A consideration of attitude jitter on Digital Elevation Model(DEM) estimation with EOS-AM1/ASTER

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Abstract

Theoretical accuracy assessment of Digital Elevation Model(DEM) to be derived from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) of EOS-AM1(Earth Observing System-AM1) platform was conducted under the assumption of with/without Modulate Transfer Function(MTF) degradation due to sensor motion. As the results, it was found that Root Mean Square(RMS) error in terms of DEM estimation accuracy was 27.98 m with GCP for without sensor motion while that with random sensor motion of one fifth of Instantanuous Field of View (IFOV), 0.88 arcsec in terms of standard deviation of random motion was 29.21 m. In the same time MTF degradation due to random motion was around 9.5% results in about 5% decreasing cross correlation between 32 x 32 pixels image chips of stereo pair. Also it was found that matching accuracy was degraded from 0.85 to 1.35 pixel.

1. Introduction

ASTER which is to be carried on the EOS-a1 Platform will have 3 bands in the visible and near infrared (VNIR) region, 6 bands in the short wave infrared(SWIR) region and 5 bands in the thermal infrared(TIR) region with the high spatial resolution, 15 m of IFOV for VNIR bands, 30 m of IFOV for SWIR bands and 90 m of IFOV for TIR bands, respectively. On the other hand, VNIR radiometer will have stereoscopic viewing capability with fore and nadir viewing optics with the B/H ratio of 0.6. By using this capability, we may obtain not only stereoscopic view of ground cover targets but also may generate a Digital Elevation Model(DEM)(Ref. 1-3).

This paper briefly describes the major characteristics of ASTER then applicability of DEM derived from ASTER data will be followed. Then with respect to the generation of DEM, the parameters will be shown together with reasonable methods for DEM generation followed by a theoretical limitation on the DEM accuracy will be discussed(Ref. 4, 5). Finally the results the from accuracy assessment with the present baseline of satellite position and attitude accuracy, in particular, attitude jitter.

2. Major characteristics of ASTER

ASTER is composed with three components, VNIR, SWIR and TIR radiometers. Major characteristics of VNIR radiometer is shown in Table 1.

VNIR radiometer will have a stereoscopic viewing capability with Base Height Ratio of 0.6 and also will have a pointing capability in cross track direction(over +/- 24 deg.). In addition a calibration system with a high stable internal lamp source will be installed. Although final decision has not been made for the dynamic range for each band, VNIR radiometer will have a variety of application such as observation of land/ocean surface, the atmosphere, even cloud with an adequate noise equivalent reflectance so that a gain change will also be capable.

SWIR radiometer will have capabilities of pointing in the cross track direction and gain change. Major characteristics are shown in Table 2.

By using pointing capability, we may observe 60 km of swath width within +/- 116 km in the cross track direction.

Table 1 Major characteristics of VNIR radiometer

Wave length regions(um)				
Band	Center	Width	NEdR	IFOV : 21.3urad for nadir viewing 18.1urad for forward viewing The angle between Nadir/Fore : 29.7 deg. Pointing angle in CT : +/-24 deg.
1	0.56	0.08	<0.5%	IFOV on the ground : 15 m
2	0.66	0.06	<0.5%	Base Height Ration : 0.6
3N	0.81	0.10	<0.5%	Swath width : 60 km
3F	0.81	0.10	<0.5%	Quantization : 8 bit

Also SWIR radiometer will have a calibration capability. These VNIR and SWIR radiometers are array sensors, push-broom type of sensors.

Meanwhile TIR radiometer is a mechanical scanning type of a whisk-broom sensor. Major characteristics of TIR radiometer is shown in Table 3.

TIR radiometer will have an active cooling subsystem to realize a reasonable noise equivalent temperature and will also have a calibration capability with an internal blackbody of which the temperature will be changed from 270 - 340 K.

3. Parameters related to DEM generation

Major parameters regarding with stereoscopic view is shown in Table 4.

