Performance and functionality of SRI detector array and focal plane electronics

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ABSTRACT The SRI(Super Resolution Imager) with 800mm aperture primary mirror is the ground development model of the high resolution satellite camera. The SRI focal plane electronics including detector array generates the data for high-resolution images by converting incoming light into digital stream of pixel data. Since the focal plane including a detector is the basic building block of the camera system, the main system performances is directly determined by its performance. This paper measures the SRI focal plane electronics' performance such as the dark signal, the dark signal noise, the linearity, the PRNU(Photo Response Non-Uniformity), the SNR(Signal to Noise Ratio) and the sensor saturation capability. In addition, this paper verifies the various functionalities of the SRI focal plane electronics. The electrical test equipment with the specialized software and the optical test equipments such as the integrating sphere, the rotation stage and the target are implemented and used to verify these functionalities and performances.

KEY WORDS: Camera Performance, CCD, SRI, Focal Plane Electronics

1. SRI CAMERA AND INTRODUCTION

The SRI(Super Resolution Imager) is the ground development model for the high resolution satellite camera which has 800mm aperture primary mirror. The SRI camera consists of the panchromatic and the 3 colour multi-spectral cameras. Both cameras use the common telescope, but they have different electronics including the detector. Both panchromatic and multi-spectral cameras use the line CCD as a detector. Two-dimensional image can be acquired using the continuous line images. The SRI focal plane electronics including detector generates the data for high-resolution images by converting incoming light into pixel data. Since the focal plane electronics is the basic block of the camera system, the main system performances is directly determined by its performance.

This paper shows the SRI focal plane array performance such as the dark signal, the dark signal noise, the linearity, the PRNU(Photo Response Non-Uniformity), the SNR(Signal to Noise Ratio) and the sensor saturation capability. In addition, this paper verifies the various functionalities of the focal plane electronics. Another purpose of these tests is the rehearsal for next satellite camera such as the KOMPSAT-3 payload. Thus, the test algorithm and method can be also verified, corrected and modified through these tests in advance before applying to satellite camera.

2. FUNCTIONALITY TEST OF SRI CAMERA ELECTRONICS

The functionality test is performed before the camera performance test. The functionality test includes the image chain test to see the camera operation, the line-continuity and the spectral response. Especially, the SRI camera can adjust the gain and the offset of the video processor to increase the system SNR. This function can be verified by this functionality test as well.

2.1 Image Chain Test

The camera operation, the line-continuity and the spectral response can be verified through the image chain test. The rotational stage, the target, the light source and test-optics are needed for this test. The electrical test equipment, of course, is needed with the specialized software and the frame grabber to get image data. Figure 1 shows the test setup for image chain test.

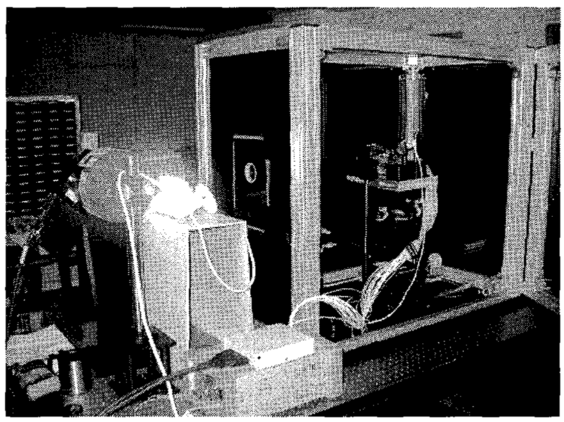

Figure 1. Test setup for image chain test

For the image chain test, the target rotation speed and the camera's line-rate should be synchronized. The line rates of panchromatic camera and multi-spectral camera are 2870 lines/sec and 790 lines/sec respectively. The target speed shall be controlled since the cameras' line-rates are fixed. The motion controller can control the speed of rotation stage.

