GROUND CALIBRATION OF COMPACT INFRARED CAMERA (CIRC) FOR EARTH OBSERVATION

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ABSTRACT

The compact infrared camera (CIRC) is an uncooled infrared array detector (microbolometer) with the primary goal of detecting wildfires, which are major and chronic disasters affecting numerous countries in the Asia-Pacific region. Eliminating the cooling system reduces the size, cost, and electrical power of the sensor. Two CIRCs have been developed, which will be launched in JFY 2013 and 2014 onboard the Advanced Land Observing Satellite-2 (ALOS-2) and CALorimetric Electron Telescope (CALET). We have finished the ground calibration test of the CIRC Proto Flight Model (PFM) onboard ALOS-2 and CALET. The imaging quality and radiometric quality have been confirmed. We obtained the data needed for image correction and constructed a data correction algorithm. An airborne experiment with a ground test model was also carried out to verify the data correction algorithm.
In this paper, we provide an overview of the CIRC and the ground calibration results.

Index Terms**—** CIRC, ALOS-2, CALET, microbolometer, wildfire

1. INTRODUCTION

Microbolometers are widely used in commercial and military applications. Their advantage is that they do not require a cooling system, such as a mechanical cooler. Sensors without a cooling system for a detector are small in size, lightweight, and consume less power. Although the sensitivity of a microbolometer is lower than that of an HgCdTe-based photonic infrared detectors, its advantage of not requiring a cooling mechanism makes it suitable for small satellites or sensor systems whose resources are limited.

We have developed the Compact Infrared Camera (CIRC) [1,2,3] as a technology demonstration payload for thermal infrared imaging from space using a microbolometer. The main mission of the CIRC is to detect wildfires, which are a major and chronic disaster that affects many countries, especially those in the Asia-Pacific region; therefore, their early detection is important. An effective means of early detection is to increase their observation frequency. Our aim is to realize frequent observations by loading CIRCs in as many satellites as possible by taking advantage of there small size, low weight, and low power consumption. Other mission targets of the CIRC are volcanoes or heat island phenomena in a city. The CIRC will be carried as a technology demonstration payload of the Advanced Land Observing Satellite-2 (ALOS-2) [4], and CALorimetric Electron Telescope (CALET) [5] , which will be attached to the Japanese Experiment Module (JEM-EF) at the International Space Station (ISS).

In this paper, we present the verification results of the athermal characteristics and the calibration of the shutter-less system with the CIRC Proto Flight Model (PFM). The specifications of the CIRC is described in section 2. In section 3, the ground calibration results of the CIRC PFM onboard ALOS-2 and CALET is presented. The airborne observation with the CIRC ground test model is shown in section 4. In section 5, the conclusion is provided.

2. SPECIFICATIONS OF CIRC

The baseline specifications of the CIRC are listed in Table 1. We set the baseline specifications to meet the requirements for wildfire detection. The detector has a large format (640 × 480 pixels) to capture a wide field of view. The spatial resolution is an important factor for wildfire detection; it is 200 m from an altitude of 600 km (ALOS-2) and 130 m from an altitude of 400 km (CALET). Eliminating the cooling system reduces the size (110 mm × 180 mm × 230 mm) and the power consumption (<20 W) of the CIRC.

The CIRC PFM onboard ALOS-2 is shown in Figure 1. The CIRC is based on a commercial infrared camera. We modified the hardware design so that it can be applicable for a space application. CIRCs have key technologies, i.e., microbolometer, athermal optics, and shutter-less system, for achieving small size, low weight, and low power consumption.

Table 1. Specifications of CIRC

Parameter	Specifications
Size	110 mm × 180 mm × 230 mm
Mass	3 kg
Detector	Uncooled infrared detector
Wavelength	8–12 μm
Number of pixels	640 × 480
Spatial resolution	<200 m @600 km (ALOS-2) <130 m @400 km (CALET)
Field of view	12° × 9°
Exposure	33 ms
Dynamic range	180−400 K
NEDT	0.2 K @ 300 K
FPN	0.3 K @ 300 K
Temperature accuracy	4 K (goal : 2K @ 300 K)

