Assessment of Remote Sensing Image Quality and its Application Due to Off-Nadir Imaging Acquisition

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***Abstract*—One advantage of using microsatellites for remote sensing is their maneuverability so that the target area can be captured from any viewing angle based on specific needs. However, the image captured under off-nadir acquisition will have reduced quality in both geometry and radiometric aspects. This research aims to find the effect of off-nadir acquisition on remote sensing image quality in general and its accuracy on land use land cover (LULC) application based on LAPAN-A3 microsatellite image data. Both images from the nadir and off-nadir acquisition of one specific target, which had several days/weeks difference, are compared to the nearest Landsat-8 image data. Based on several target images used in this research, the imaging viewing angle indeed affects the quality of the remote sensing images, both in general image quality and land use land cover application accuracy. The degradation of LULC accuracy can be considered acceptable however, where in general, it can be modeled to -0.5 percent/degree, i.e., an image taken under 20 degrees off-nadir acquisition will have reduced 10 percent accuracy. This result shows that the off-nadir microsatellite imaging technique can be used for specific remote sensing needs without compromising quality.**

Keywords—Land cover; land use; LAPAN-A3; microsatellite; off-nadir; revisit time

I. Introduction

Microsatellites are quite popular these days for remote sensing missions due to their low cost and flexibility to accommodate specific missions. Research Center for Satellite Technology (PRTS-BRIN) has already launched three micro-satellites, one of which was the LAPAN-A3 satellite. Its main missions are remote sensing and maritime monitoring for the Indonesian region. The satellite has an RGB-NIR multispectral imager with a 15-meter resolution and an RGB digital matrix camera with a 3-meter resolution. The multispectral one has consistently produced daily images for Indonesia region coverage since its launch in 2016. Still, the payload has made significantly fewer images in the past two years due to its age. Aside from providing daily images for the Indonesia region like any other international satellite such as Landsat and Sentinel, the LAPAN-A3 satellite is also often used for specific missions based on requests from users from various institutions in Indonesia, both for research and operational purposes.

One of the most common requests from users is to capture one specific target with high frequency in a relatively short period, for example, for imager vicarious calibration [1], monitoring the effect of natural disasters [2], or other remote sensing application [3]. These requests are not feasible in regular satellite operation in nadir acquisition since the satellite and its imaging payload usually have a fixed revisit time, which depends on satellite orbit and imager swath width. For example, the Landsat-8 payload has a revisit time of 16 days, and two Sentinel-2 satellites have a combined 5 days revisit time [4], [5], [6], while the multispectral imager of LAPAN-A3 has 21 days revisit time. An off-nadir acquisition technique must be employed to capture one specific target on earth more often than the revisit time. During acquisition, the roll angle of the satellite, which rotates the satellite left and right, is adjusted so that the imager can capture the area far away from the satellite ground track [7], [8].

However, images taken under off-nadir acquisition usually have lower quality than those taken under nadir acquisition, both in terms of geometric and radiometric points of view. Geometrically, the image produced will have a lower modulation transfer function (MTF) [9], and also will not have a square pixel when projected to the earth's surface, where the shape and size distortion of the projected pixel depends on a combination of three-axis angles, i.e., yaw, pitch, and roll angle [10]. In the radiometric aspect, the images will have different sunlight illumination compared to nadir acquisition [11], which, in some cases, could produce a sun-glint effect [12], [13]. Although the off-nadir images could serve well for naked-eye inspection and manual interpretation, these two disadvantages could raise some questions about the quality of the resulting images when used for remote sensing applications, such as land use and land cover (LULC) [14], [15], among others. However, this is not a trade-off between image quality and imaging frequency for one particular target area since nadir acquisition will produce precisely one perfect image in one revisit time interval. In contrast, the off-nadir acquisition will produce one ideal image and several distorted images, so the off-nadir technique will always be better in this case. Instead, is it worth sacrificing another area that could not be captured that day in favor of distorted off-nadir images? If the quality of off-nadir images is good, it is well worth it because the user request will be considered successful. Still, if the quality is not good, doing an off-nadir acquisition could be considered a waste of time.

This research aims to find the effect of off-nadir acquisition on the quality of the image produced, both in terms of general image quality and in terms of accuracy of remote sensing application, in this case land use land cover, with Landsat-8 images being used as reference. The classification accuracy of two images that captured one specific target, one taken under nadir and one under off-nadir acquisition with about several days/weeks difference of acquisition time, is compared. The research uses several target areas, classification algorithms, and classes for each case to properly conduct the analysis. Besides classification accuracy, general image metric quality, including blurring and brightness effects, will be analyzed to show further off-nadir acquisition's impact on the resulting image captured. This research will also explore other aspects of LAPAN-A3 satellite operation regarding off-nadir acquisition technique, such as satellite attitude comparison and solutions to irregular path-rows that the satellite had since it did not have a propulsion system to adjust the orbit during its seven years of operation. The outcome of this research would be to show that the off-nadir acquisition technique could be one of the methods to solve remote sensing needs or missions requested by the user.

Section II will discuss off-nadir acquisition of LAPAN-A3 satellite, theory about generic image quality analysis, as well as method of land use and land cover (LULC) classification for LAPAN-A3 satellite imagery using maximum likelihood and minimum distance algorithm. Results, analysis, and some discussions are presented in Section III, while conclusion and some recommendations are presented in Section IV.