4. Theoretical error analysis with orientation to a reference datum

(1) Assumptions

- Stereo model is assumed to have proper orientation with all Y-parallax removed with appropriate GCPs.
- Stereo matching error:S = 0.5 pixel
- Timing error:T = 0.1 ms x 7.51 km/s = 0.751 m

(2)Error analysis

- The errors of concern are in the X-direction, which is represented by the base.

$$B = 0.6\ H \qquad (1)$$
$$dH = dB/0.6 \qquad (2)$$
$$dB = SQRT(SS + TT + PP) \qquad (3)$$

where P is error cased by attitude change in pitch angle.

P = H*d(a)/cos(a)cos(a)
  = 705*d(a)/0.72544(a=31.6deg.) (4)
  = 15m for 4.4 arcsec/9sec
    (travel time/scene)
  = 7.5m for 2.2 arcsec/9sec

dH = 27.98 m for 4.4 arcsec/9sec (5)
   = 17.72 m for 2.2 arcsec/9sec

5. Effect of attitude jitter in DEM estimation

Comparatively high frequency component of attitude change is referred to attitude jitter. If we assume the

Table 2 Major Characteristics of SWIR radiometer

Band	Center(um)	Width(um)	NEdR	
				IFOV : 30 m, 42.6 urad
				Swath width : 60 km
4	1.655	0.100	<0.5%	Quantization : 8 bit
5	2.165	0.040	<1.3%	Pointing : +/-8.55 deg.
6	2.205	0.040	<1.3%	
7	2.260	0.050	<1.3%	
8	2.330	0.070	<1.0%	
9	2.395	0.070	<1.3%	

Table 3 Major characteristics of TIR radiometer

Band	Center(um)	Width(um)	NEdT	IFOV : 90 m, 127.8 urad
10	8.30	0.350	<0.3K	Swath width : 60 km
11	8.65	0.350	<0.3K	Quantization : 12 bit
12	9.10	0.350	<0.3K	Dynamic range : 200 - 370 K
13	10.60	0.700	<0.3K	Pointing : +/-8.55 deg.
14	11.30	0.700	<0.3K	

Table 4 Major parameters for ASTER stereoscopic viewing

Satellite altitude:H=705km, Velocity = 7.51 km/s
Band(Wave length region):Band 3(0.76 - 0.86um)
IFOV:A=15m for nadir viewing
Base height ratio with fore and nadir looking:B/H=0.6
Definition of one scene:60km x 60km
Pointing angle in direction of cross track:+/-8.54deg.
MTF:0.25 for nadir viewing
Requirement of attitude change in pitch(the dominant angle for DEM estimation) = 4.4 arcsec/9sec(Baseline)
= 2.2 arcsec/9sec(Option)
Requirement of attitude change in roll
= 8.8 arcsec/9sec(Baseline)
= 4.4 arcsec/9sec(Option)
Requirement of attitude change in yaw
= 52 arcsec/9sec(Baseline)
= 26 arcsec/9sec(Option)
Bias pointing error such as miss-alignment will be corrected through a statistical analysis on geometric accuracy

attitude jitter is random(Normal distribution) image motion within an exposure time, MTF of the imaging system is degraded as shown in Fig.1(Ref.6).

MTF degradation results in degradation of cross correlation between image chips of stereo pair. It implies stereo matching error results in decreasing DEM estimation accuracy.

5.1 Simulation of MTF degradation

In order to generate MTF degraded image, an image motion is simulated with Fast Fourier Transform(FFT). Firstly 16 of FFT transformed SPOT/HRV data in frequency domain are used for determination of the shifted pixel due to random image motion with Normally distributed random number. Through this process, all the pixels at the pixel location of one 16th of the pixel interval can be determined. Namely, analogue image motion is quantized by 4 bits, 16 steps. This process is applied to SPOT/HRV data in direction of pitch.

Due to the fact that the most dominant factor on DEM estimation is attitude changes in pitch direction as is shown in the above section so that, in this study, image motion is simulated in pitch direction.