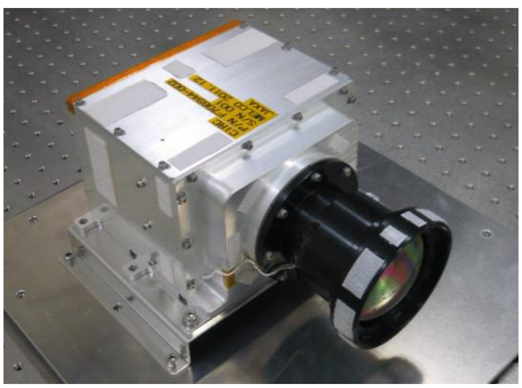

Figure 1. CIRC PFM onboard ALOS-2

3. GROUND CALIBRATION OF CIRC PFM ONBOARD ALOS-2 AND CALET

We carried out a ground calibration test of the CIRC PFM onboard ALOS-2 and CALET. The aims of this calibration were (i) to construct a data correction algorithm and (ii) to confirm the imaging quality and the radiometric quality.

3.1. Constructing data correction algorithm

The stray light (i.e., the overall radiation except that from the target) had to be removed, because a dark image cannot be taken as a result of the shutter-less system. We constructed a calibration data table (stray light correction coefficient and gain coefficient) and algorithm using blackbody images at various temperatures (–15°C to 50°C) obtained with CIRC PFM at various environmental temperatures (–10°C to 50°C). A flow chart of the data correction is shown in Figure 2.

① Bad pixel correction

A bad pixel is a pixel that has a brightness lower or higher than the surrounding pixels. We correct the brightness of a bad pixel by substituting the mean brightness of the normal surrounding pixels.

② Dummy correction

The electrical background is subtracted using dummy pixels, which have no sensitivity to incident infrared rays.

③ Stray light correction

Stray light correction is performed for each pixel by using the stray light correction coefficient.

④ Gain correction

Sensitivity correction is performed for each pixel by using the gain coefficient.

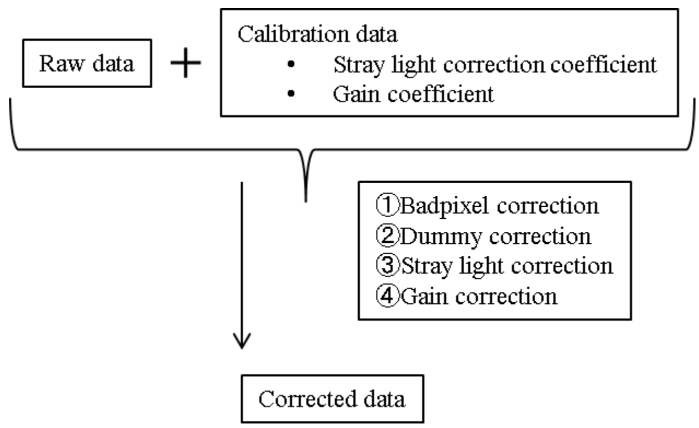

Figure 2. Flow chart of data correction

The experimental setup for the construction of the calibration data table is shown in Figure 3. The CIRC was installed in a vacuum chamber and enclosed a shroud to control its ambient temperature with a heater and cooler. The blackbody was set up in the front of the lens.

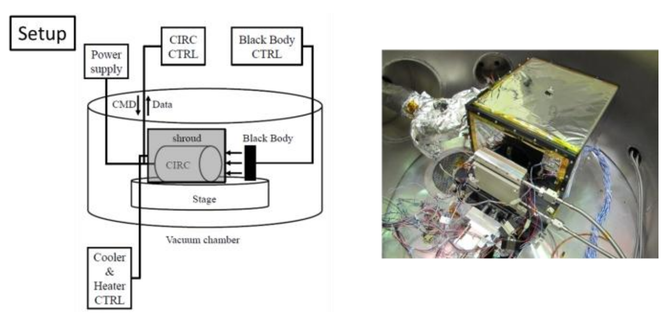

Figure.3 Experimental setup for the construction of the calibration data table

3.2. Confirming performance

We confirmed the imaging quality and radiometric quality of the image after the data correction discussed in section 3.1.

3.2.1. imaging quality

The modulation transfer function (MTF) was measured in order to evaluate the imaging quality of CIRC at various operating temperatures (–10°C to 50°C). The experimental setup for MTF measurement is shown in Figure 4. The collimated infrared rays passed through a germanium window on the side of the vacuum chamber. The CIRC was able to capture images of the four-bar target. Figure 5 shows the measurement points of the four-bar target for MTF, at the center, ±5° in the cross-track (CT) direction, and ±3.5° in the along-track (AT) direction.

