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DUBAISAT-1 CAMERA: PRE-LAUNCH PERFORMANCE CHARACTERIZATION

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ABSTRACT

With the completion of the flight model development, DubaiSAT-1 camera, capable of the earth observation at 2.5 m resolution and 20 km swath width at the altitude of 685 km, has been characterized for its pre-launch performance. The topics discussed in this paper include the measurement of system modulation transfer function (MTF) and pixel line-of-sight (LOS); characterization of focal plane assembly (FPA) and signal processing electronics; radiometric and spectral calibration; end-to-end imaging. The MTF was obtained with knife-edge scanning method, which is also used to align the FPA. For band-to-band registration, relative pixel LOS was measured using theodolite and the effective focal length of the telescope was derived from the measurement. For the FPA and signal processing module, dark reference, pixel-to-pixel response variation and response linearity have been quantified. This paper describes the key features of the DubaiSat-1 camera, focusing on the pre-launch performance and delivers an update for the status of the mission as of October 2009.

1. INTRODUCTION

1.1. Subheading

1.1.1. Sub-Subheading

Satrec initiative has been developing and providing successfully the series of earth-observation cameras for small and micro-satellites, including:

- EOS-A class
  - IRIS, to be onboard X-SAT (Singapore)
  - OIS, to be installed on RASAT (Turkey)
- EOS-C class
  - MAC, installed on RazakSAT (formerly MACSAT for ATSB, Malaysia)
- EOS-H class

- TIS, the demonstration model of hyperspectral imaging based on Three-Mirror Anastigmatic Optical System

Since the successful development of MAC camera (2002 ~ 2005), the effort has been exercised to make the design of camera system optimized for enhanced performance so that it can be a reference design classified as 'EOS-C'. For the mission of DubaiSAT-1, international collaborative mission, EOS-C design has been optimized further and named as DMAC.

The development of DMAC began in 2006 and it took 2 and half years to reach the phase of flight model. DubaiSAT-1 was launched on July 29^{th}, 2009 with DMAC as the main payload by DNEPR at Baikonur, Kazakhstan. [1], [2]

In this paper, on-ground effort to characterize the performance of DMAC and the test result will be summarized.

2. DESIGN AND FEATURES

DMAC uses a modified Ritchey-Chrétien (RC) telescope as shown in Figure 1, which has 300 mm of entrance pupil diameter. The telescope uses two aspheric mirrors of Zerodur, ultra-low expansion glass and two correction lenses. The mirrors are light-weighted in order to reduce the mass to enhance the dynamic characteristics. [3]

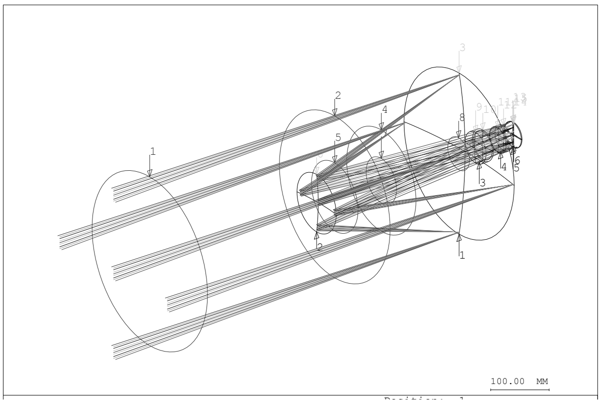

Figure 1. Optical Layout of DMAC Camera System

It employs Focal Plane Assembly (FPA) using five linear CCDs on a single plane without any beam splitters. The five channels include one panchromatic band with 2.5m, and multispectral band with 5m of Ground Sampling Distance (GSD) at a nominal altitude of 680 km.

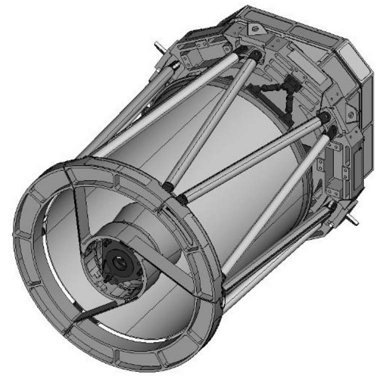

Figure 2. Assembly Model of DMAC Camera

The electronics subsystem includes a signal processing unit and a payload management system for power supply, 64-Gbit mass storage, and thermal unit for active thermal control. DMAC weighs less than 38.7 kg and consumes 53.2 W at peak with the heaters on. The features are summarized in the following table:

	Specification	Remark
Spectral Band	420 ~ 890	1 PAN, 4 MS
GSD	2.5 m / 5 m	PAN / MS
Swath width	> 20 km	@ 680 km
MTF	> 8.0 / > 12.0	@ Pixel Nyquist
Power Cons.	53.2 W	Peak Power
Mass	38.7 kg	Flight Configuration

Table 1. Key Parameters of DMAC

3. PERFORMANCE CHARACTERIZATION

For pre-launch performance characterization, DMAC camera is tested in geometrical, spectral, and radiometric performance. The characterization of geometrical performance includes the measurement of Modulation Transfer Function (MTF), Field-of-View (FOV), Instantaneous Field-of-View (IFOV), and relative Line-of-Sight for band-to-band registration.