II. Methodology

In general, this research can be divided into three parts. In the first part, the off-nadir acquisition technique employed on the LAPAN-A3 satellite will be described, including the basic theory of satellite maneuver, the resulting satellite attitude during observation, and an example of using the technique to solve specific tasks. In the second part, the quality of images produced under off-nadir acquisition will be compared to images under nadir acquisition, both in general image analysis and the accuracy of LULC classification. Finally, the advantages and disadvantages of using the off-nadir technique will be discussed, and some suggestions will be given.

A. *Off-Nadir Acquisition of LAPAN-A3 Satellite*

LAPAN-A3 satellite uses the momentum bias technique as a control strategy to keep the satellite at nadir during observation by using a star tracker sensor (STS) and gyro as attitude sensors as well as a reaction wheel and magnetorquer as attitude actuators [16]. In momentum bias control, only one wheel and three magnetorquers are used to maintain the satellite in the nadir position, thus saving power consumption. Although the momentum bias could be executed automatically, in actual LAPAN-A3 satellite operation, manual interference by the satellite operator is needed, mainly to take corrective action to ensure that the satellite perfectly points in the nadir position. The average attitude angle of the satellite during observation since its launch in 2016 is about under 2 degrees for all yaw, pitch, and roll angles, which is quite good. As a small satellite, LAPAN-A3 also suffers from attitude nutation, which has a pattern of the sinusoidal-like curve in roll angle with 0,3 amplitude and a period of 70 seconds. Fig. 1 shows a mosaic of the Indonesia region from LAPAN-A3.

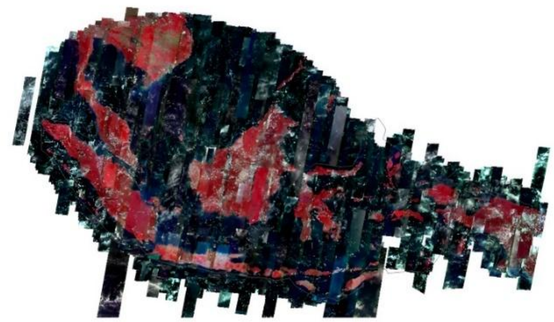


Fig. 1. Mosaic of Indonesia region of LAPAN-A3 multispectral images in nadir pointing.

As stated earlier, one advantage of using momentum bias control is reducing power consumption. However, it has disadvantages when it comes to satellite maneuvers. While it is straightforward in other control techniques to do off-nadir maneuvers, it is not so straightforward in the momentum bias technique. LAPAN-A3 satellite uses two off-nadir maneuver techniques, i.e., inertial pointing and pure-roll nadir pointing [17]. The attitude maneuver needed in the most common maneuvers is only roll angle, i.e., the angle that rotates the satellite left and right when moving forward. Out of the two, the inertial pointing technique is arguably the more straightforward to implement since it only needs to set both pitch and roll angle to some predetermined value once before and once after the acquisition. However, in inertial pointing, the pitch angle of the satellite i.e., the angle that rotates the satellite forward and backward when moving forward, is set to zero degrees (nadir position) only in the latitude of the target area. This produces non-uniform pixel spacing, where pixel which is far from the target (in along-track direction) will have longer pixel compare to pixel in target area. In the other hand, pure-roll nadir pointing technique needs more complex pre-determined set of command to set angular velocity of both roll and pitch angle. This pure-roll nadir technique produces more uniform image pixel spacing since the pitch angle will always be adjusted to zero degrees (nadir position) at any given time. Fig. 2 compares the concept of inertial pointing and pure-roll nadir pointing.

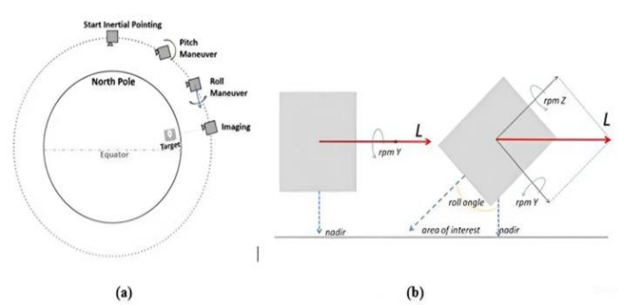


Fig. 2. Off-nadir technique: (a) inertial pointing vs. (b) pure-roll nadir pointing

B. *Generic Image Quality Assessment*

Depending on the value of the roll angle needed, images produced in off-nadir acquisition often have significant distortion in both geometric and radiometric aspects. Blurring and irregular pixel shape are two examples of geometric distortion that might occur [18], [19], [20], [21]. Pixel shape and size can be theoretically calculated by using standard co-linear projection, while blurring effect can be evaluated from the attitude profile produced by the star tracker sensor. Several other image quality metrics are commonly used to analyze the degradation of distorted images [22], [23]. However, most of these metrics can hardly be seen visually from an image by the naked eye or visual interpretation unless the image is zoomed in to the highest detail.

Another image metric that will be evaluated is the radiometric aspect of the images that degenerated due to off-nadir acquisition. One prominent example is the sunlight reflection angle. In nadir observation, the incident angle of sunlight coming from the sun, reflected by the object, and entering the camera usually has a nominal value, which is the same from day to day, depending on the satellite's equatorial crossing time. In off-nadir acquisition, since the roll angle can be set randomly, there might be a chance that the sunlight will reflect perfectly from the surface into the camera, which will cause the images to be too bright or often saturated [20]. To measure this problem, the histogram approach is used for each band of the imager, where the difference in each histogram curve can measure the level of distortion.

