LAPAN-A3/IPB multispectral imager to cover much larger Indonesia area by using real-time acquisition mode.

3.1. Data Rate of LAPAN-A3/IPB Multispectral Imager

Since multispectral imager of LAPAN-A3/IPB satellite has four color channels, which are blue, green, red and near-infrared (NIR), with 8000 effective pixels for each channel and 16 bit radiometric resolution for each pixel, the imager will produce 4x8000x16=0.512 Mbit data for every repetition period. With current setup of 1.9 ms repetition interval, then the imager will produce 269.47 Mbps data rate. Considering LAPAN-A3/IPB satellite uses CCSDS packet data format for its payloads, the actual multispectral imager data rate would be around 323.37 Mbps.

However, LAPAN-A3/IPB satellite downlink transmission capacity is only 105 Mbps. Therefore, to be able to transmit multispectral imager data in real-time mode, imager data rate should be lowered from 323 Mbps to fit the downlink transmission capacity of 105 Mbps. Data rate reduction ratio of 3.1 or higher is needed to achieve multispectral imager real-time acquisition. The data rate reduction can be accomplished by several ways, including least significant bit (LSB) truncation, image dimension reduction, or the most efficient ways, by using image compression techniques.

3.2. Actual LAPAN-A3/IPB Multispectral Image Compression Ratio

LAPAN-A3/IPB satellite employs both lossless and lossy compression algorithm to reduce imager data rate to fit 105 Mbps satellite transmission rate. In lossless compression method, the image is down-
sampled from 16 bit into 10 bit, and then lossless algorithm of DPCM is used. Meanwhile, in lossy compression method, the image is down-sampled from 16 bit to 12 bit, and then lossy algorithm of FFT is used. Table 2 shows compression ratio produced for several LAPAN-A3/IPB multispectral images by using both lossless and lossy algorithm. The images were taken from March to May 2017 by observing area relatively near to Bogor ground station, to simulate the real-time acquisition mode which can only happens when the satellite observing area covered by Bogor ground station. Parameter of K=512 in lossy algorithm is called scaled-factor, one of important parameter that can be adjusted in lossy compression algorithm. Value of K=512 is the lowest possible value that can be set, producing the least compression ratio with maintaining the best decompressed image quality.

| Date      | Source Image    | Lossless Mode | Lossy Mode K=512 | Average |
|-----------|-----------------|---------------|------------------|---------|
|           |                 | B  | R  | N  | G  | B  | R  | N  | G  |         |         |
| 13/03/17  | Jakarta         | 2.58| 2.51|2.53|2.51| 3.68| 3.04| 3.27| 3.04| 2.53    | 3.26    |
| 24/03/17  | Rengasdengklok  | 2.63| 2.56|2.58|2.58| 3.95| 3.28| 3.68| 3.26| 2.59    | 3.54    |
| 04/04/17  | Pamanukan       | 2.61| 2.56|2.57|2.57| 3.80| 3.21| 3.46| 3.18| 2.58    | 3.41    |
| 09/04/17  | Ujungkulon      | 2.59| 2.59|2.56|2.59| 3.54| 3.03| 3.15| 3.01| 2.58    | 3.18    |
| 15/04/17  | Losarang        | 2.57| 2.55|2.57|2.56| 3.25| 2.74| 3.16| 2.77| 2.56    | 2.98    |
| 20/04/17  | Banten          | 2.63| 2.58|2.60|2.59| 3.98| 3.24| 3.61| 3.32| 2.60    | 3.54    |
| 26/04/17  | Cirebon         | 2.56| 2.53|2.55|2.53| 3.37| 2.79| 3.10| 2.84| 2.55    | 3.02    |
| 01/05/17  | Kepulauan Seribu| 2.62| 2.57|2.59|2.59| 3.93| 3.23| 3.71| 3.26| 2.59    | 3.54    |
| 07/05/17  | Cirebon         | 2.57| 2.58|2.57|2.58| 3.38| 2.95| 3.09| 2.92| 2.57    | 3.09    |
| 12/05/17  | Sindangbarang   | 2.59| 2.56|2.57|2.56| 3.65| 3.07| 3.44| 3.09| 2.57    | 3.31    |
| **Average** |                 | 2.60| 2.56|2.57|2.57| 3.65| 3.06| 3.37| 3.07| 2.57    | 3.29    |