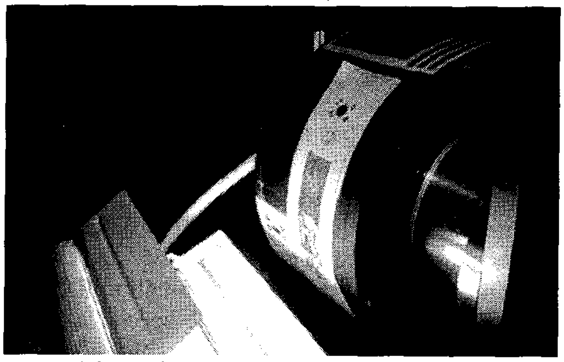

Figure 2. Target and Rotational Stage

Figure 2 shows the target picture and the rotation stage. The reflected target scene enters into test optics. The test optics focuses the energy on the detector. The focal plane electronics including detector array generates the data for high-resolution images by converting incoming light into digital stream of pixel data.

Figure 3 and Figure 4 show the acquired image by the panchromatic camera and the multi-spectral camera respectively. The image quality is not interested since the purpose of this test is to verify camera operation and the test optics is used. The line-continuity and the spectral response can be verified by this image chain test as well.

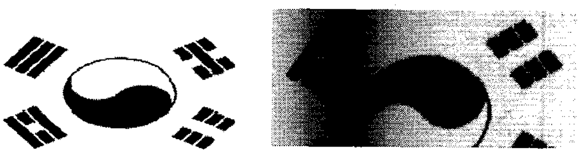

Figure 3. Target and panchromatic image

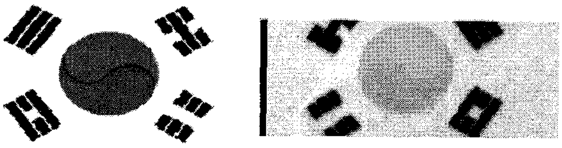

Figure 4. Target and multi-spectral image

2.2 VP Gain and Offset Adjustment

The SRI camera has functionality of the gain and the offset adjustment of the video processor. The quantization noise can be reduced by this gain and the offset adjustment. That is to say, the SNR(Signal to Noise Ratio) can be increased by their adjustment.

Table 2 and Table 3 show the gain and the offset adjustment test results respectively. These tests are performed in the panchromatic camera and the blue colour channel of the multi-spectral camera.

Table 1. VP Gain Test Result

	×1(No Gain) (DN)	×2 (DN)	×3 (DN)	×4 (DN)	×6 (DN)
PAN	581	1129	1677	2172	3232
MS1 Blue	1735	3449	-	-	-

Table 2. VP Offset Test Result

	0mV(No Offset) (DN)	73mV (DN)	-36mV (DN)	36mV (DN)	73mV (DN)
PAN	784	687	741	-	-
MS1 Blue	1733	1635	1684	1781	1831

3. PERFORMANCE TEST OF SRI CAMERA ELECTRONICS

Since the focal plane electronics is the basic building block of the camera system, the main system performances is directly determined by this characteristics. Another purpose of these tests is verification of test algorithm and method as well as SRI camera verification. The some test algorithm is corrected and modified during this verification. Figure 5 shows the general test setup to test the SRI camera performance. The integrating sphere is used to provide the uniform radiance into the test-setup. Also, the electrical test equipment with the specialized software is used to get image data and analyze data. The dark signal, the dark signal noise, the linearity, the PRNU(Photo Response Non-Uniformity), the SNR and the sensor saturation capability are measured in these performance tests.