Several metrics above are standard metrics used to analyze image quality to compare its quality to the quality of the original image, which is often considered a perfect or ideal reference. While these general image analyses are usually enough to describe the quality of distorted images, this research will further analyze the effect of off-nadir acquisition on the quality of the images captured by using a remote sensing application approach, which is land use land cover (LULC) classification [24], [25].

C. Land Use and Land Cover Classification

The off-nadir images used in this research are LAPAN-A3 multispectral images taken for the on-field vicarious imager calibration process. Several on-field vicarious calibration campaigns were conducted from 2017 to 2022 in several target areas in Indonesia, which needed highly uniform bright areas such as deserts or karst mining areas. Jaddih (East Java) and Kupang (NTT) were two areas that were used for the LAPAN-A3 multispectral imager calibration process. The ideal satellite image that should be used for calibration is the image taken from the nadir acquisition. However, in case of cloudy observation or general failed acquisition, each campaign always takes two or three acquisitions in consecutive days. In three-day type of acquisition, the second day will give nadir images, while the first and last days give an extreme off-nadir image with around a 40 degree roll angle in the opposite direction. On the other hand, in the two-days type of acquisition, no nadir image was captured both images were taken from slight off-nadir acquisition, around 15 to 20 degrees of roll angle, in the opposite direction. Table I shows the data used in this research, consisting of the date and location of the image, as well as the imaging viewing angle for each data.

TABLE I. LAPAN-A3 MULTISPECTRAL DATA

Target Area	Acquisition Date	Roll angle	Image Status
Case 1 Data: Kupang	11 April 2018	-11 degree	Clear
Case 1 Data: Kupang	12 April 2018	+29 degree	Clear
Case 1 Reference: Landsat-8	29 April 2018	Nadir	Clear
Case 3 Data: Jaddih	29 Oct 2018	-40 degree	Cloudy
Case 3 Data: Jaddih	30 Oct 2018	+1.5 degree	Clear
Case 3 Data: Jaddih	31 Oct 2018	+40 degree	Clear
Case 3 Reference: Landsat-8	30 Oct 2018	Nadir	Clear

LAPAN-A3 multispectral images used in this research have been systematically corrected for lens vignetting radiometric distortion, band co-registration geometric error and geo-referenced using Landsat data as reference. The classification process consists of three main stages, i.e., pre-processing data, class classification, and accuracy test using reference data, as seen in Fig. 3. A critical step in the pre-processing stage is geo-referencing off-nadir images, where the image is often heavily distorted geometrically due to the significant viewing angle. Thus, the process needs to be conducted carefully. The classification uses supervised and unsupervised approaches [26], [27], [28]. In supervised classification, two standard algorithms are used, i.e., minimum distance and maximum likelihood [29], [30], to show the consistency of the result. Several classes of land cover are used in the classification process, such as water bodies, vegetation, human-made structures, and open areas, among others, depending on the image evaluated. Moreover, the two images of the nadir and off-nadir images generally have short, different times of time acquisition to ensure the fairness of classification comparison.

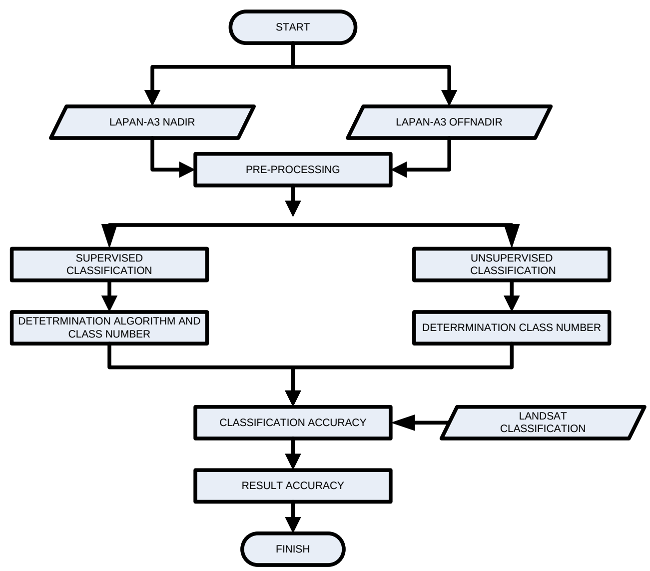


Fig. 3. Image classification (LULC) procedure.

Classification results of LAPAN-A3 multispectral images, both nadir image and off-nadir image, are then compared to the nearest Landsat image to produce classification accuracy of each image. The focus of this research is to analyze the characteristics of the classification accuracy curve concerning roll viewing angle, i.e., how far the accuracy falls when the viewing angle is increased. The actual accuracy itself is not the focus of this research because the actual accuracy is heavily influenced by imager quality or, in other terms, the cost of the satellite. Several studies have been done previously related to the exact classification accuracy of LAPAN-A3 multispectral images [31].

III. Result and Discussion

A. Improvement of Imager Revisit Time

As mentioned earlier, one of the advantages of using micro-satellites for remote sensing is their ability to maneuver so that the satellite can capture the area that is not on its ground track, thus increasing the frequency of acquisition of one particular location at the expense of not capturing another area. In nominal operation, the LAPAN-A3 multispectral imager has 21 day revisit time. However, with off-nadir technique acquisition, the frequency could be increased, with roll angle allowance determining how often the area could be captured. Based on the simulation, mathematically, Table II shows revisit time improvement of the LAPAN-A3 multispectral imager concerning the roll angle allowed, with several percent overlaps between images. It can be seen that, in the most common assumption of 50 percent image overlap, the revisit time could be improved from 21.49 days to 5.14 days if a 20-degree roll angle is allowed. If a 40-degree roll angle is permitted, the revisit time could be further improved to 2.36 days, which was the case of both LAPAN-A3 multispectral imager acquisition of the Palu natural disaster and the calibration campaign.

