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RESEARCH ARTICLE

IMAGE QUALITY ESTIMATION FOR SATELLITE OPTICAL INSTRUMENT USING CALIBRATION SITE IN VIETNAM.

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Abstract

Optical instrument on Earth observation satellite performs the conversion from incoming radiance to digital image. Practically, there is always distortion or noise infringed on the output image. On the other hand, the instrument is suffering from degradation due to hard operating environment and aging. Therefore measurement and correction of optical image quality parameters must be done by ground station in order to maintain the reliable and accurate remote sensing products. This paper describes the methodology to evaluate the Modulation Transfer Function (MTF) and Signal to Noise Ratio (SNR) of received images to control the image quality of the optical satellite. MTF and SNR of VNREDSat-1 satellite are verified using on-ground calibration sites in Vietnam. The output provides important figures for next-step instrument calibration process.

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Introduction:-

Earth observation small satellites are becoming more and more widely used in many important applications. Vietnam Academy of Science and Technology (VAST) has completed the project: "Vietnam natural resources, environment and disaster monitoring small satellite project" (VNREDSat-1). The VNREDSat-1 satellite was successfully launched in 07/05/2013 and providing image data for various applications such as agriculture, forestry, urban area management, natural resources, environment and disaster monitoring. Modulation transfer function (MTF) characterizes the contrast and spatial resolution of the optical image, whereas Signal to noise Ratio (SNR) is a key parameter to evaluate the degradation of the image due to noisy input [1]. Before launch of the satellite, these parameters were carefully tested and verified against the designed requirements. After launch, the optical instrument is operating in space orbital latitude of around 680km and suffers from aging. In order to calculate MTF and SNR, satellite images are captured over specific sites on ground with typical patterns. The site is called calibration site. In case of VNREDSat-1, calibration site has been designed and located in Buon Ma Thuot, Central Highland of Vietnam.

Overview of VNREDSat-1 optical instrument:-

The optical instrument, installed on VNREDSat-1 is a "New Astrosat Observation Modular Instrument" (NAOMI) product of Earth observation optical payload. The instrument provides data of one Panchromatic (PAN) and four multi spectral (MS) bands with ground sampling distance of 2.5m and 10m resolutions respectively. The optical instrument is based on a push-broom concept with about 1.5° optical Field of View. It is capable of capturing square images of 17.5 km x 17.5 km by one 7000 pixel PAN and four 1750 pixel MS detectors from 680 km altitude, which

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is the orbital height of the satellite above the Earth surface. The row scanning is obtained by the sampling of Time-Delayed-Integration (TDI) linear detector and the column scanning is obtained by the satellite velocity on its orbit. The lightweight and compact optical payload is composed of the camera and its electronics. The camera, core of the instrument, is composed of a telescope, a focal plane embedding the TDI detector together with the optical filters and the video front-end electronics and a main structure interfacing with the satellite and the telescope via iso-static mounting devices. The payload electronics module is composed of analogue video and digital electronics. This electronics acquires the 12 video outputs (8 for PAN channel and 4 for MS channel) from the video front-end electronics module (F2EM). [2]

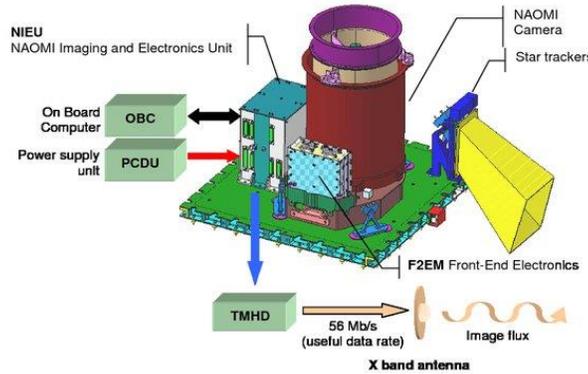


Figure 1:-Overall of NAOMI instrument [2].

The optical assembly of NAOMI instrument is based on a Korsch-type telescope including three aspheric mirrors (M1, M2 and M3) and two folding mirrors (FM1 and FM2). The focal plane of the optical instrument presents several key advantages compared to classical CCD based focal plane: use of TDI technology for enhancement of Signal to Noise ratio performances without slewing, availability of 4 MS channels registered with respect to PAN channel thanks to the monolithic structure of the detector, improved and secure radiometric performances through the ability to adjust the effective integration time by modifying the number of active TDI lines, compactness and low power dissipation [2].

