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Study Method for Testing Image Quality of Optical Remote Sensing Satellite of Vietnam

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Abstract

VNREDSat-1 satellite had been launch on 7th May 2013 with 5 years life time designed and it opens up new opportunities for natural resources and environment monitoring in Vietnam. Precise information on the Earth surface which is extracted from remote sensing data including VNREDSat-1 depends on parameters such as spatial resolution, radiometric resolution, temporal resolution, and spectral resolution. Image quality is evaluated by spatial and radiometric resolution. MTF (Modulation Transfer Function) shows quality of spatial resolution and sharpness. Radiometric resolution is delineated through noise value characterized by signal to noise ratio (SNR). VNREDSat-1 is the first multi-spectral Vietnamese satellite that suitable image quality assessment methods should be built and possible applied for similar future satellites. MTF could be estimated by algorithms as general mathematical framework based on Wiener filter (1949), target based absolute MTF; or direct and indirect parametric models of MTF. SNR estimation could be performed by several methods which are single view for homogeneous and quasi- homogeneous area or synthetic landscape such as the desert, snowy expans of Greenland or Antarctic, etc. Outputs of this work are methodology and algorithm for VNREDSat-1 image quality assessment and similar future satellites that is suitable with characteristics of Viet Nam test site.

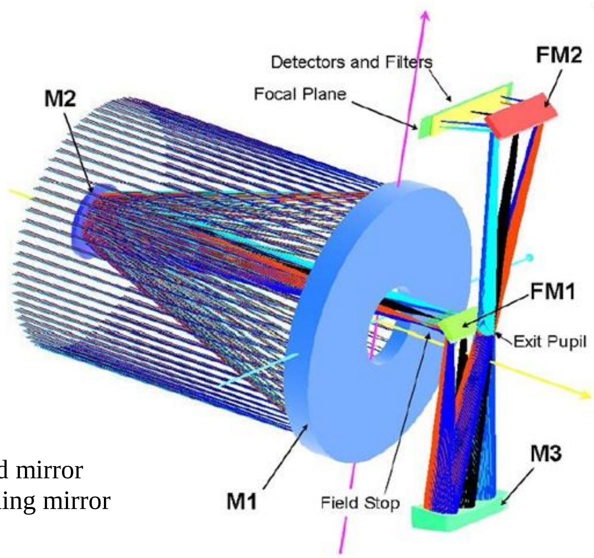
Keywords

Image quality, Optical satellite, VNREDSat-1.

1. Introduction.

VNREDSat-1 satellite has been designed and used AstroSat100-bus of EADS Astrium, with Myriade platform and instrument as NAOMI-125, which is a high resolution pushbroom imager. It provides imagery of 2.5m in Panchromatic and 4 multispectral bands of 10m GSD (VAST, 2013a). The optical system in NAOMI-125 (Fig.1) is one of the most important sub-systems, built on Korsch telescope with a Three-mirror Anastigmat design to ensure lightness and provide good optical quality with three aspherical mirrors (Luquet et al, 2008).

Once VNREDSat-1 has been operated, validation and calibration activities have been performed cyclically, but mainly for radiometric (DSNU and PRNU). Therefore, it is necessary to propose image quality assessment method for not only VNREDSat-1 but also similar satellites in the future. In this article, the authors focus on two main parts related to image quality: radiometric and geometric.



M1, M2, M3: curved mirror
FM1, FM2: flat folding mirror

Source: EADS Astrium

Figure 1. The optical concept of the Korsch telescope

2. Material and Methods

In orbit test (IOT), VNREDSat-1 has been validated radiometric and geometric parameters related image quality. During operational phase, calibration and validation activities should be continued. In that, related geometric is MTF and related radiometric are SNR and PRNU.

2.1. Geometric testing

Modulation Transfer Function is defined as the modulus of the Fourier Transform of the Point Spread Function (Hearn, 2005):

$$MTF(f_x, f_y) = \left|FT[PSF](f_x, f_y)\right| \tag{1}$$

There are some method to estimate MTF such as: general mathematical framework based on Wiener filters (Wiener, 1949), based on targets, bi-resolution, etc.

a. MTF estimation method using general mathematical framework

General mathematical framework based on Wiener (1949) is an interesting method. It allows not only MTF estimation but also the error of the MTF absolute estimation, without considering MTF/PSF/LSF or ESF, which reduce the impact of measurement noise and aliasing effects on the MTF absolute estimation (Hearn, 2005).