TABLE II. Revisit Time of LAPAN-A3 Multispectral Imager

Roll angle allowed	Overlap 90%	Overlap 50%	Overlap 10%
Nadir	121.75	21.49	12.18
Roll 10 deg	12.59	8.49	6.52
Roll 20 deg	6.30	5.14	4.30
Roll 30 deg	3.97	3.48	3.07
Roll 40 deg	2.57	2.36	2.17

In actual implementation, the imager was able to produce seven images under two weeks duration, averagely about 2 days of revisit time, when monitoring the effect of earthquake in Palu (Sulawesi) in 2018. Out of these seven images, one image was taken from nadir position, four images taken from slight off-nadir position, and two images taken from extreme off-nadir position. Although most of the images were heavily distorted, the images were successfully used to complement other satellite data to evaluate the effect of the earthquake. Fig. 4 also shows the results of the off-nadir acquisition of the Jaddih karst area on 29 to 31 October 2018 for the imager calibration campaign, where, the imager could produce three images in three consecutive days [32]. Nadir's image was taken on the second day of the campaign, while the other two images were taken from the extreme off-nadir position, because the roll angle was around 40 degrees, it can be seen that off-nadir images are heavily distorted, thus subject to quality degradation, which will be analyzed in the next section.

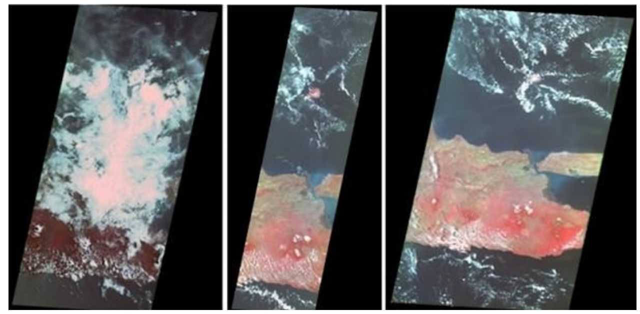


Fig. 4. Vicarious calibration images of the Jaddih area on October 2018, 3 images in 3 days.

B. Off-Nadir Image Quality Analysis

Before analyzing the image quality of the resulting off-nadir images, satellite stability in all three axes will be compared between nadir and off-nadir acquisition. The stability of the imager during observation is essential since it directly affects the geometry aspect of the images. Fig. 5 shows the profile comparison of yaw, pitch, and roll angle during observation in nadir and off-nadir acquisition. The values of all angles have been normalized to make analysis easier, where each angle value in one particular axis has been subtracted from its average angle value during observation. In general, the pure-roll technique could replicate nadir pointing behavior quite well, while the inertial pointing technique could not. The most notable disadvantage of inertial pointing is pitch angle drifting, about 6 degrees in 90 seconds, which could produce non-uniform pixel spacing, especially in long observation. However, inertial pointing techniques outperform pure-roll technique and nadir pointing in terms of roll and yaw angle behavior, where it could reduce the nutation effect significantly. The pure-roll technique still inherits a sinusoidal-like profile caused by the nutation effect, just like in nadir pointing. In the image domain, both pitch drifting and nutation effects will make image geo-location much harder, especially for long images. Therefore, localized image geo-location should be conducted to produce an accurate result.

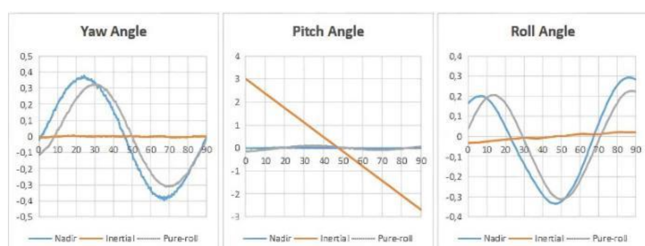


Fig. 5. Satellite attitude comparison between nadir and off-nadir observation (Y: degree, X: second).

The blurring effect is evaluated to further analyze the quality of the off-nadir image, particularly in terms of geometry. While previous analyses focus on a greater picture of attitude profiles, such as drifting and nutation, blurring analyses focus on a more detailed attitude profile. Blurring on an image could be caused by significant movement, be it translational or rotational, in a short period. Fig. 6, shows this blurring metric, where the rotational movement is recorded by STS every 270 milliseconds. With an image ground sampling distance of 15 meters and a satellite altitude of 500 km, a 1-pixel degree of blurring corresponds to 0.0017 degrees in pitch and roll angle axes. Note that the effect of the yaw angle is not as significant as the other axes. It can be seen that, like previous results, inertial pointing out perform pure-roll technique in yaw and roll axis, while pure-roll technique produces better pitch axis performance. However, by combining blurring effect in pitch and roll angle, pure-roll technique gives a lower blurring effect, thus giving better images. For the actual blurring value itself, at worst, pure-roll produces around 5 pixels of blurring compared to 10 pixels with inertial pointing, assuming the same blurring profile with STS data recorded every line interval of 1.9 ms.