The spectral response is measured at the system level and the data is normalized to the peak value within each band. The measurement of radiometric response is performed at the detector level and the camera is queued on for the measurement at the system level to the input of Albedo-1 level.

3.1. Modulation Transfer Function (MTF)

The modulation transfer function of DMAC camera is measured using Knife-edge scanning method. [4]

The measurement scheme is described in the following figure. A 1000 Watt tungsten-halogen lamp is used as the light source to project the image of the knife-edge through the collimator on the CCD at the focal plane. The knife-edge is scanned by three-axis actuators.

The edge-spread function, which is the projection of the knife-edge, is differentiated to the line-spread function and fourier-transformed to obtain the MTF profile. Table 2 summarizes the MTF measurement.

BAND	(-1,Y)	(0,Y)	(+1,Y)
PAN	> 10	> 11	> 9
RED	> 23	> 24	> 19
GREEN	> 29	> 29	> 29
BLUE	> 29	> 29	> 24
NIR	> 14	> 15	> 15

Table 2. MTF Values of DMAC Camera

3.2. Optical Parameters

After the FPA alignment, the optical parameters have been measured, using the collimator with pinhole at its focus, the flat mirror, and the autocollimator. The optical parameters include effective focal length (EFL), field of view (FOV), instantaneous field of view (IFOV), and relative line of sight (LOS) for band-to-band registration.

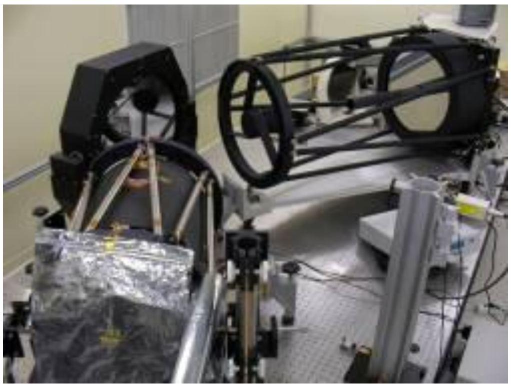

Figure 3. Measurement Scheme of LOS

To measure the geometric parameters, the pinhole of 25 μm diameter is placed at the focus of 400 mm diameter collimator. The pinhole size is approximately equivalent to a 2.5 m sized-object at 680 km altitude. The image of the pinhole is reflected and projected into the camera by the flat mirror that is placed in front of DMAC camera. Then the pinhole image is captured by the CCD as a cross section of point-spread-function

Table 3 summarizes the measurement result of the optical parameters of IFOV, FOV, and EFL.

BAND	IFOV	FOV	EFL
PAN	< 3.6	> 1.6	> 1407
RED	< 7.2	> 1.6	> 1405
GREEN	< 7.2	> 1.6	> 1407
BLUE	> 7.2	> 1.6	> 1394
NIR	> 7.2	> 1.6	> 1398

Table 3. Optical Parameters of IFOV, FOV, and EFL

The relative line-of-sight (LOS) is measured at each 500 pixels. The measurement data is processed to produce the distortion fitting equation to predict the angular position of each pixel. Figure 4 shows the example of measurement and fitting equation for panchromatic band

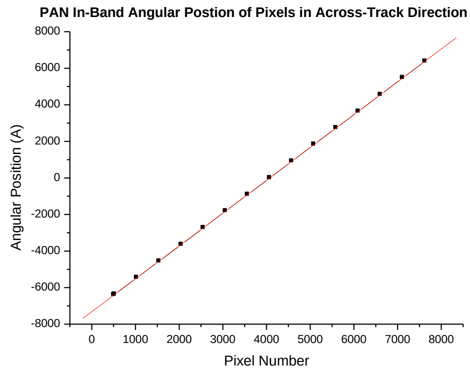

Figure 4. Measurement of Horizontal Angular Position

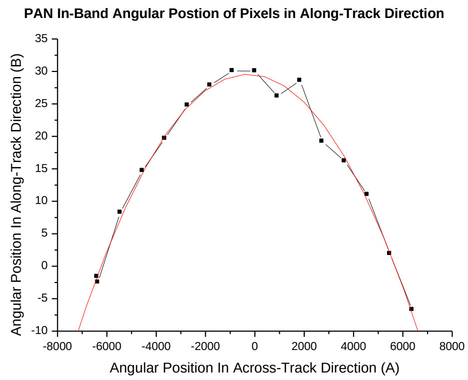

Figure 5. Measurement of Vertical Angular Position

3.3. Spectral Response

The measurement of the spectral response uses the same configuration of the measurement of the optical parameters with the output of monochromator at the focus of the collimator. Small integrating sphere has been used to provide uniform illumination.