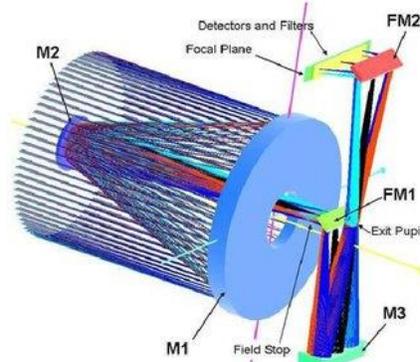


Figure 2:-Optical design of NAOMI Instrument [2].

Calibration site for optical satellite in Vietnam:-

In order to perform the image quality control over VNREDSat-1 or equivalent satellites, a calibration site was built for this purpose. The site design is dedicated for optical instrument and the ground track of VNREDSat-1 has been taken into account to for target-based MTF estimation. The site is located in the Buon Ma Thuot, Central of Vietnam and it is designed as follows:

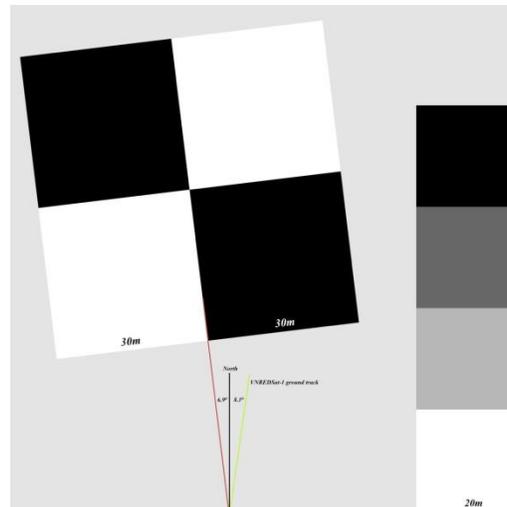


Figure 3:-Calibration site patterns for VNREDSat-1

The site is 100m x 100m square area and painted with different gray level varying from 0 to 100% reflectance. This specific pattern is selected to create a reference area of calibration with certain contrast and signal variation expected on the digital image.

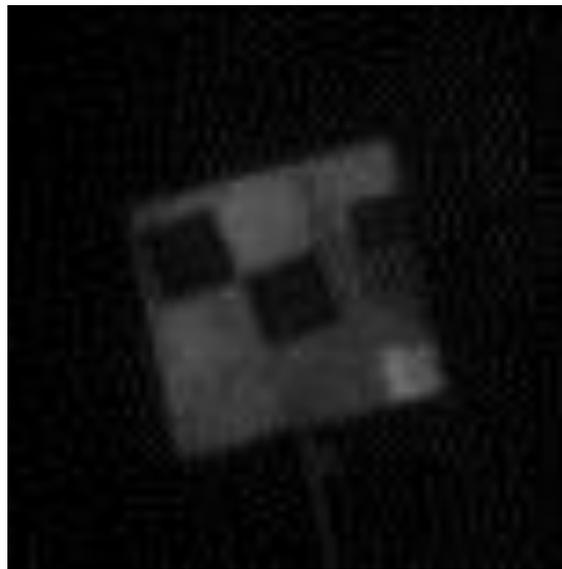


Figure 4:-VNREDSat-1 image over the calibration site in Vietnam

The captured image of interest is then extracted and its digital number (DN) will be further utilized for MTF and SNR estimation. It is clearly that the accuracy of the results is much dependent on the input image which is blurred by cloud, bad weather or inclined image. Therefore moment and mode of imaging the calibration site should be carefully considered.

Image quality verification for VNREDSat-1:-

Modulation transfer function (MTF) and SNR estimation methodology for earth observation satellite in-orbit is described in [3]. In this paper, MTF and SNR of VNREDSat-1 image is estimated using calibration site in Vietnam and verified against the designed requirement of the system before launch.

Data used to estimate MTF and SNR of VNREDSat-1 are:

1. VNREDSat-1 image over Buon Ma Thuot calibration site in 2017.
2. Supporting data: specific location of calibration site, off-nadir angle, sun azimuth and elevation,...
3. VNREDSat-1 image quality requirements for MTF and SNR.