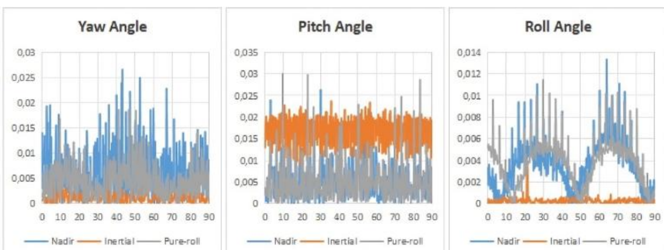


Fig. 6. Blurring effect estimation based on 270 ms attitude data of all axes angle (Y: degree, X: second).

For radiometric aspect, Table III shows comparison of average digital number of image taken under nadir condition and image taken under off-nadir condition. In general out of four bands, off-nadir images produce brighter images compared to nadir images. While brighter image can be considered as good images, it could lead to saturated images, where some really bright object such as cloud, become all-white (saturated). Perfect match between satellite roll angle and sun illumination angle could produce sun-glint effect where sun light is directly reflected by earth surface into the imager. Fig. 7 shows histogram of each band digital number of nadir and off-nadir images for Jaddih area.

TABLE III. AVERAGE OF DIGITAL NUMBER FOR NADIR AND OFF-NADIR IMAGES

Target Area	Roll Angle	NIR	Red	Green	Blue
Kupang Slight Off-nadir	-11 degree	1704	4179	6215	1541
Kupang Off-nadir	+29 degree	3184	8321	10787	4774
Jaddih Nadir	+1.5 degree	7175	12545	14648	3938
Jaddih Off-nadir	+40 degree	9298	16668	22705	12267

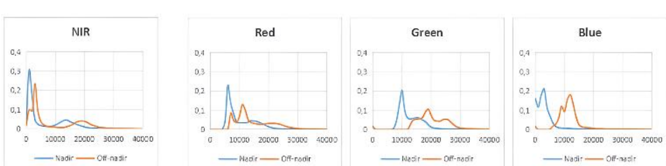


Fig. 7. Histogram of digital number for each band of Jaddih images.

C. Accuracy of LULC Classification

Ultimately, the quality of off-nadir images produced will be analyzed in the remote sensing domain, using accuracy of land use and land cover (LULC) application. Both supervised and unsupervised classification are used, where in supervised classification, maximum likelihood (ML) and minimum distance (MD) algorithms are used. Table IV and Table V shows a summary of accuracy assessment of the classification, with all parameters considered, i.e., the classification type, the algorithm used, and number of classes. It can be seen that from Jaddih data set, for supervised classification of two classes (water/land) with ML algorithm, the accuracy of nadir images, with a roll angle of 1.5 degree, is about 95.01percent while its off-nadir image with 40 degree roll angle has 88.02 percent accuracy. There are 6.99 percent accuracy degradation which is caused by 38.5 degree increased roll angle. MD algorithm also produces similar result, for the same two classes supervised classification, produces 7.47 percent accuracy degradation. Adding more classes (from two to four) will lower accuracy for both nadir and off-nadir images, but the accuracy difference between the two is more or less similar as previous, 8.06percent for ML and 4.18 percent for MD. Unsupervised classification produces slightly higher accuracy difference between nadir and off-nadir images, with 4.68 percent (two classes), 12.21 percent (three classes), 10.94 percent (four classes), and 13.56 percent (five classes) accuracy difference. Kupang data set result also gives similar patterns, but with lower accuracy degradation, due to lower difference between nadir and off-nadir viewing angles.

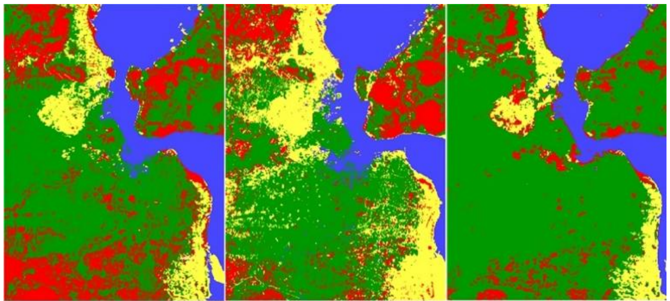
TABLE IV. ACCURACY ASSESSMENT OF LAPAN-A3 MULTISPECTRAL OFF-NADIR IMAGES (JADDIH – EAST JAVA)

Method	Number of classes	Nadir Image (1.5 deg)	Off-nadir Image (40 deg)
Unsupervised	2	83.31%	78.63%
	3	62.30%	50.09%
	4	55.75%	88.02%
Supervised (ML)	2	88.98%	81.51%
	4	51.56%	43.50%
Supervised (MD)	2	55.75%	44.81%
	4	45.69%	41.51%

TABLE V. ACCURACY ASSESSMENT OF LAPAN-A3 MULTISPECTRAL OFF-NADIR IMAGES (KUPANG – EAST NUSA TENGGARA)