From Table 2, it can be seen that lossless algorithm produce 2.57 compression ratios, while lossy algorithm with K=512 produce 3.29 compression ratios. The requirement of data reduction ratio of 3.1 or higher clearly fulfilled by this lossy compression, and since setting value of K=512 is enough to achieve 3,1 compression ratios, it is not recommended to increase the value of K since higher value of K will lower image quality with unnecessary increasing compression ratio. In the other hand however, lossless compression ratio still need further reduction, since it only produces 2.57 compression ratios, lacking around 1.2 reduction ratios to fulfill the requirement of 3,1 compression ratio. This problem can be solved by reducing multispectral image dimension that will be transmitted. In LAPAN-A3/IPB lossless mode, there is parameter that can be adjusted to control the swath-width of image that will be transmitted. For example, to achieve the additional 1,2 reduction ratio, the parameter can be set so that 1000 pixels on each image side will be discarded, meaning that only 6000 pixels in the middle that will be transmitted in this lossless real-time acquisition mode.

### 3.3. Image Coverage Analysis under Several Compression Modes

Based on above image compression ratio calculation, it can be said that LAPAN-A3/IPB multispectral imager real-time acquisition can be realized either by using lossless method with 2000 pixels swath-width reduction or by using lossy method with full image swath-width. This section will analyze the comparison of daily image coverage area produced by LAPAN-A3/IPB multispectral imager when either lossless and lossy images is used in real-time acquisition of western parts of Indonesia region, compare to image coverage area produced by recorded mode only, without real-time acquisition of western parts of Indonesia region.

Before calculating the influence of real-time acquisition mode to daily image coverage area, the image coverage area produced by recorded-only observation will be analyzed. Since Bogor ground
station will have new X-band receiver antenna, LAPAN-A3 satellite would be able to download its payload data more frequent than before, which currently only able to download once a day in polar ground station. Currently, LAPAN-A3 satellite is able to download roughly 5,632 GB multispectral imager data from polar ground station, or about 1383 km length by 120 km swath-width coverage area. This image coverage area usually consists of same portion of eastern parts and western parts of Indonesian region.

By addition of X-band receiver antenna in Bogor ground station, LAPAN-A3 satellite would be able to increase its download capacity. With rough calculation, two satellite passes every night in Bogor ground station would produce at least 8 GB of multispectral imager data that can be downloaded daily. Even without further downloading payload data in polar ground station, Bogor ground station alone can support a full RAM-limited observation of 1006 km length for both eastern and western parts of Indonesia region, for total of 2012 km length by 120 km swath-width coverage area. The addition of polar ground station for receiving LAPAN-A3/IPB data to Bogor ground station will not add the daily image coverage of Indonesia area produced, since RAM memory in PDHS LAPAN-A3/IPB satellite could only allow the imager to capture 4 GB of image in one single pass (1006 km length). However, polar ground station downloading capability could increase the overall satellite mission flexibility and can overcome the problems when the transmission failure occurs in Bogor ground station.

Although without real-time acquisition mode it seems that LAPAN-A3/IPB multispectral imager could produce vast coverage area, the 1006 km length coverage for each satellite pass is not even close to observe full Indonesia region in some particular satellite path. The longest path that the satellite will observe Indonesia region in one single pass is around 1800 km length, which happens when the satellite passes through North Sulawesi province all the way to East Nusa Tenggara province. In this particular pass, LAPAN-A3/IPB multispectral imager needs two-passes to observe this full 1800 km path, which can only realized by waiting for 21 days of imager revisit time. Figure 3 shows illustration of the length of satellite passes when observing Indonesia [12]. As we can see, half of the path has more than 1006 km length, which indicates that many area in Indonesia region cannot be observed properly every 21 days of imager revisit time.

![Figure 3. The length of LAPAN-A3 satellite passes when observing Indonesia.](https://example.com/figure3.png)

With real-time acquisition mode when the satellite observing western parts of Indonesia region, this problem can be partially solved. For any satellite passes that covered by Bogor ground station, it can be guaranteed that the imager could observe and transmit all of the area it passes. Real-time acquisition does not need the use of on-board memory storage, so the imager could produces image lines infinitely to be transmitted. As long as the ground station receiver is able to receive the data transmitted by the satellite, which is constrained roughly by satellite line of sight from the ground station, the real-time acquisition mode could potentially produce more than 6 GB of compressed images or equivalently around 4000 km by 120 km coverage area, assuming 8 minutes effective ground station contact. This memory-less mode of acquisition of western part of Indonesia allows acquisition of eastern part of Indonesia, which must be executed in recorded mode, for the RAM memory buffer limit of 1006 km by 120 km coverage area.