However, this method only considers relationship between LSF, PSF and MTF in one dimension (without loss of generality). LSF is defined for a given orientation and corresponds to the integration of the PSF over the orthogonal to that direction. LSF's two particular directions are important because it corresponds to the separable axis of the detector and the motions blur MTF.

b. MTF estimation method using target

Most of absolute MTF estimation is based on image analysis from acquisition of specific well known targets, they can be artificial objects such as bridges, buildings, etc. or dedicated targets such as painted surfaces, single or multiple spotlights, etc. or even natural objects such as fields and so on. In general, there are two main targets used for MTF estimation: the pulse target and edge target. According to the design, test site in Vietnam will be similar with edge target. Therefore this study did not consider pulse target.

An edge target corresponds to high contrast Heaviside edge (Fig-2). The main parameters are: the differential radiance Δ_L between the dark and bright part, the width of the target in the direction of MTF profile $\mathbf{L_W}$, the orientation angle α with respect to the direction of the MTF profile, and the height $\mathbf{L_H}$ of the target in the orthogonal direction of the MTF profile (Hearn, 2005).

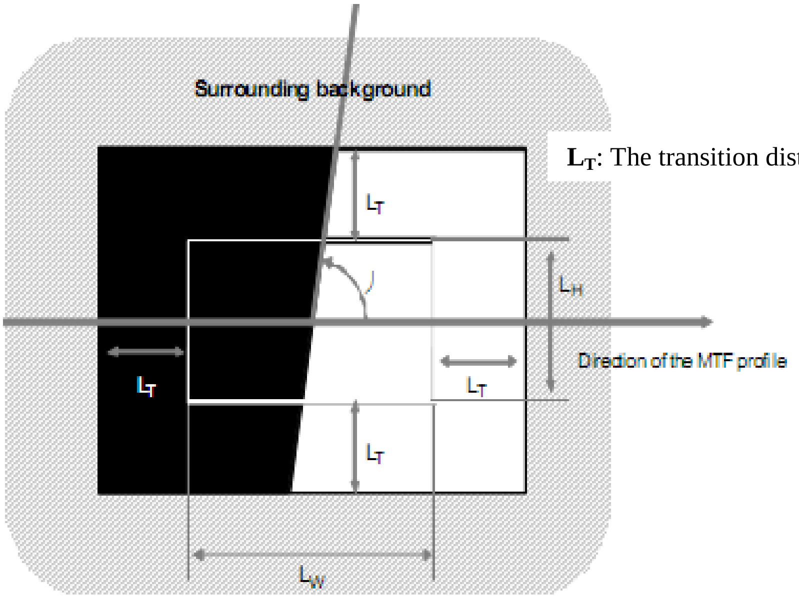


Figure 2. The design of edge target for MTF estimation

Based on those principles, Vietnamese test site is designed and constructed which consists of two parts:

- About MTF validation and measurement: in square shape, the longitudinal edge is tilted to a certain angle to the North, and is shaped bay a 2x2m chessboard, each box is painted black and white alternately.
- About SNR validation and measurement which can also simultaneously calculate the dynamic range and radiance responds on the instrument: in the form of four consecutive squares, painted from white-light gray-strong gray-black, with the same side north.

c. Bi-resolution MTF estimation method

This method use spectrum ratios in the Fourier domain of two images of the same scene in order to estimate the ratio of their respective MTF. It requires specific pre-processing such as geometric registration and radiometric alignment. Change detection algorithm could be also used to determine temporally stable areas between the two acquisitions.