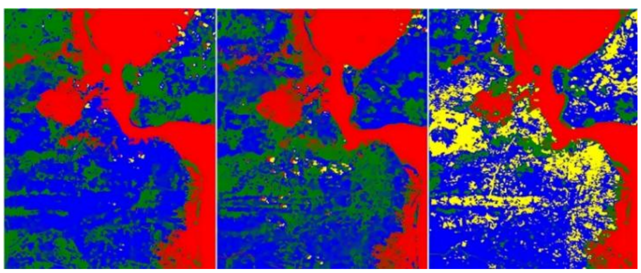
Method	Number of classes	Nadir Image (11 deg)	Off-nadir Image (29 deg)
Unsupervised	2	96.36%	95.84%
	3	70.36%	69.33%
	4	67.99%	62.76%
Supervised (ML)	2	97.82%	95.61%
	4	68.12%	56.22%
Supervised (MD)	2	96.30%	95.76%
	4	63.02%	51.25%

Fig. 8 shows classification results of the nadir image (a), off-nadir image (c), and its Landsat reference image (b) of Jaddih area by using supervised classification of four classes with Maximum Likelihood algorithm, while Fig. 9 shows the result of unsupervised classification with four classes. It can be seen visually that nadir images (a) produce more similar result to Landsat images (b) in both cases compared to off-nadir images (c). However, classification results from supervised and unsupervised algorithms are not quite similar in some areas of the image, but this is out of the scope of this research and thus will be investigated in future research.



(a) (b) (c)

Fig. 8. Four classes supervised classification results of Jaddih using ML algorithm.



(a) (b) (c)

Fig. 9. Four classes unsupervised classification results of Jaddih.

D. Discussion

The main focus of this research is to find the effect of off-nadir acquisition on the image quality of the produced image, especially for remote sensing applications, which in this case is land use land cover classification. With several adjustable classification configuration, such as classification type (supervised/unsupervised), classification algorithm (maximum likelihood/minimum distance), and number of classes (2/3/4/5), different results were obtained. However, all of these results show that images that were taken under off-nadir observation will produce lower classification accuracy. In this section, a model of accuracy degradation with respect to roll viewing angle will be developed. Different parameter configuration could produce different result. However as previously discussed, the accuracy degradation will not different that much. Based on data from Table IV and V, Fig. 10 shows the distribution of accuracy degradation from all data samples (15 cases), which has an average of -0.25 percent/degree. Discarding some outliers, outside the standard deviation range, at worst, the accuracy degradation can be approximated by -0.5 percent/degree. It means that, in general, the accuracy will decrease 5 percent for 10 degree roll angle increment. For example, there will be a 10 percent accuracy drop when the roll angle is set to 20 degree when the satellite is capturing the target area.

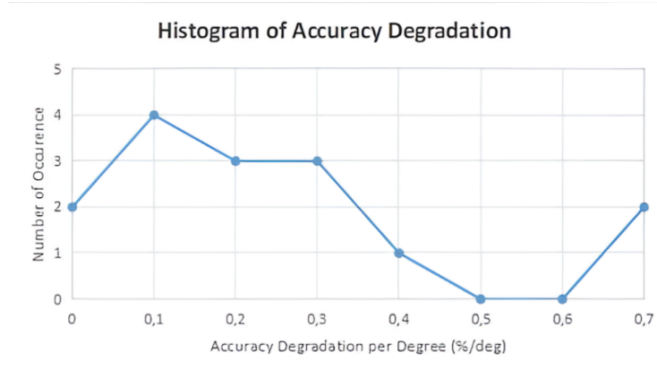


Fig. 10. Distribution of accuracy degradation of all data samples.

Another interesting finding, although not significant and not related to nadir and off-nadir images, is the difference in classification results by using different configurations. First, supervised classification produces better accuracy than unsupervised classification with the same number of classes. Second, classification with fewer number of classes produces better accuracy, which has a straightforward explanation, i.e., more complex classification often produce lower accuracy. Imagine in two-class classification of water body and land surface, the accuracy must be very high, regardless of what type of classification and algorithm is used. Last, the maximum likelihood algorithm produces better accuracy compared to the minimum distance algorithm.

Based on all of these results, i.e., satellite attitude profile, blurring effect, and histogram for generic image quality as well as accuracy of land use and land cover for remote sensing applications, images produced from off-nadir observation suffered acceptable quality degradation compared to images from nadir observation. However, the acceptance level could differ from one application to another and from one user to another. When some users need a perfect image for their application, then off-nadir acquisition is not the solution. However, as previously stated, this is not a trade-off between image quality and frequency of acquisition. Off-nadir acquisition will always be better than nadir acquisition in this aspect, because one optimal-quality image plus several sub-optimal quality images are better than just one optimal-quality image. The disadvantage of using off-nadir acquisition is not the quality of the resulting image, but rather the lost opportunity to capture the area beneath the satellite (nadir on satellite ground track) that could not be done due to the satellite rolling to the right or left of the area. For most cases, when the importance of some specific tasks that need off-nadir acquisition is high, this disadvantage is often acceptable, since the area can be captured in the next revisit time of the satellite payload.

IV. Conclusion

The off-nadir technique has been employed on LAPAN-A3 multispectral image acquisition in order to increase imaging frequency of one particular target based on specific user needs, where the revisit time could be improved from 21 days to 5 days for 20 degree allowed roll angle and to 2.5 days for 40 degree allowed roll angle. Off-nadir acquisition on the LAPAN-A3 satellite has been successfully executed to monitor the effects of several natural disasters in Indonesia, as well as to capture calibration sites for several consecutive days. The images produced however, have degraded quality both in generic image quality and in remote sensing application accuracy. Blurring effect could be minimized by using a better off-nadir technique, but the images tend to be bright (saturate) when the satellite is facing into sun reflection direction. For land use/land cover classification application, off-nadir images have about -0.5 percent/deg of accuracy degradation with respect to roll viewing angle, meaning with 20 deg viewing angle, the accuracy is reduced by 10 percent. Some aspects of classification, such as the type, algorithm, and number of classes, are also influence to classification accuracy, but not significantly. These moderate results show that off-nadir multispectral images of the LAPAN-A3 satellite could still be used for land use and land cover classification when high frequency acquisition of one particular area is needed and moderate accuracy is accepted.

