

IN-ORBIT MTF MEASUREMENT FOR THEOS IMAGING SYSTEM

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ABSTRACT:

THEOS, the Thai earth observation satellite, is planned to launch into the orbit by the end of this year. In order to ensure the image quality performance complied with the specification, image performance verification will be performed during the In-Orbit Testing (IOT).

The Modulation Transfer Function (MTF) is a fundamental image quality used to quantify the spatial frequency response of remote sensing imaging system. This essential parameter is used to define the sharpness of satellite images. The in-orbit measurement will be performed to determine both along and across track MTF by imaging on the ground target. The implementation of high contrast target is required with the dimension and orientation based on image ground sampling distance (GSD) and instrument scanning direction. The methodology of selected MTF measurement; target size and orientation, material used and analysis method will be presented and discussed in this paper.

1. INTRODUCTION

Thailand Earth Observation System (THEOS) is the first satellite of Thailand. This program is developed under the cooperation between Geo-Informatics and Space Technology Development Agency (Public Organization) (GISTDA), Ministry of Science and Technology, with European Aeronautic Defence and Space Company – Astrium (EADS Astrium SAS), in France, as a prime contractor. It will be launched by Ukrainian rocket, Dnerp by the end of year 2007. After satellite reaching to the operational orbit, image performance parameters will be measure during the In-Orbit Testing (IOT) in order to verify the conformity to specification. Another objective is to update the configuration parameters for image ground segment computation parameters (Calibration Parameter File, CPF).

The Modulation Transfer Function (MTF) is a fundamental image quality used to characterise the spatial frequency response of an imaging system. On image quality aspect, MTF specifies the contrast of an image that can be useful for end users to compare image quality from different sensors. MTF is mathematically defined as the normalized magnitude of the Fourier Transform of image point spread function (PSF). The purpose of in-flight MTF measurement for THEOS system is first to verify the system requirement, then to assess the need of refocusing, and finally to adjust the deconvolution parameters.

This paper will present the MTF measurement methodology selected for THEOS system. The ground pattern specification required for satellite acquisition in order to analysis in-orbit MTF. It is used to measure for MTF of PAN image only. The pattern size for MS would be much too large. In order to derive MTF for MS, another method will be applied by compare the spectrum of MS and PAN image with not described in the scope of this paper.

2. THEOS INSTRUMENT

THEOS satellite acquires imagery from the nominal altitude of 822 km with 2 m GSD for panchromatic and 15 m for multispectral instrument respectively at nadir condition. Operational orbit is sun-synchronous with inclination angle of 98.7°. MTF specification in each spectral band is described in Table 1.

Spectral Band	Nyquist Frequency	MTF
Panchromatic	$1 / (2 \times 2 \text{ m}) = 0.25 \text{ m}^{-1}$	0.10
Blue	$1 / (2 \times 15 \text{ m}) = 0.033 \text{ m}^{-1}$	0.12
Green	$1 / (2 \times 15 \text{ m}) = 0.033 \text{ m}^{-1}$	0.12
Red	$1 / (2 \times 15 \text{ m}) = 0.033 \text{ m}^{-1}$	0.12
Near Infra-Red	$1 / (2 \times 15 \text{ m}) = 0.033 \text{ m}^{-1}$	0.12

Table 1: Modulation Transfer Function specification

3. MTF MEASUREMENT METHODOLOGY

There are multiple methods for determining the in-flight MTF of imaging system; impulse, sinusoidal, knife-edge, pulse method. In general, specific target are required with size and orientation based on the GSD and instrument scanning direction to retrieve good performance (Kohm, 2004). For high resolution image (less than 3 m GSD) as THEOS PAN, edge targets are used for MTF analysis along two orthogonal directions (across and along track) as a case of SPOT5, ALOS PRISM, Kompsat-2 etc. The principle of this method is to evaluate Edge Spread Function (ESF) created by edge pattern slanted across the instrument scanning direction. The differentiation of ESF is an estimation of Point Spread Function which MTF can be retrieved by Fourier transform (Figure 1).