There are two cases for this method. In the first case, using two unknown images and their respective GSD are comparable, so only relative MTF can be estimated. In the second case, using two images that are different GSD, one image has higher at least a factor 5 between GSDs (Li et al, 2015). In this case, even if MTF of higher resolution image is unknown, it will be assumed to correspond to a certain value at the scale of low resolution image. In other words, this case will be allowed estimation MTF of lower resolution image.

d. MTF estimation method with specific on-board devices

There are some specific devices today allow of MTF estimation without having the knowledge of the scene or object, named “blind” method. An example for this method is the specific on-board devices, which is the phase diversity method. Image processing technique for this method will infer the global MTF from a set of more than two associate images of the same extend object or rich natural scenes (Paxman et al, 1992). In fact, image processing process corresponds to the general estimation and repeat of deconvolution processing, taking into the account of the estimated MTF previously.

And MTF taking into account the current estimation of the unknown object. These two processes are performed until convergence.

2.2. Radiometric calibration

a. Photo Response Non-Uniformity (PRNU)

Imagery for PRNU validation can be deserts for example in Lybia, Algeria, Arabia, Australia, etc. These are areas of uniform landscape, uniform radiance level, and less affected by the seasonal weather cycle to the measured radiance level. So they can be used to validate all year round.

b. Signal-Noise-Ratio (SNR) assessment

Signal-Noise-Ratio (SNR) is one of the factors that affect image quality, and it is characterized by radiometric noise. The image noise quantifies the difference in radiance levels for a homogeneous area is estimated by the formula 2 (Wang, et al., 2009):

$$SNR = m/\sigma \tag{2}$$

Where, m is the mean of a series of radiance for uniform landscape and σ is the standard deviation of this series.

Depend on the sensor of the instrument, it is an array or matrix that is subject to different interference effects (Kubik et al, 1998). If the sensor is an array, the noise sources of the image coming from two separated sources are colum-wise noise, also called instrument noise and line-wise noise, also called normalization noise. If the sensor is a matrix, then each detector has its own noise; because there are several normalization steps to equalize the detectors' signal, the noise is assumed to be the same as the normalization noise.

A SNR assessment method is usually created by three factors: site selection, method to compute the mean and noise, and the timing of application of assessment with respect to routine operations and other calibration operations. Site selection is important, affecting assessment results. There are usually two ways to select SNR test site: single view and synthetic landscape. Single view means taking a scene over a given site; synthetic landscape means taking several images and merging in order to create a synthetic landscape with requires properties.

- For single view, there are two cases can be occurred: homogeneous area and quasi- homogeneous area

+ Homogeneous area:

The principle of this case is to find a homogeneous area representing for uniform landscape, to calculate mean value and standard deviation on this area, and finally to get the ratio of the mean and standard deviation. However, homogeneous area selection requires areas having average radiance value in the area that needs to be high enough.

+ Quasi-Homogeneous area:

One of the most known methods using this case is the Fourier transform of a part of an image (Jenkins et al, 1969). Noise will appears at high frequencies, but chaotic operation of spectral density for high wave numbers as well as the presence of large scale trends can affect accuracy when estimating noise and mean. The requirement for reliable SNR assessment is using data capture of smooth landscape with low-energy intrinsic high frequencies.

- For synthetic landscape: The limitation of a homogeneous area can be reduced by considering a synthetic landscape. It is generated by the fusion of actual single image (Wald, 1999), properties of synthetic landscape are more suitable than single view when assessing SNR.

The Possible solution is using desert areas where having very stale reflectance in time, once corrected for bi-directional effects, such as Northern Africa area (Cosnefoy et al, 1996). A combining cloud image solution is also used to create a completely clouded composite scene.

3. Result and Discussion

Validation activities have been performed every 3 months after satellite is launch. The parameter will be calculated and compared with the previous test. If the error between the two tests exceeds the threshold, the correction will be performed. Due to the differences between working conditions such as: temperature, thermal difference between components, cosmic radiation, power supply noise, etc. calibration will be made as soon as possible after false detection. We will discuss some results as well as practical experiences in the operation VNREDSat-1 satellite.