Three further research studies could be conducted related to this research. First, a smoother off-nadir technique could be developed to ensure the stability of the satellite when maneuvering so that the image produced will have a better geometry structure. Second, an algorithm for correcting off-nadir images should be developed so that the image quality and remote sensing application accuracy could be improved. Last but not least, the off-nadir technique could be used to increase the uniformity of image coverage for the satellite with no thruster, like the LAPAN-A3 microsatellite. Since without a thruster, the satellite sometimes will enter a period of time where the ground track of the satellite is such that it could not visit one particular area for three months. On the other hand, there are other particular areas that are visited by the satellite several times a month.

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REFERENCES

[1] J. M. Yeom, J. Ko, J. Hwang, C. S. Lee, C. U. Choi, and S. Jeong, "Updating absolute radiometric characteristics for KOMPSAT-3 and KOMPSAT-3A multispectral imaging sensors using well-characterized pseudo-invariant tarps and microtops II," Remote Sens (Basel), vol. 10, no. 5, 2018, doi: 10.3390/rs10050697.

[2] S. Jabari and M. Krafczek, "Application of off-nadir satellite imagery in earthquake damage assessment using object-based HOG feature descriptor," in International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, 2019. doi: 10.5194/isprs-archives-XLII-3-W8-167-2019.

[3] J. Van Beek, L. Tits, B. Somers, T. Deckers, P. Janssens, and P. Coppin, "Viewing geometry sensitivity of commonly used vegetation indices towards the estimation of biophysical variables in orchards," J Imaging, vol. 2, no. 2, 2016, doi: 10.3390/jimaging2020015.

[4] A. B. Ahady and G. Kaplan, "Classification comparison of Landsat-8 and Sentinel-2 data in Google Earth Engine, study case of the city of Kabul," International Journal of Engineering and Geosciences, vol. 7, no. 1, 2022, doi: 10.26833/ijeg.860077.

[5] A. Runge and G. Grosse, "Mosaicking Landsat and Sentinel-2 data to enhance LandTrendr time series analysis in northern high latitude permafrost regions," Remote Sens (Basel), vol. 12, no. 15, 2020, doi: 10.3390/RS12152471.

[6] P. Jacob, P. Kommuru, R. Ruchitha, H. Kuracha, and T. Taruni, "Comparative study of MODIS, LANDSAT-8, SENTINEL-2B, and LISS-4 images for Precision farming using NDVI approach," in E3S Web of Conferences, 2023. doi: 10.1051/e3sconf/202340501004.

[7] Y. Lei, L. Yuan, Q. Zhu, Z. Wang, and J. Liu, "A Steering Method with Multiobjective Optimizing for Nonredundant Single-Gimbal Control Moment Gyro Systems," IEEE Transactions on Industrial Electronics, vol. 69, no. 4, 2022, doi: 10.1109/TIE.2021.3073357

[8] Z. Qu, G. Zhang, Z. Meng, K. Xu, R. Xu, and J. Di, "Attitude Maneuver and Stability Control of Hyper-Agile Satellite Using Reconfigurable Control Moment Gyros," Aerospace, vol. 9, no. 6, 2022, doi: 10.3390/aerospace9060303.

[9] G. Ye, J. Pan, M. Wang, Y. Zhu, and S. Jin, "Analysis: Impact of image matching methods on jitter compensation," in ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2022. doi: 10.5194/isprs-Annals-V-3-2022-611-2022

[10] S. Ban and T. Kim, "Relative Geometric Correction Of Multiple Satellite Images By Rigorous Block Adjustment," in International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, 2023. doi: 10.5194/isprs-archives-XLVIII-1-W2-2023-1699-2023.

[11] X. Wan, J. Liu, S. Li, J. Dawson, and H. Yan, "An Illumination-Invariant Change Detection Method Based on Disparity Saliency Map for Multitemporal Optical Remotely Sensed Images," IEEE Transactions on Geoscience and Remote Sensing, vol. 57, no. 3, 2019, doi: 10.1109/TGRS.2018.2865961.

[12] Luhur Moekti Prayogo and Abdul Basith, "The Effect of Sunglint Correction for Water Depth Estimation Using Rationing, Thresholding and Mean Value Algorithms ," Journal of Science and Technology, vol. 14, no. 1, pp. 39–48, 2021

[13] T. Várnai, A. Marshak, and A. Kostinski, "Operational Detection of Sun Glints in DSCOVR EPIC Images," Frontiers in Remote Sensing, vol. 2, 2021, doi: 10.3389/frsen.2021.777806.

[14] M. Gedefaw, Y. Denghua, and A. Girma, "Assessing the Impacts of Land Use/Land Cover Changes on Water Resources of the Nile River Basin, Ethiopia," Atmosphere (Basel), vol. 14, no. 4, 2023, doi: 10.3390/atmos14040749.

[15] M. Pallavi, T. K. Thivakaran, and C. Ganapathi, "Evaluation of Land Use/Land Cover Classification based on Different Bands of Sentinel-2 Satellite Imagery using Neural Networks," International Journal of Advanced Computer Science and Applications, vol. 13, no. 10, 2022, doi: 10.14569/IJACSA.2022.0131070.