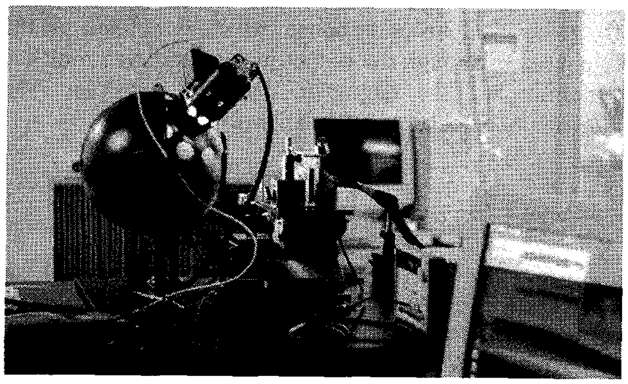

Figure 5. Test setup for camera performance test

3.1 Dark signal and Dark signal noise

The CCD output is proportional to the exposure. It means that the output can be increased by increasing the integration time. And long integration time is generally used for low-light-level operation. However, this approach is ultimately limited by dark current leakage that is integrated along with the photocurrent. Dark signal is the unwanted DC signal in the darkness condition. It is mainly derived from dark current.

Dark noise is defined as the standard deviation of dark signal. Dark noise is usually derived from dark current shot noise, but also can be derived from the reset noise, amplifier noise, and quantization noise and so on. Table 3 shows the dark signal and dark noise test results of SRI camera. We can find the dark signal is negative value from test result; this is due to the video processor sampling characteristics. However, this characteristic can overcome by the video processor offset adjustment in middle of calibration process.

Table 3. Dark signal and dark noise test result

	Dark Signal		Dark Signal Noise	
	Expected (DN)	Result (DN)	Expected (DN)	Result (DN)
PAN	10.00	-19.99	1.36	1.41
Blue	10.00	-8.17	3.00	1.39
Green	10.00	-11.00	3.00	1.30
Red	10.00	-1.43	3.00	1.38

3.2 Linearity

The camera linearity is determined from the linearity of the photon collection process, the efficiency of charge transportation to the output amplifier, and the output amplifier linearity. Non-linearity at signal levels beyond the saturation level is expected and can often vary significantly from pixel to pixel. The non-linearity of an image sensor is typically defined as the percent deviation from the ideal linear response, which is defined by the line passing through the output in the saturation radiance condition and the output in darkness condition. The equation to calculate non-linearity is as follows;

$$Non-linearity = \left(\frac{Y}{aX+b} - 1 \right) \times 100\% \qquad (1)$$

Where Y is measurement value and $aX+b$ is the ideal value which is calculated by the line passing through outputs in darkness condition and saturation condition.

Table 4 show the non-linearity test result of SRI camera.

Table 4. Non-linearity test result

	Expected (%)	10% Rad	30% Rad	50% Rad	70% Rad	90% Rad
PAN	5%	5.9%	2.4%	1.3%	0.5%	-0.2%
Blue	5%	2.0%	3.8%	2.0%	1.6%	0.1%
Green	5%	1.8%	3.5%	3.5%	1.8%	-0.3%
Red	5%	3.7%	5.0%	3.2%	1.8%	-0.4%

3.3 PRNU

The ideal detector has to give uniform signal level for the uniform radiance. However, practically, not all pixels generate uniform value for the uniform radiance. This non-uniformity comes from the different optical characteristics, the read-out characteristics, the pixel own characteristics and so on. This non-uniformity can be measured and corrected through the special calibration. The detailed non-uniformity correction algorithm can be referenced to ref [2][3].

The detector of panchromatic camera has two output ports for the odd and the even pixels. Figure 6 and Figure 7 show the PRNU test results of the odd and even pixels in the panchromatic camera. The test results show the PRNU can be increased so much by non-uniformity correction method.

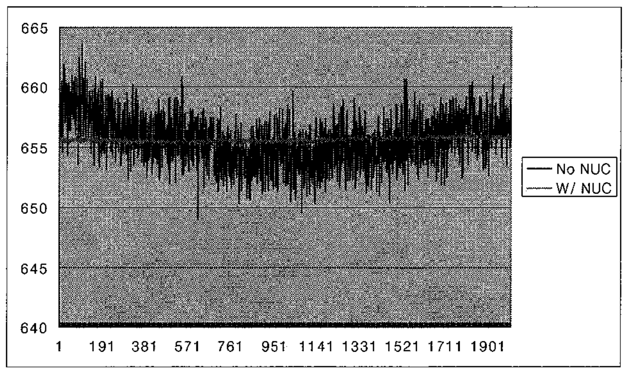

Figure 6. PRNU test for panchromatic camera(odd pixel)