3.1. Geometric validation

a. MTF estimation method using general mathematical framework

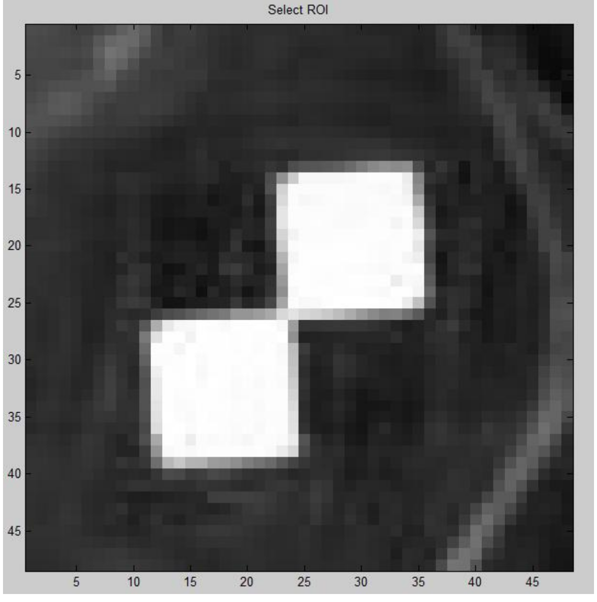
With the aim of providing an estimation method suitable not only for existing satellite systems but also for future satellites, the authors have not chosen this method, as the design of the test site is not in accordance with the algorithm used; it is lack of general when estimating MTF and considering the relationship between MTF, PSF, LSF.

b. MTF estimation method using target

In some studies, it has been shown that by using this method, the relative root mean square error of MTF estimation obtained by the Wiener filter will not be affected by aliasing. Nevertheless, this filter does not take into account neither the zero-crossing nor the radiometric noise (Helder, 2003, Helder et al, 2004, Helder and Choi, 2005). Therefore, with the design characteristics of the Vietnam test site, this method can be applied to estimate MTF for VNREDSat-1 satellite and other ones of future remote sensing satellites of Vietnam.

We would like to propose MTF estimation method based on actual condition in VietNam for existing satellite and future one, as well as test site under constructing, which is MTF estimation using edge target. On that basis, we validated the MTF with VNREDSat-1 image, which taken on 18 July 2016 and 25 April 2016 at the Salon de Provence test site, France (Fig.3).

The illustration in (Fig.4 and 5) shows that, MTF@ Nyquist frequency in image taken on 25 April is 0.22, and on 18 July is 0.25. These results is quite similar to the survey conducted by ADS after VNREDSat-1 was launched, is 0.21. The slight difference may be due to the different meteorological conditions at the Salon de Provence test site. The results in the image taken on 18 July, MTF curve has some point up. This phenomenon may be due to noise during sampling.



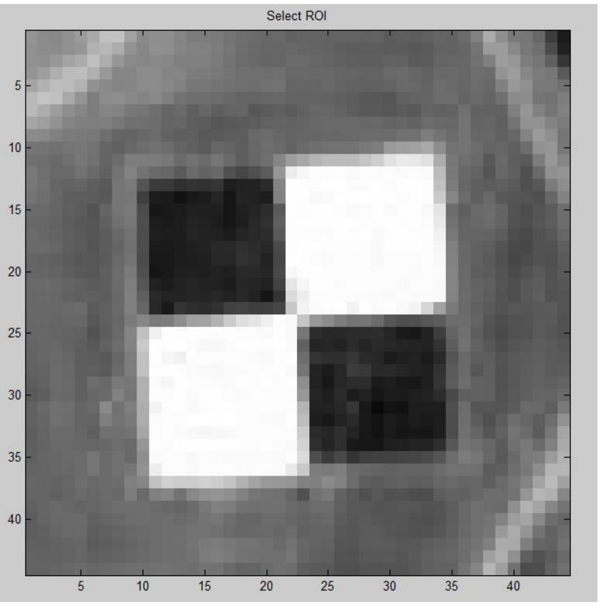


Figure 3. Salon de Provence test site on 25th April2016 (left) and on 18th July2016 (right)