[16] P. R. Hakim, A. H. Syafrudin, S. Utama, and A. P. S. Jayani, "Band co-registration modeling of LAPAN-A3/IPB multispectral imager based on satellite attitude," in IOP Conference Series: Earth and Environmental Science, 2018. doi: 10.1088/1755-1315/149/1/012060

[17] N. M. N. Khamsah, S. Utama, R. H. Surayuda, and P. R. Hakim, "The development of LAPAN-A3 satellite off-nadir imaging mission," in Proceedings of the 2019 IEEE International Conference on Aerospace Electronics and Remote Sensing Technology, ICARES 2019, 2019. doi: 10.1109/ICARES.2019.8914347.

[18] Tamilselvi. K and Prof. T. Thenmozhi, "Restoration Techniques Available for Satellite Image Sensing Applications – A Review," International Research Journal of Engineering and Technology , vol. 07, no. 12, pp. 259–264, 2020.

[19] D. Llaveria, A. Camps, and H. Park, "Correcting the ADCS Jitter Induced Blurring in Small Satellite Imagery," IEEE Journal on Miniaturization for Air and Space Systems, vol. 1, no. 2, 2020, doi: 10.1109/JMASS.2020.3013440

[20] Han Zhang, Baorong Xie, Shijie Liu, Rongli Ding, Zhen Ye 1, and iaohua Ton, "Detection And Correction Of Jitter Efefct For Satellite Tdiccd Imagery," The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. XLIII, no. B1, pp. 79–84, 2022.

[21] K. Arai, "Change Detection Method with Multi-temporal Satellite Images based on Wavelet Decomposition and Tiling," International Journal of Advanced Computer Science and Applications, vol. 12, no. 3, 2021, doi: 10.14569/IJACSA.2021.0120307.

[22] S. Rajkumar and G. Malathi, "A comparative analysis on image quality assessment for real time satellite images," Indian J Sci Technol, vol. 9, no. 34, 2016, doi: 10.17485/ijst/2016/v9i34/96766.

[23] S. Suzuki, S. Takeda, R. Tanida, Y. Bandoh, and H. Shouno, "Distorted image classification using neural activation pattern matching loss," Neural Networks, vol. 167, 2023, doi: 10.1016/j.neunet.2023.07.050.

[24] A. Herawan, A. Julzarika, P. R. Hakim, and E. A. Anggari, "Object-Based on Land Cover Classification on LAPAN-A3 Satellite Imagery Using Tree Algorithm (Case Study: Rote Island)," Int J Adv Sci Eng Inf Technol, vol. 11, no. 6, 2021, doi: 10.18517/ijaseit.11.6.14200.

[25] W. Salhi, K. Tabiti, B. Honnit, N. Saidi Mohamed, and A. Kabbaj, "Hybrid Deep Learning Architecture for Land Use: Land Cover Images Classification with a Comparative and Experimental Study," International Journal of Advanced Computer Science and Applications, vol. 13, no. 12, 2022, doi: 10.14569/IJACSA.2022.01312104.

[26] M. Dimyati, A. Husna, P. T. Handayani, and D. N. Annisa, "Cloud removal on satellite imagery using blended model: case study using quick look of high-resolution image of Indonesia," Telkomnika (Telecommunication Computing Electronics and Control), vol. 20, no. 2, 2022, doi: 10.12928/TELKOMNIKA.v20i2.21085.

[27] Y. Zhang, Z. Wang, Y. Luo, X. Yu, and Z. Huang, "Learning Efficient Unsupervised Satellite Image-based Building Damage Detection," in Proceedings - IEEE International Conference on Data Mining, ICDM, 2023. doi: 10.1109/ICDM58522.2023.00206.

[28] Y. Zhang, Z. Wang, Y. Luo, X. Yu, and Z. Huang, "Learning Efficient Unsupervised Satellite Image-based Building Damage Detection," in Proceedings - IEEE International Conference on Data Mining, ICDM, 2023. doi: 10.1109/ICDM58522.2023.00206.

[29] T. Anthony, N. Shaban, and C. Nahonyo, "Land Cover Change as a Proxy of Changes in Wildlife Distribution and Abundance in Tarangire-Simanjiro-Lolkisale-Mto wa Mbu Ecosystem," Tanzania Journal of Science, vol. 49, no. 1, 2023, doi: 10.4314/tjs.v49i1.17.

[30] H. Ouchra, A. Belangour, and A. Erraissi, "Machine Learning Algorithms for Satellite Image Classification Using Google Earth Engine and Landsat Satellite Data: Morocco Case Study," IEEE Access, vol. 11, 2023, doi: 10.1109/ACCESS.2023.3293828.

[31] E. A. Anggari et al., "Assessing the Accuracy of Land Use Classification Using Multi-spectral Camera From LAPAN-A3, Landsat-8 and Sentinel-2 Satellite: A Case Study in Probolinggo-East Java," Int J Adv Sci Eng Inf Technol, vol. 13, no. 5, 2023, doi: 10.18517/ijaseit.13.5.18570.

[32] Sartika Salaswati et al., "Vicarious Radiometric Calibration Of Lapan-A3/Ipb Satellite Multispectral Imager In Jaddih Hill Madura," Jurnal Teknologi Dirgantara, vol. 18, no. 1, pp. 31–41, 2020.