MTF estimation is based on “edge method”. Therefore, selected image samples must contain transition region between black and white. Samples cropped from satellite image are as follows:

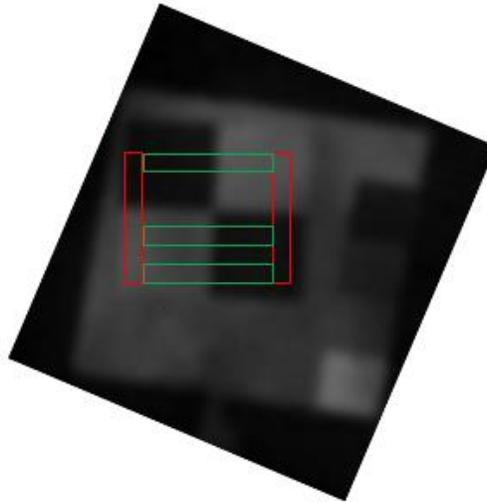


Figure 5:-Selected samples for image quality over calibration site

Five samples have been selected containing clear gray contract and line patterns which will be used for MTF estimation. Gray-scaled images of the samples are shown below:



Figure 6:-Three horizontal samples
MTF estimation outcome for each sample are:

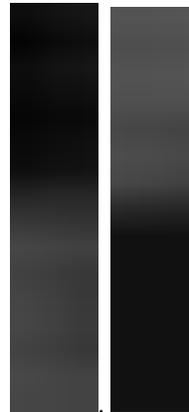


Figure 7:-Two vertical samples

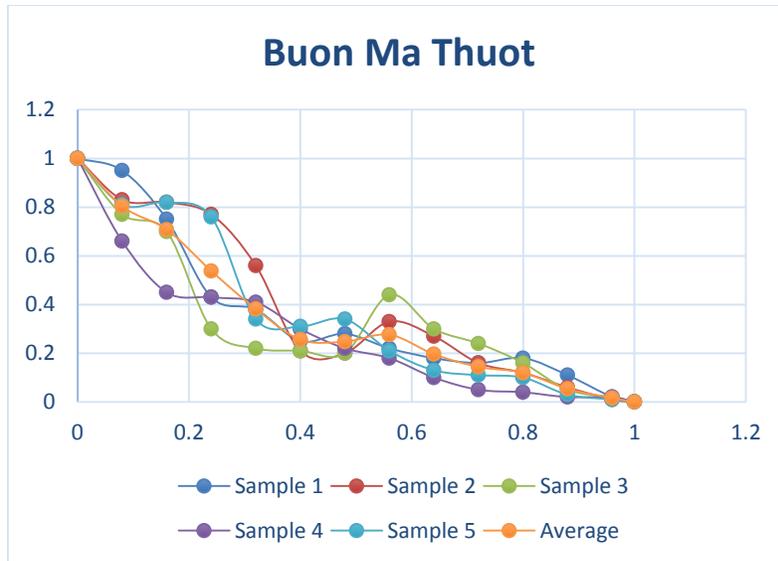


Figure 8:-MTF estimation result using Buon Ma Thuot calibration site

MTF result (for panchromatic band) at 0.7 (0.7 x Nyquist frequency) is averaged around 0.14. This figure is better than system requirement for MTF of 0.12 for PAN.

In order to estimate the SNR, the squares on the image are selected thanks to their gray level uniformity. The SNR outcome of VNREDSat-1 image varies with reflectance level of the samples.

Reflectance	0.9	0.6	0.4	0.2
SNR	116	87	42	30

Table 1:-Estimated SNRs at samples with different reflectance level.

Estimated SNR at 0.9 reflectance level is around 116, which is quite close to the system requirements (120). As mentioned earlier, the MTF outcome is much influenced by the satellite image captured over the calibration site. Practically, the image over Buon Ma Thuot site used for this paper was in light cloudy and not-nadir image. These factors partially blurred the image and the deteriorated the fidelity of the signal. That is the reason for close to requirements SNR result.

Conclusion and wayforwads:-

In order to maintain the image quality performance, MTF and SNR must be monitored regularly. This paper demonstrated the estimation of SNR and MTF of VNREDSat-1 optical satellite with support of dedicated calibration site in Vietnam. The results are quite good for MTF and acceptable for SNR. It is due the following reasons: unsatisfactory imaging conditions (weather, off-nadir direction) and lack of calibration input image. Therefore, the following study could be developed:

1. Improvement of estimation results: by using more dataset and more calibration sites.
2. Image quality improvements: correction of the optical conversion model by quality-based inverse convolution method

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