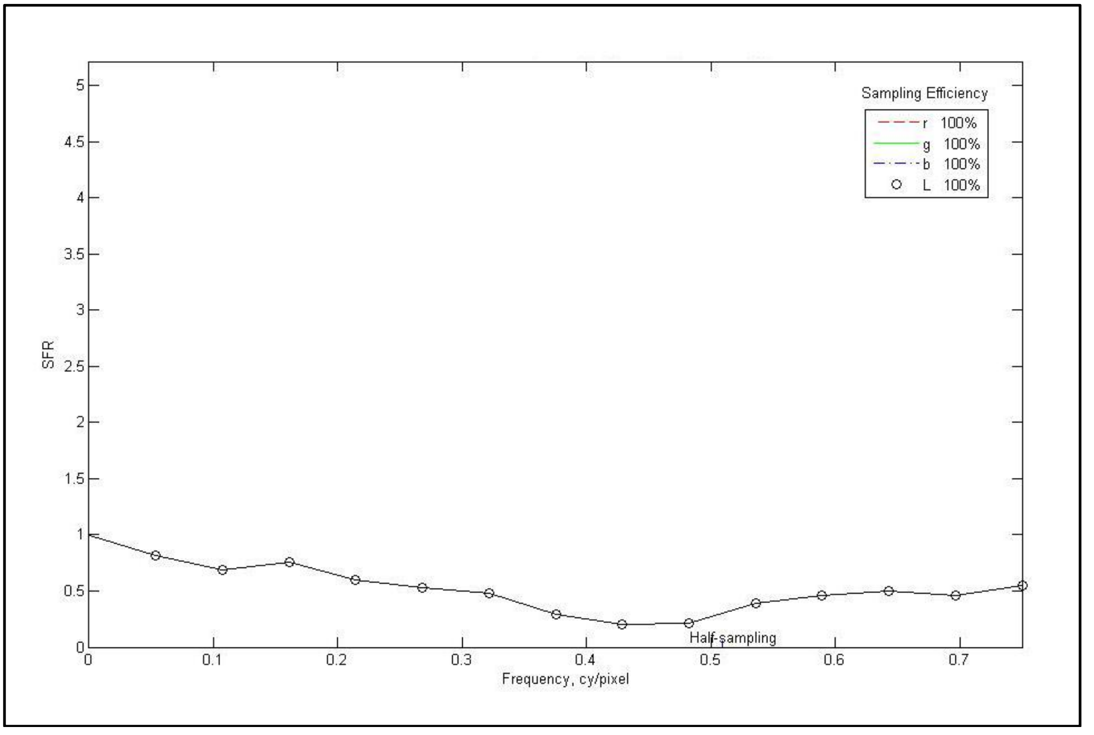


Figure 4. MTF@ Nyquist frequency in data taken on 18th July2016

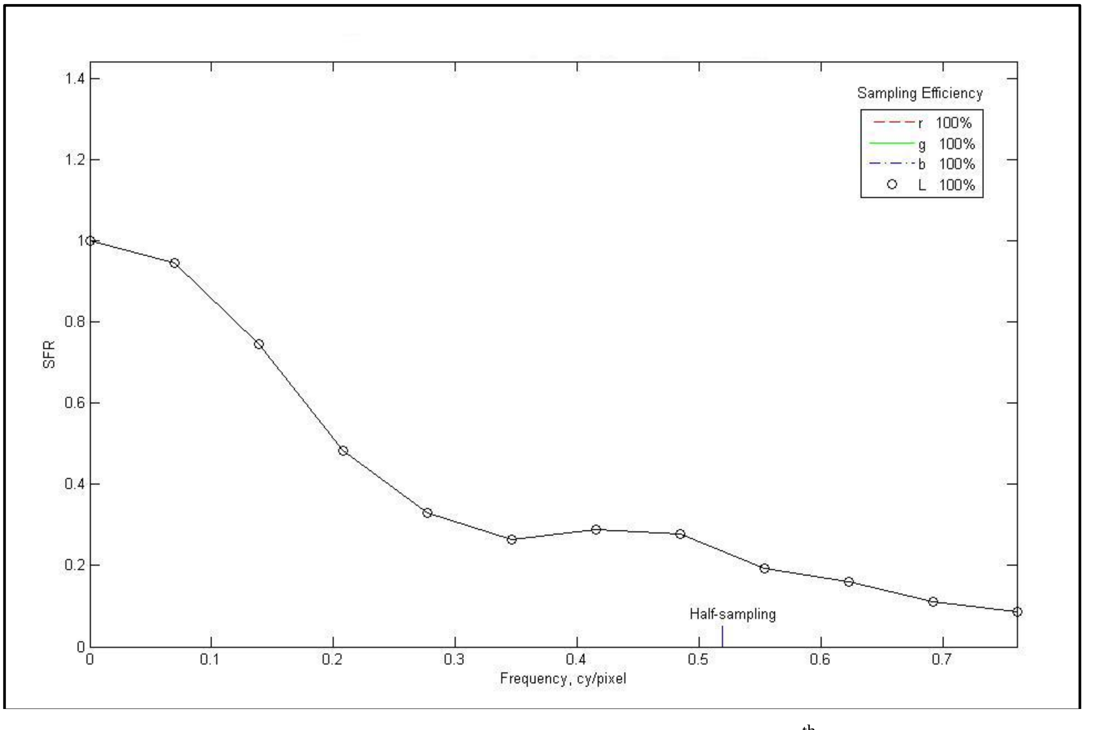


Figure 5. MTF@ Nyquist frequency in data taken on 25th April2016

c. Bi-resolution MTF estimation method

In fact, this direct application of the bi-resolution method suffered from an over-estimation of MTF due to aliasing effects; this has been noticed and confirmed by some scientists in previous studies (Viallefont-Robinet, 2003). In addition, applying this method always requires having a higher resolution image than ones need to estimate MTF. This would be difficult in the case of new satellite system with very high resolution, which would be difficult to find at higher resolution even using aerial imagery. For example, the image needs to estimate MTF has resolution 0.5m, there must be images with higher resolution of 0.2m or 0.1m. If new satellite designed with resolution 0.1m, what would be happened? Thus, this method is highly applicable but must be selected and balanced before using.

d. MTF estimation method with specific on-board devices

This method is suitable for satellite systems with specific on-board devices to estimate MTF and is designed from beginning. For VNREDSat-1 currently operating, there are no such devices, so it is impossible to use this method for MTF estimation.

