地上検証用小型赤外カメラ(CIRC)を用いた校正試験結果報告

中村 良子† 片山 晴善† 内藤 聖貴† 原田 昌朋†
加藤 恵理† 菅沼 正洋† 中右 浩二† 佐藤 亮太†
†宇宙航空研究開発機構 〒305-8505 茨城県つくば市千現 2-1-1 筑波宇宙センター
E-mail: nakamura.ryoko@jaxa.jp

あらまし 小型赤外カメラ(CIRC)は非冷却赤外検出器(マイクロボロメータ)を用いた技術実証センサである。非冷却式を採用することで小型軽量・低価格・低消費電力を実現している。CIRC の主要ミッションは、森林火災検知である。森林火災はアジア太平洋諸国で頻発する主要な災害であり、衛星による初期検知が望まれている。我々は CIRC の打ち上げ前地上校正試験手順を確立するため、地上検証用モデルを製作した。これまでに検証用モデルを用いて結像性能を測り、アサーマル性を確認している。本公演では CIRC の開発状況とともに、詳細な校正試験結果について報告する。

キーワード リモートセンシング、熱赤外イメージャー、非冷却検出器、森林火災

Calibration Results of the Compact Infrared Camera (CIRC) Ground Test Model

Ryoko NAKAMURA† Haruyoshi KATAYAMA† Masataka NAITOH† Masatomo HARADA†
Eri KATO† Masahiro SUGANUMA† Koji NAKAU† and Ryota SATO†

†[1]Japan Aerospace Exploration Agency, 2-1-1 Sengen, Tsukuba, Ibaraki, 305-8505, Japan
E-mail: nakamura.ryoko@jaxa.jp

Abstract The compact infrared camera (CIRC) is a technology demonstration instrument equipped with an uncooled infrared array detector (microbolometer). Eliminating the cooling system reduces the size, cost, and electrical power of the sensor. The main mission of the CIRC is the technology demonstration of the wildfire detection. Wildfires are major and chronic disasters affecting many countries in the Asia-Pacific region. The CIRC ground test model was made to establish a prelaunch calibration method. We have measured imaging quality in a vacuum environment. We also confirmed the athermal characteristics of CIRC. In this paper, we show the current status of the CIRC development, and the calibration results of the CIRC ground test model.

Keyword remote sensing, thermal infrared imaging, uncooled infrared detector, wildfire

1. Introductions

Microbolometers are widely used in commercial and military applications, such as night vision. Microbolometers have the advantage of not requiring a cooling mechanism, such as a mechanical cooler. Eliminating the detector cooling system reduces the size, cost, and electrical power of the sensor. Although the sensitivity of microbolometers is lower than that of HgCdTe-based photonic infrared detectors, the advantage of not requiring a cooling mechanism is suitable for small satellites or resource-limited sensor systems.

JAXA has researched the application of microbolometers for Earth observation [1]. In order to demonstrate the potential of microbolometers to thermal infrared imaging from space, the Compact Infrared Camera (CIRC) is developed as a technology demonstration payload of the Advanced Land Observing Satellite-2 (ALOS-2), and CALorimetric Electron Telescope (CALET) which will be attached to the Japanese Experiment Module (JEM-EF) of the International Space Station (ISS).

In this paper, we show the current development status of CIRC. In §2, we briefly describe ALOS-2 and CALET.

The mission and the details of the CIRC are shown in §3 and §4, respectively. In §5, we show the feasibility study of wildfire detection with CIRC spatial resolution. In §6, initial calibration results of the CIRC ground test model that has been studied with laboratory experiments to establish a prelaunch calibration method is shown. Discussion and Summary are shown in §7.

2. ALOS-2 and CALET

2.1 ALOS-2

ALOS-2 [2] is a follow-on mission from ALOS, which has been contributing to cartography, regional observation, disaster monitoring, and resource surveys, since its launch in 2006. JAXA is conducting research and development activities to improve wide and high-resolution observation technologies developed for ALOS in order to further fulfill social needs. These social needs include: 1) Disaster monitoring of damage areas, both in considerable detail, and when these areas may be large 2) Continuous updating of data archives related to national land and infrastructure information 3) Effective monitoring of cultivated areas 4) Global monitoring of tropical rain forests to identify carbon sinks. Alos-2 will be launched in 2013.

ALOS-2 succeeds the L-band Synthetic Aperture Radar (SAR) observation of ALOS PALSAR with enhanced capabilities. Table 1 shows the baseline specifications of ALOS-2. The mounting location of CIRC is shown in figure 1. Basically, CIRC will take images of the target area during the SAR pointing to the right at its off-nadir angle of 30 degrees.