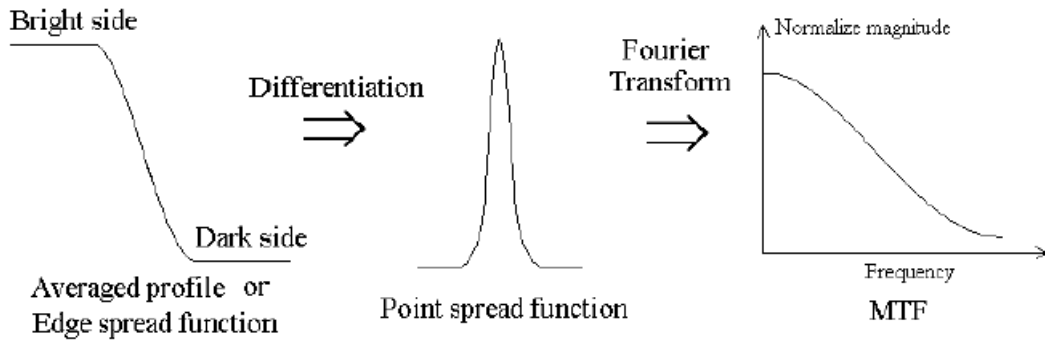


Figure 1 Methodology to achieve MTF by ESF method (Taeyoung, 2002)

Scene with natural sharp between dark and bright uniform area can be used to retrieve MTF, if the edge transition is slanted with respect to instrument scanning direction. However, this method needs sufficiently uniform areas that may be difficult to select and the results may not give a good accuracy as required (Kubik, 1998). The artificial slanted edge target is preferred and necessary for MTF analysis with dimension and orientation requirement related to instrument characteristic.

2.1 THEOS instrument

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Table 1: Modulation Transfer Function specification

3.2 Available edge patterns

There are edge patterns; black and white target dimension 60 m x 60 m, available for MTF measurement both along and across direction during THEOS IOT, located at Salon-de-Provence (Figure 2) latitude 43° 36' 21" N longitude 5° 07' 13" W and at Pong Hu at latitude 23° 31' 11" N longitude 119° 35' 00" E respectively.



Figure 2 Satellite image of edge target at Salon-de-provence test site (Valorge, 2003)

Actually, MTF analysis is required not only in the commissioning phase but also through the satellite life time in order to ensure the image quality to the users. As the owner and the operator of THEOS system, GISTDA plans to implement edge pattern in Thailand used to monitor MTF quality and increase the possibility of target accessible apart from the two existing due to image acquisition criteria of MTF measurement that need to be at near-nadir condition with no cloud cover above the pattern site. Area selection is still in process. It is, however, most likely that the target site will be located at THEOS satellite control station, Siracha, Chonburi latitude $13^{\circ} 06' 00''$ N longitude $100^{\circ} 55' 57.1''$ E. The following section will explain in more detail on size and orientation angle of edge pattern.

4. PATTERN SPECIFICATION

3.1 Pattern Size

Edge pattern will be implemented as a chessboard shape suitable for across and along track MTF calculation. Concrete surface will be painted with matted color of black and white to avoid the reflection effect. Pattern dimension is relating to sub-pixel resolution when oversampling on ESF and analysis accuracy required. For pattern dimension as 60 m width and 60 m long is acceptable with sub-pixel resolution as factor 4 and can get a good accuracy on MTF analysis due to the number of available line. A semi-permanent MTF pattern is another interesting aspect due to its reasonable expense and flexibility. In such a case, the suitable material used is polyester coated with PVC to provide additional weight and stability. However, weight of such pattern size is over 1,000 kg for mentioned material, it is almost impossible for moving and maintenance purpose. Pattern size decreasing is necessary to investigate in more detail.