Normal distributed random numbers with mean of zero and variance of 0.44, 0.88 and 1.32 arcsec which correspond to one 10th, two 10th and three 10th of IFOV were generated. With these numbers, image motion was added to the original SPOT/HRV image with FFT/IFFT rpocesses in pitch direction. Thus MTF degraded images were simulated. A portion of simulated image is shown in figure 3. With these images, cross correlation between image chips, matching accuracy and DEM estimation accuracy were investigated assuming the same image motion is existing on both optics for stereo imaging system.

The original SPOT/HRV imagery data and MTF degraded images are shown in figure 2.

5.2 Experimental results

Table 5 shows a relationship between standard deviation of random motion of attitude jitter and DEM accuracy degradation.

(1) MTF degradation

If the random image motion is considered for ASTER/VNIR, MTF degradation is shown in Table 5.

MTF degradation implies stereo matching error results in decreasing DEM estimation accuracy. MTF degradation in nadir viewing differes from that in backward viewing if the random sensor motions in both viewings are same. Thus MTF degradation causes a stereo matching error. Sensitivities of X, Y and Z directions on the ground for nadir and backward viewings are shown in Table 6.

Let us assume that sigma values of random image motion in pitch, roll and yaw directions are the same and also MTF degradations in X, Y and Z directions occures in independently, then the MTF degradations for nadir and backward viewings are 15.411 VS 73.245. This implies that if same sigma value of random motion occures for both nadir and backward viewings, MTF degradations

(2) Stereo Matching Error

In order to assess an effect of MTF degradation on stereo matching error, the following SPOT/HRV panchromatic data of stereo pair is used.

512 x 400 pixel were extracted in the stereo pair. Within a subset of stereo pair, 9 tip images which consists of 32 x 32 pixels were extracted. MTF of the tip images was degraded by using spatial filtering then cross correlation

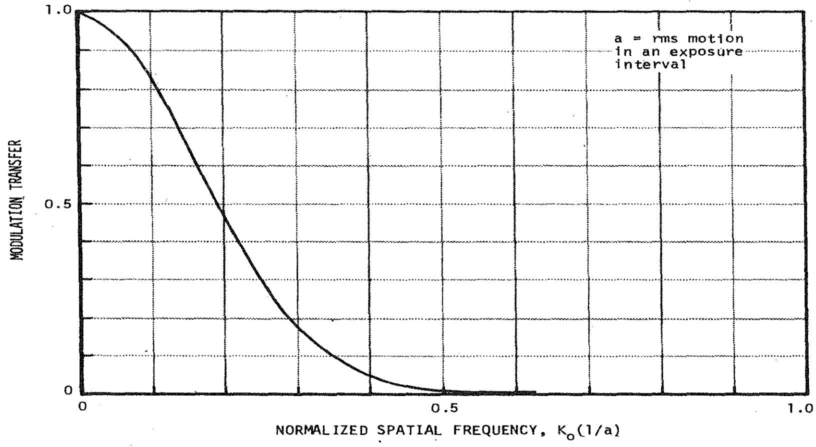
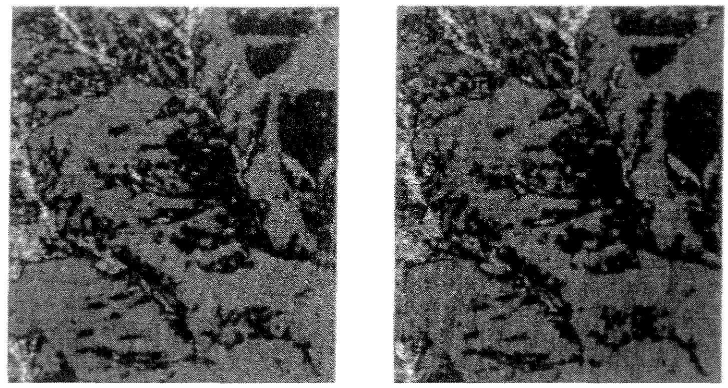
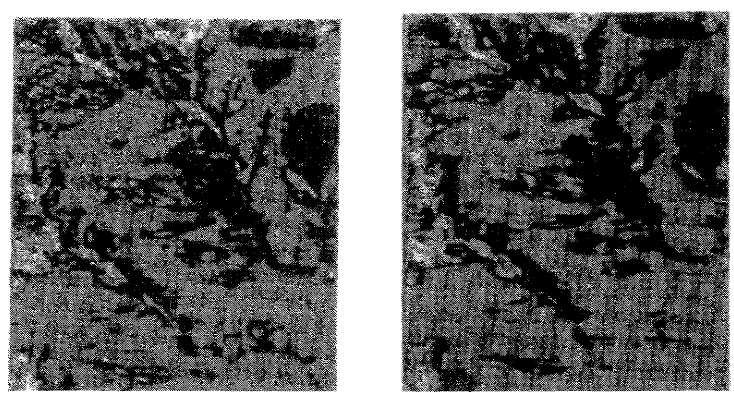