3.2. Radiometric validation

a. PRNU validation

PRNU has been calculated from imagery input data. This value is in LSB and averaged the dark signal noise on all the images (after excluding the abnormal image). PRNU has been calculated on all rows of image. Each image will be calculated PRNU, then use high pass filter to eliminate the low frequency variable components. The post-filter PRNU is multiplied by the PRNU value at low frequency that is measured on the ground to recreate PRNU value of the instrument.

To determine whether calibrate the instrument or not, the dark signal and PRNU are taken as averages from all images, then compared with the standard value. If it is not exceed the threshold, it will not need to conduct calibration activities.

Figure 6 shows result of SNR assessment. On the left is the original image and on the right is enhanced image. The figure shows that after enhancing, the noise streaks are more clearly expressed on the original data.

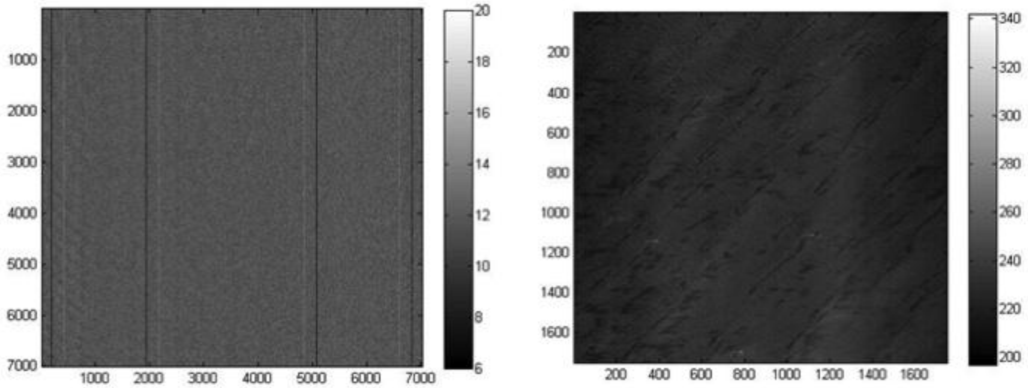


Figure 6: Original image and enhanced image

b. SNR validation

As mentioned above, the SNR assessment can use the data in two ways: single view and synthetic landscape. Under conditions in Vietnam, the proposed SNR assessment methodology would be single view-homogeneous area, and the calculation model would follow the definition given in section 2.