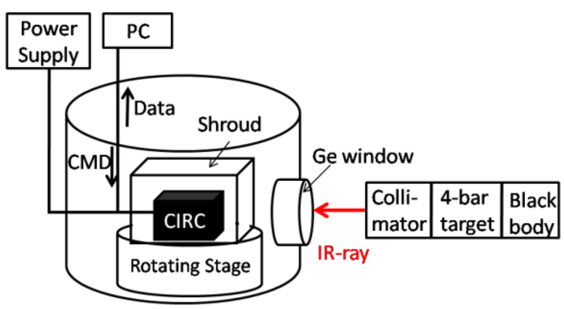

Figure 4 Experimental setup of MTF measurement

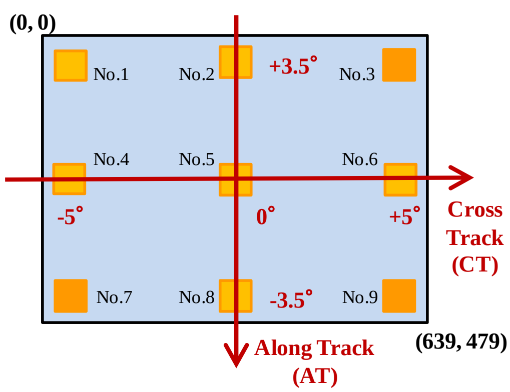

Figure 5. Measurement points of MTF on image acquired by CIRC

Figure 6 and Figure 7 show the MTF results of CIRC PFM. The MTF in the CT direction (Figure 6) are constant, which is regardless of the environmental temperatures. In contrast, MTF in the AT direction (Figure 7) are slightly lower in low-temperature environments. Both ALOS-2/CIRC and CALET/CIRC show the similar trend on the environmental temperature dependence. MTF was found to be effective at capturing clear images across the entire range of operating temperatures for both CIRC PFM. We confirmed the athermal optical performance of the CIRC.

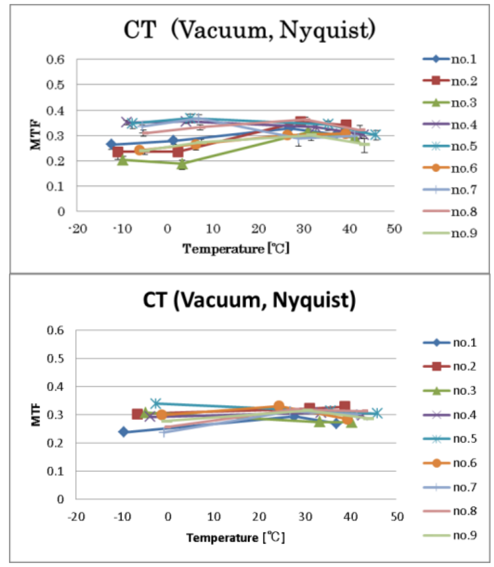

Figure 6. Measurement results of MTF in the CT direction of ALOS-2(top) and CALET(bottom)

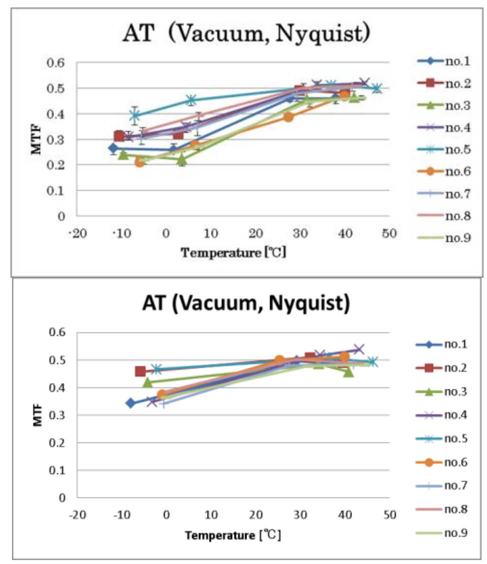

Figure 7. Measurement results of MTF in the AT direction of ALOS-2(top) and CALET(bottom)

3.2.2.radiometric quality

The noise equivalent differential temperature (NEdT) and flat pattern noise (FPN) were measured, shown in Table 2. These are the results expected from the design of the CIRC, and satisfied its specifications.