Fig.1 Attitude jitter is random(Normal distribution) image motion within an exposure time, MTF of the imaging system is degraded

Modulation Transfer Functions(MTFs) for image motion (normalized to a spatial frequency K0 = 1/a where a = rms motion in an exposure interval).



MTF degradation(%) 0 6.25



MTF degradation 9.375 12.5

Fig. 2 The original SPOT/HRV imagery data and MTF degraded images

between tip images of stereo pair was assessed. The averaged cross correlation for 9 tip images are shown in Table 7.

Then a relationship between cross correlation and stereo matching error was assessed. Assuming the well known matching method based on cross correlation, the averaged matching error was assessed by using the aforementioned 9 tip images of MTF degraded stereo pair. The results are shown in Table 8.

(3) DEM accuracy degradation

Table 9 shows a relationship between sigma value of random sensor motion in terms of attitude jitter and DEM accuracy degradation.

Therefore not only attitude changes but also attitude jitter should be taken into account in DEM estimation.

Table 5 MTF degradation due to random image motions

Sigma value of random motion(arcsec)	0.44	0.88	1.32	1.76	2.20
MTF degradation(%)	5	12	30	45	60

*IFOV of ASTER/VNIR is corresponding to 4.4 arcsec.

Table 6 The sensitivities(m/arcsec) of X, Y and Z directions on the ground for nadir and backward viewings

	Nadir Viewing			Backward Viewing		
	X(K1)	Y(K2)	Z(K3)	X(K4)	Y(K5)	Z(K6)
Pitch	3.423	0.111	0.653	0.009	0.142	8.314
Roll	0.111	1.722	0.423	0.112	1.707	0.544
Yaw	0.146	0.016	0.278	0.057	0.893	0.282

6. Concluding Remarks

Theoretical accuracy assessment of Digital Elevation Model(DEM) to be derived from Advanced Spaceborne Thermal Emission and Reflection Radiometer(ASTER) of EOS-AM1 platform was conducted under the assumptions of with/without GCP. As the results, it was found that RMS error in terms of DEM estimation accuracy was 27.98m with GCP. Further by considering a random sensor motion due to active cooler, high gain anttena drive, solar paddle drive, etc. MTF degradation was assessed. It is found that DEM accuracy degradation can be supressed under 4.4(%) if the sigma value of the random motion is under 1/5(pixel), 0.88 arcsec.

Further investigation is highly required for assessment of experimental accuracy of DEM estimation with simulation data to be derived from models and existing stereoscopic view of imageries.

References

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Table 7 A relationship between the averaged cross correlation between 9 tip images for stereo matching and MTF degradation

MTF degradation(%)	0	6.25	9.375	12.5
Cross Correlation	0.842	0.809	0.804	0.743

Table 8 A relationship between cross correlation between 32 x 32 pixels tip images of stereo pair and matching error

Cross Correlation	0.842	0.809	0.804	0.743
Matching Error(pixel)	0.85	1.21	1.29	1.88

Table 9 A relationship between amplitude of attitude jitter and DEM estimation accuracy.

Sigma value of random motion(arcsec)	0.0	0.44	0.88	1.32
Stereo Matching Error(pixel)	0.0	0.09	0.56	2.4
DEM accuracy(m)	27.98	28.01	29.21	45.59