3.2 Orientation Angle

The edge pattern has to be slightly inclined with respect to satellite ground track in order to create the edge profile construction when the knife edge method was applied. In order to install pattern on test field, pattern orientation angle with respect to the north is calculated concerning sub-pixel resolution when oversampling on ESF, satellite orbit inclination and skew effect due to earth rotation.

In this measurement sub-pixel resolution is selected to be sampled as factor 4 derived to pattern orientation angle wrt instrument direction as 14.04° . ($\text{Arctan } 1/4 = 14.04^{\circ}$)

Edge pattern orientation can be as follow:

THEOS ground speed	6.58 km/s
Pattern orientation angle wrt to CCD line	14 °
Pattern distance passed by satellite	= 60 / cos 14°
	= 61.837 m
Time used during satellite passing the pattern (t)	= $\frac{61.837}{6.58 \times 10^3}$
	= 9.4 x 10 ⁻³ s

Earth rotation effect (skew effect) is different up to latitude.

Latitude at pattern site (Siracha)	13.1°
Earth radial at pattern site (Figure 3)	= cos 13.1° x 6,378 km
	= 6,212.02 km

Earth rotation effect at pattern location during satellite passing period	= $\frac{2\pi r * t}{86164}$
	= $\frac{2 \times \pi \times 6212.02 \times 10^3 \times 9.4 \times 10^{-3}}{86164}$
	= 4.25 m

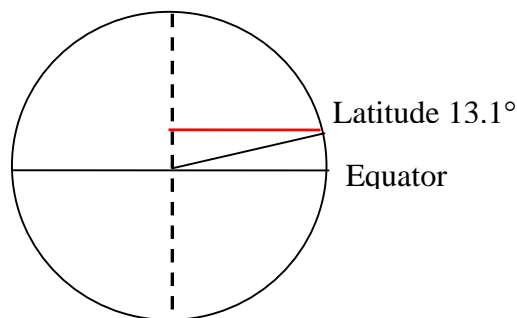
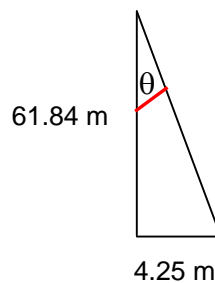


Figure 3 earth distance (a) at pattern site



During the satellite passing above the pattern edge (61.84 m), earth moving forward 4.25 m

Skew effect at pattern location	θ	= arctan ($\frac{4.25}{61.84}$)
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The pattern direction has to be moved backward	= 3.93°
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Orientation angle of CCD line wrt the north	= 8.7 °
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Orientation angle of pattern wrt the CCD line	= - 14°
Orientation angle of pattern wrt the North	= -5.3°
Move pattern direction backward	= 3.93°
Pattern orientation wrt the north	= -5.3° + 3.93°
	= -1.37 °

Due to inclination angle of THEOS is 98.7° and the skew effect due to earth rotation, the direction of the edge pattern that compensated the mentioned effect with respect to the north will be - 1.37 °. (figure 3)

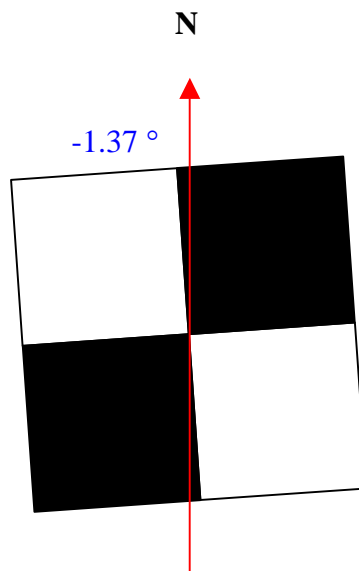


Figure 4 Edge pattern orientation angle with respect to the North

5. CONCLUSION

A method for in-flight MTF measurement of THEOS imaging system is presented. Available existing edge pattern is foreseen to use during In-Orbit Test. During operational life time, MTF analysis has to be monitor in order to confirm image quality, another edge pattern is planed to be implemented in Thailand. Explanation of size and orientation angle specification is demonstrated in detail.

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