Table 2. Results of NEdT and FPN

	NEdT [K]	FPN [K]
ALOS-2/CIRC	0.19	0.27
CALET/CIRC	0.18	0.21

Figure 8 shows a comparison between a raw image and corrected image obtained by PFM for ALOS-2. Performing data correction makes it possible to capture smooth images without using a shutter system. The temperature accuracy is less than 2 K in a comparison of the brightness temperature of the corrected image and the actual blackbody temperature. This is within the specification for the temperature correction accuracy. In the case of CIRC PFM for CALET, the temperature accuracy is 0.5 ~ 2.8 K, which is also within the specification.

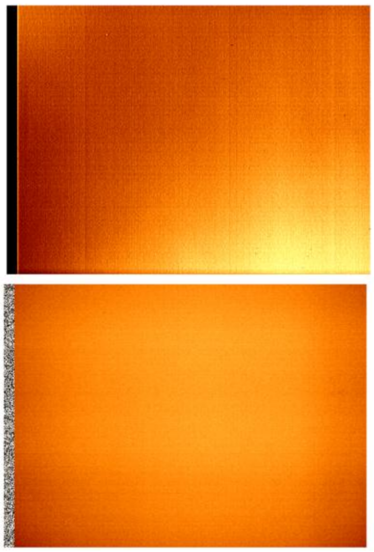

Figure 8. Blackbody image obtained by CIRC onboard ALOS-2: (top) raw image and (bottom) data corrected

4. AIRBORNE OBSERVATION WITH THE CIRC GROUND TEST MODEL

We carried out airborne observations using the ground test model (GTM) of CIRC, which has optical and radiometric performances equivalent to the corresponding PFM. The flight altitude ranged from 300 m to 750 m. The ground sample distance (GSD) at these altitudes ranged from about 10 cm to 25 cm.

Figure 9 shows a comparison between the raw image and corrected image captured by an airborne observation from an altitude of 750 m. We confirmed that the data were corrected in the shutter-less system and that the actual images could be corrected by using the ground calibration data.

The temperature correction accuracy was checked using the image of the pond area shown in Figure 9 (bottom) with the white box. The temperature of the pond measured using a water temperature gauge was about 11°C. The corrected data obtained by CIRC GTM revealed a temperature of 11.5°C, with the assumption that the emissivity of the water was 0.98. The temperature correction accuracy was about 0.5°C, which is within the specification of 2 K with the environmental temperature of ~ 300K.

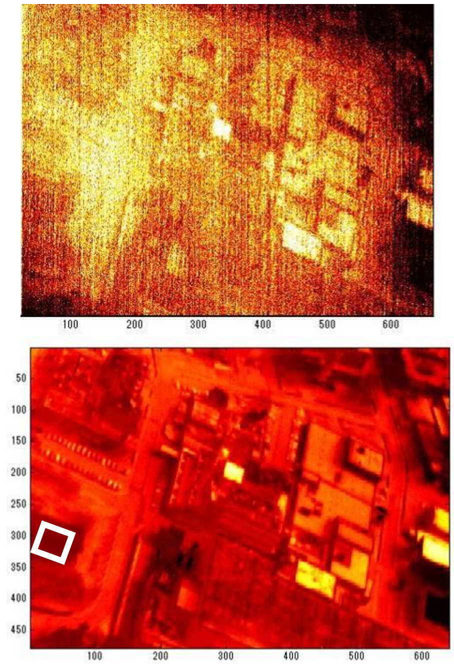

Figure 9. Image captured by airborne observation: (top) raw image and (bottom) data corrected image, where white box shows pond area

5. CONCLUSION

CIRC is an instrument equipped with an uncooled infrared array detector, which will be launched in JFY 2013 onboard ALOS-2, and in JFY 2014 onboard JEM/CALET. We have finished the ground calibration test of the CIRC onboard ALOS-2 and CALET, and have confirmed that its performance is as expected and sufficient for launch. We have also performed data correction using a shutter-less system by analyzing the data obtained through airborne observations. The temperature correction accuracy was about 0.5°C, which is within the specification of 2 K.

6. REFERENCES

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