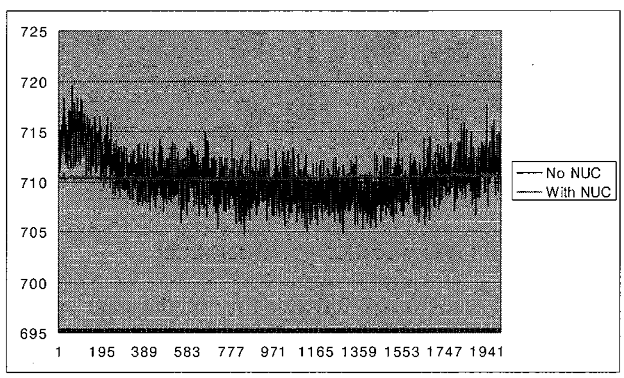

Figure 7. PRNU test for panchromatic camera(even pixel)

Table 5 shows the PRNU test results of the SRI camera. The PRNU result can be calculated using equation (2).

$$PRNU = \frac{(P_{max} - P_{min})}{P_{average}} \qquad (2)$$

Where subscript *min, max, mean* represent the minimum, maximum and average output value respectively.

Table 5. PRNU test result

Rad	Odd		Even	
	No NUC	W/ NUC	No NUC	W/ NUC
0%	1.27%	2.02%	0.70%	0.67%
10%	1.87%	0.37%	1.35%	0.26%
30%	2.17%	0.17%	1.94%	0.18%
50%	2.21%	0.17%	2.10%	0.16%
70%	2.25%	0.13%	2.10%	0.13%
90%	2.18%	0.13%	2.12%	0.11%
100%	2.18%	0.11%	2.16%	0.11%

3.4 SNR

The SNR depends on the various characteristics of the system such as the F# the optical transmittance, the characteristics of the detector, the quantization noise of electronics and the radiance from ground, and so on.

The SNR for *i*th pixel can be calculated using equation (3).

$$SNR_i = \frac{MEAN_i}{SD_i} \tag{3}$$

Where $MEAN_i$ is pixel average value in *i*th pixel for all lines and SD_i is its standard deviation value. Finally system SNR can be described as minimum value of SNR_i.

Table 6 shows the SNR test results for the nominal radiance, which is assumed as 50% of saturation radiance.

Table 6. SNR test result for nominal radiance

	SNR		Average(DN)
	Expected	Result	
PAN	100	401.02	769.8
Blue	100	388.60	1544.5
Green	100	402.70	1590.8
Red	100	364.60	1386.2

Table 7 shows the SNR test result for saturation radiance. Generally, we can expect the SNR will be higher when signal level is getting higher.

Table 7. SNR test result for saturation radiance

	SNR	Average(DN)
PAN	401.02	769.8
Blue	388.60	1544.5
Green	402.70	1590.8
Red	364.60	1386.2

4. CONCLUSION

This paper verifies the various functions in the SRI focal plane array and measures its performance such as the dark signal, the dark signal noise, the linearity, the PRNU, the SNR and the sensor saturation capability. In the functionality tests, the paper verifies the camera operation, the line-continuity, the spectral response and gain and offset adjustment. And its performance is also verified. Even though most of performance is better than expected, the dark signal is not satisfied due to the video processor sampling characteristics. However, this characteristic can be overcome by the video processor offset adjustment during the calibration process. This paper shows that the PRNU performance can be increased so much by non-uniformity correction as well.

These tests are performed for the purpose of the exercise for next satellite camera such as KOMPSAT-3 payload as well as the SRI camera verification. The test algorithm and method was corrected and modified through these tests. The updated algorithm shall be used to next satellite camera verification.

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