These results in Figure 6 show that SNR calculated on the Pan bands of VNRDSat-1 on 25/4/2016 and on 18/7/2016 correspondent 86.15 and 116.22, which are higher than reference value (average SNR =143 on L2 (VAST, 2013b)). They only reached the asymptotic level, due to the basic calculate model, and the small test site in compare with the whole scene. Also the radiance at test site is not accurately verified at L2. We will continue to refine the model more precisely, experimenting in large scale site such as desert areas, even panoramic imaging is the oceans.

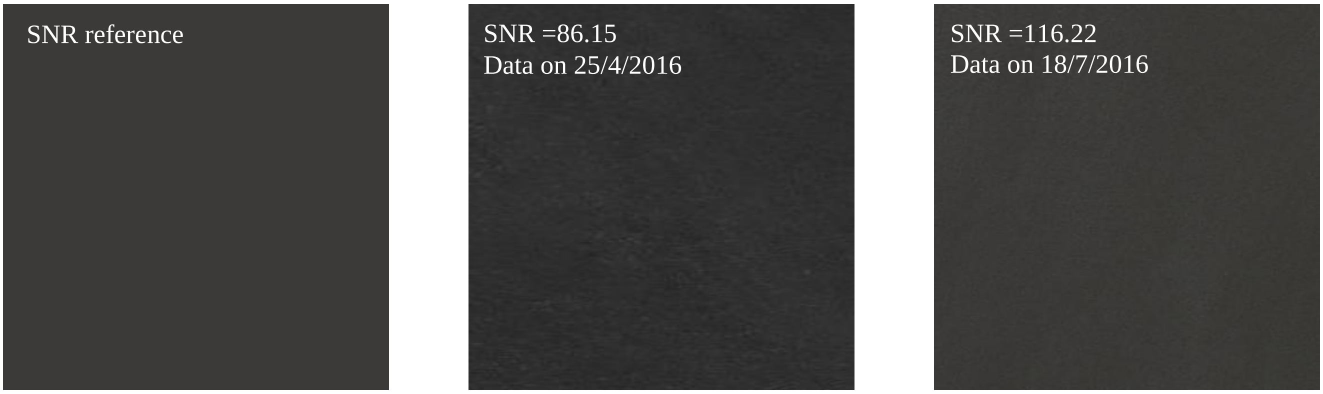


Figure 6. SNR validated on 25th April2016 and 18th July2016

4. Conclusion

Validation image quality of the instrument NAOMI-125 of the VNREDSat-1 satellite, in term of geometry and radiometry has been performed by using data on 25th April2016 and 18th July2016. Geometric validation is based on MTF method and using the test site at Salon de Provence, France. The results show that, the values of MTF@Nyquist frequency validated are higher than the one provided by ADS at IOT (0.22 and 0.25 compared with 0.21). For the radiometric validation, there are two parameters have been calculated: PRNU and SNR. PRNU and SNR validations have been performed by using VNREDSat-1 images taken in the Atlantic Ocean on 25/4 and 18th July2016. The SNR values are calculated correspondent 86.15 and 116.22, lower than result at IOT (SNR average is 143@L2). The results confirmed that the geometric validation using MTF method and radiometric validation using natural targets such as deserts, oceans are suitable to the conditions of VietNam.

The results also show that the geometric and radiometric quality of the instrument NAOMI-125 still having the required stability, but also show slight changes in compare with at IOT. That signals show an aging of optical sensor, and need to be monitored and verifying more often. This is feasible when VietNam's test site is available in the near future and the reliability of testing methods suitable for VietNam conditions has been verified through this study.

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