This calculation of course, depends on minimum elevation angle needed for the satellite to be able to transmit the payload data properly. From polar ground station experiences, 15 degrees elevation angle
is enough to transmit the data properly. Figure 4 shows Bogor ground station coverage area, which covers all western parts of Indonesia up to Sulawesi and Timor islands. It can be said that only Maluku islands and Papua province that cannot be observed by using real-time acquisition mode. The calculation will be slightly different, if for example, the minimum elevation angle is somewhat larger than 20 degree which can be caused by significant frequency-interferences from ground station neighborhood or there are obstacles such as mountain though it is very unlikely.

![Figure 4](image_url)

**Figure 4. Illustration of daily LAPAN-A3/IPB multispectral observation.**

Based on the estimated length of each satellite passes on figure 3 and illustration of daily LAPAN-A3/IPB multispectral imager observation on figure 4, table 3 summarizes image coverage produced by LAPAN-A3/IPB multispectral imager when real-time acquisition mode is used when observing western parts of Indonesia. The table also compares image coverage produced to image coverage of recorded-only observation, considering the utilization of Bogor and polar ground station to download the payload data.

| Operation Mode                  | Daily Image Coverage (km) | Daily Area Covered (ha) |                  |                  |
|---------------------------------|---------------------------|-------------------------|------------------|------------------|
|                                 |                           |                         | Eastern Indonesia| Western Indonesia*| Others| Indonesia**| Others|                  |
| Current Setup: Recorded, Polar | 692x120                   | 692x120                 | 0                | 16,60 ha         | 0     | 0          |       |                  |
| Recorded Mode, Bogor           | 1006x120                  | 1006x120                | 0                | 24,14 ha         | 0     | 0          |       |                  |
| Lossless Mode, Bogor           | 1006x120                  | 4000x90                 | 1006x120         | 48,07 ha         | 12,07 ha |           |       |                  |
| Lossy Mode, Bogor              | 1006x120                  | 4000x120                | 1006x120         | 60,07 ha         | 12,07 ha |           |       |                  |
| Recorded Mode, Bogor-Polar     | 1006x120                  | 1006x120                | 1383x120         | 24,14 ha         | 16,60 ha |           |       |                  |
| Lossless Mode, Bogor-Polar     | 1006x120                  | 4000x90                 | 2389x120         | 48,07 ha         | 28,67 ha |           |       |                  |
| Lossy Mode, Bogor-Polar        | 1006x120                  | 4000x120                | 2389x120         | 60,07 ha         | 28,67 ha |           |       |                  |

* Area within satellite pass covered by Bogor ground station, including South China Sea and Indian Ocean

** Including countries around Indonesia such as Singapore, Malaysia, Brunei and Thailand

From table 3 above, it can be concluded that in terms of image coverage point of view, real-time acquisition should always be used when LAPAN-A3/IPB multispectral imager observe western parts of Indonesia.
Indonesia region. In addition of capability in observing all Indonesia regions properly every 21 days of imager revisit time, the real-time acquisition mode also allows the imager to capture another part region of the world, including parts of South-East Asia countries or even Europe, Africa and America continent for another satellite missions.

4. Image Quality Analysis
In real-time acquisition mode, LAPAN-A3/IPB multispectral image is compressed to accommodate satellite downlink transmission rate of 105 Mbps by using either lossless or lossy algorithm. The quality of the decompressed images produced will be degraded, which is caused either by digital number down-sampled for both algorithm, or reduced swath-width in lossless algorithm, or direct quality degradation of lossy compression process. The down-sampling of image digital number from the original 16 bit into 12 bit for lossy or 10 bit for lossless would not cause serious effect since the effective radiometric resolution of any imager system would be less than the maximum bit, due to the presence of noise. In the other hand, the reduced swath-width in lossless algorithm will cause the image produced losses perhaps 25 percent its swath-width, but this can be well overshadowed by the much higher coverage improvement in along-track direction produced by real-time acquisition of LAPAN-A3 multispectral imager.