Figure 6 represents the measurement result of the spectral response of DMAC at the system level.

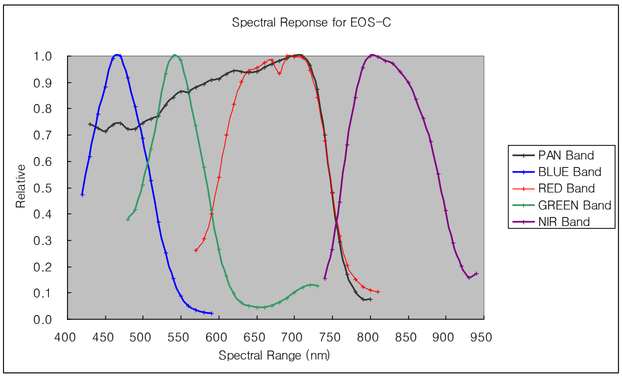

Figure 6. Spectral Response of DMAC Camera

3.4. Spectral Response

The radiometric response of DMAC detector has been measured, using small uniform light source, to investigate and estimate Response Linearity, Gain Linearity, and Signal-to-Noise Ratio (SNR).

Figure 7 and 8 show the measurement of the response linearity and the gain linearity for the panchromatic band of DMAC.

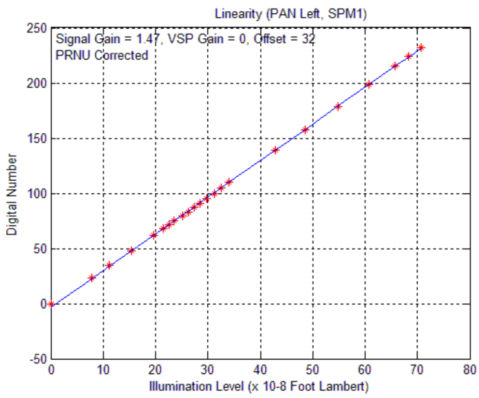

Figure 7. Measurement of Response Linearity for PAN Band

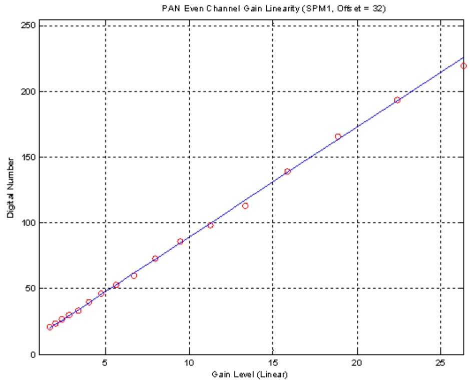

Figure 8. Measurement of Gain Linearity for PAN Band

For the measurement of SNR, illumination levels were adjusted to give pixel responses as follows according to the conditions specified for SNR.

- 1976 US Standard atmosphere, rural extinction
- Visibility = 23 km
- Target reflectance = 0.25 (Lambertian), Solar zenith = 30

Image data of 256 pixels × 450 lines with flat response is used and corrected for the pixel-to-pixel dark reference variation and PRNU. For the calculation of SNR, pixel-to-pixel means and standard deviations were calculated and total mean and standard deviation were calculated by averaging these values over the whole 256 pixels.

Table 4 shows the estimated vales of SNR based on the response measurement.

BAND	SNR
PAN	> 107.3
RED	> 153.1
GREEN	> 122.5
BLUE	> 123.6
NIR	> 115.8

Table 4. SNR Values for Each Band

4. CONCLUSION

DubaiSAT-1 has been launched successfully on July 29^{th}, 2009. Even though it is in its early operation, DubaiSAT-1, along with DMAC camera is demonstrating its capability in the high-resolution imaging area that used to be the domain of conventional large satellites.

DMAC, as the main payload of DubaiSAT-1, shows its high performance as tested on the ground and generates clear images that can be predicted from the parameters summarized in this paper.

The details of image quality will be estimated and investigated through the profiled images [5] through the successful operation of DubaiSAT-1 and the results will be presented in the following conferences.

REFERENCES

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