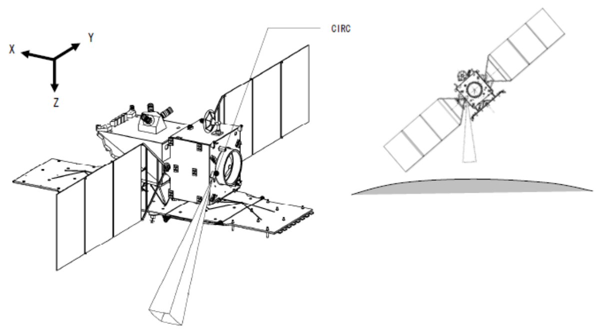

Fig. 1 Schematic view of ALOS-2 and the mounting location of CIRC

Table 1. Baseline specifications of ALOS-2

Parameter	Specification
Size	9.9m x 16.5m x 3.4m
Mass	< 2000 kg
Bus power	> 5200W
Communication	< 800Mbps
Orbit	628 km

2.2 CALET

CALET [3] is an international program for the ISS that will search for signatures of Dark Mater and provide the highest energy direct measurements of the cosmic ray electron spectrum in order to observe discrete sources of high energy particle acceleration in our local region of the Galaxy. CALET will address many of the outstanding questions including (1) the nature of the sources of high energy particles and photons, through the high energy spectrum, (2) the details of particle transportation in the Galaxy, and (3) signatures of dark matter, in either the high energy electrons or gamma ray spectrum. It will also be capable of monitoring gamma ray transients and solar modulation. CALET will be launched in 2013.

The baseline specifications of CALET are shown in table 2. CIRC will be mounted on the bottom of CALET, shown in figure 2.

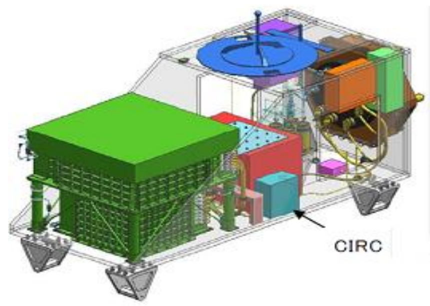

Fig. 2 Schematic view of CALET and the mounting location of CIRC

Table. 2 baseline specifications of CALET

Parameter	Specification
Mass	< 500 kg
Bus power	< 500W
Communication	< 300kbps
Orbit	407 km (nominal)

3. Mission of CIRC

The main mission of CIRC is a technology demonstration of a wildfire detection using the microbolometer. Wildfires are one of the major and chronic disasters affecting many countries in Asia-Pacific region, and some suggestions are that this will get worse with global warming and climate change. In Sentinel Asia project to share the disaster information in near real-time across the Asia-Pacific region, the wildfire detection is chosen as one of the important activities. It is possible to increase observational frequency of wildfires if CIRCs are carried on various satellites by taking advantages of small size, light weight and low power consumption. The other

CIRC mission targets are volcanoes or heat island phenomena in a city. The observations of these targets with thermal infrared imager will become a useful tool to monitor volcanoes or to solve the heat island problem.

4. Baseline specifications of the CIRC

Baseline specifications of the CIRC are shown in Table 3. We set the baseline specifications to meet requirements for the wildfire detection. The detector is a large format (640 × 480) to obtain a wide field of view. The spatial resolution is an important factor for the wildfire detection. The spatial resolution is 200 m from the altitude of 600 km (ALOS-2), and 130 m from the altitude of 400 km (CALET), respectively. Eliminating the cooling system reduces the size (110mm x 180mm x 230mm) and electrical power (<20 W).

Table 3. Baseline specifications of the CIRC

Parameter	Specification
Size	110mm x 180mm x 230mm
Mass	~3kg
Detector	Uncooled infrared detector
Wavelength	8 - 12 μm
Number of pixels	640 × 480
Special resolution	< 200 m @ 600 km (ALOS-2) < 130m @ 400km (CALET) (< 0.33 mrad)
Field of View	12°× 9°
Exposure	33 ms
Dynamic range	180 K - 400 K
NEdT	0.2 K@300 K
Power	< 20W

5. Feasibility study of wildfire detection

For feasibility study of the wildfire detection and other possible application, we used Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) / thermal infrared (TIR) [4)] data. ASTER has a significant advantage over previous datasets because of the combination of high spatial resolutions (15–90 m) and enhanced multispectral capabilities, particularly in the TIR. The spatial resolution and swath of the ASTER/TIR are 90m and 60km, respectively. The 90m spatial resolution in the thermal infrared band is useful to simulate various case of a spatial resolution.

In order to check the detectability of wildfire, we obtained the wildfire data taken by ASTER. Table 4 shows the list of wildfire data we checked. These are typical wildfire data including forest fires, tundra fires, and peat fires.

Table 4. Analyzed wildfire data of the ASTER/TIR

Location	Date	Type
Alaska	2004-07-17	Forest fire
Alaska	2007-09-08	Tundra fire
California	2003-10-26	Forest fire
Indonesia	2006-10-12	Peat fire

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In order to investigate the difference of the wildfire detectability depending on the spatial resolution, we made simulated images of which spatial resolutions are 180m and 270m from the original ASTER/TIR image.

Fig. 3 show simulated images of the forest fire in California and the peat fire in Indonesia. We searched the image for regions of anomalously high brightness to detect wildfires. In general, the wildfire detection using satellite data uses short or medium infrared images in addition to the TIR image. However, by optimizing a threshold level, we can detect a wildfire only from the thermal infrared image. Hotspots are detected by contextual threshold method. A pixel is defined as hotspot if the anomaly in 11μm brightness is higher than 3σ, where σ is standard deviation of brightness in pixels within 1km radius.