4.1. Lossless Compression Image
Normally, lossless compression algorithm will produce decompressed image without any image quality degradation. However, digital number down-sampling from 16 bit to 10 bit in LAPAN-A3 multispectral image lossless compression causes the decompressed image produced suffers from slight degradation in image quality. Based on the imager radiometric calibration, standard deviation of each pixel readings is around 0.5 percent of its nominal value. Table 4 shows examples of digital number value readings from several sampled images of the imager when observing uniform light source of integrating sphere. It can be assumed that for the actual digital number value of 10000 for example, the pixel would produce digital number readings ranging between digital numbers of 9950 to 10050. This characteristic exceeds the digital number down-sampling of 6 bits, therefore the effect of this down-sampling is theoretically not significant.

| Calibration Images | Nominal Value of Pixel Digital Number | Standard Deviation of Pixel Readings |
|--------------------|-------------------------------------|-------------------------------------|
|                    | G        | N        | R        | B        | G        | N        | R        | B        |
| Image-1 (5111)     | 11034    | 15375    | 15585    | 2893     | 59       | 77       | 75       | 42       |
| Image-2 (5311)     | 11837    | 17467    | 17461    | 3199     | 61       | 82       | 80       | 43       |
| Image-3 (5193)     | 28233    | 35557    | 35630    | 8334     | 159      | 199      | 194      | 118      |
| Image-4 (1002)     | 21451    | 36177    | 34393    | 7327     | 98       | 139      | 132      | 66       |
| Image-5 (5321)     | 27796    | 42417    | 41843    | 8061     | 147      | 196      | 190      | 103      |
| Image-6 (5421)     | 28637    | 44754    | 44052    | 8289     | 151      | 202      | 196      | 105      |
| Image-7 (1012)     | 25706    | 56518    | 52810    | 7727     | 85       | 129      | 124      | 51       |

Figure 5 shows decompressed image of LAPAN-A3/IPB image by using both lossless and lossy compression algorithm. The image was taken on May 1, 2017, capturing Indonesia capital province of Jakarta with Thousands Islands in the north. The image is visualized on NRG composite format, which shows vegetation land cover in red color and non-vegetation land cover in green color. The image has also been corrected systematically after decompression process, including radiometric vignetting correction and geometric band co-registration correction.

4.2. Lossy Compression Image
As explained earlier, in LAPAN-A3/IPB lossy compression algorithm, there are several parameters that can be adjusted to produce optimal performance between compression ratio and decompressed image quality. One of these parameters is compression scaled-factor which can be set to either of 512, 1024, 2048 or 4096. The higher scaled-factor will produce higher compression ratio but with lower decompressed image quality. Figure 5 shows results example of decompressed images of LAPAN-A3/IPB image by using scaled-factor of 512 and 4096. It can be seen that by using lossy compression method with any scaled-factor, there is no significant degradation of image quality that can be seen visually. However, for scaled factor of 4096, the more detailed decompressed image will show noticeable image degradation in several parts of the image.

![Decompressed images of LAPAN-A3/IPB image; from left to right: original image, lossless image, lossy image with K=512, and lossy image with K=4096.](image)

**Figure 5.** Decompressed images of LAPAN-A3/IPB image; from left to right: original image, lossless image, lossy image with K=512, and lossy image with K=4096.

### 4.3. Trade-Offs Analysis between Image Coverage and Quality

Based on Figure 5, it can be seen that there is no significant image quality degradation resulted from image compression process, both for lossless and lossy compression with K=512. Therefore, LAPAN-A3/IPB multispectral imager should use real-time operation mode whenever possible to maximize image coverage area produced. Based on several analyses about the trade-offs between image coverage and image quality produced by real-time mode operation of LAPAN-A3/IPB multispectral imager, it can be concluded that in circumstances that need the best images possible, image acquisition must be done in recorded mode as current setup. For circumstances that need collection of vast coverage area in short period of time, real-time acquisition mode with lossy algorithm could be used. Meanwhile for circumstances in between which needs fast coverage with moderate quality, real-time acquisition mode with lossless algorithm could be used.
5. Conclusions
By using real-time acquisition mode, LAPAN-A3 multispectral imager could produce images at least twice as many as images produced by using recorded acquisition mode, thus greatly improves the ability of the imager to provide more coverage of Indonesia area in shorter period of time. The quality of images captured in real-time acquisition mode is slightly degraded due to image compression used to accommodate 105 Mbps downlink transmission rate. When slight image quality degradation is allowed, it is recommended to always use real-time acquisition mode whenever it possible. Further research of finding optimal Huffman table that will be used for image compression should be conducted to increase the quality of image which is transmitted from the LAPAN-A3/IPB satellite in real-time acquisition mode, both for lossless or lossy compression scenario.

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