In order to check the detectability, we used the MODerate-resolution Imaging Spectroradiometer (MODIS) Thermal Anomalies/Fire products (MOD14v4). MOD14 algorithm detects fire locations using 4μm and 11μm brightness temperatures with the spatial resolution of 1km.

From this simulation, we found that the detectability of forest fire or tundra fire using thermal infrared images of which spatial resolution of 180m is comparable to that of MOD14 algorithm. On the other hand, the detection of the peat fire needs higher spatial resolution. Because the burning temperature of peat fires is lower than that of other wildfires.

Although further improvements of the detection algorithm are needed especially for peat fires, we find that 200m spatial resolution is almost appropriate for the wildfire detection. The detectability of wildfires should have a dependency to the burning area. In addition to that, there is a possibility to detect a "false alarm" wildfire in a city due to various heat sources like heat power plants. So we are planning to apply this algorithm to other various dataset and check the detectability.

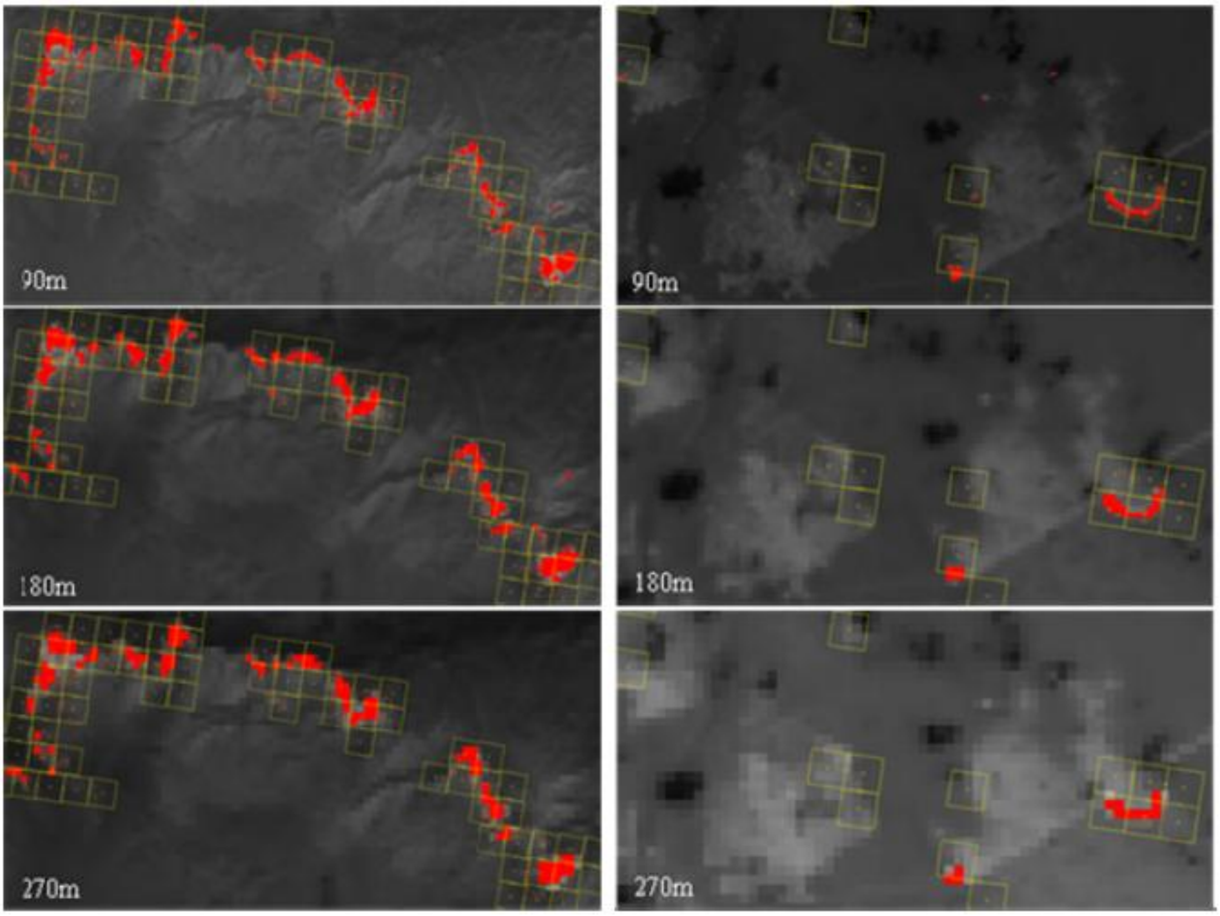


Fig. 3. ASTER/TIR images of forest fire in California on October 26, 2003 (left) and peat fire in Indonesia on October 12, 2006(right). The spatial resolutions are 90m (top), 180m (middle), and 270m (bottom). Red filled squares are the results of wildfire detection using thermal infrared data only. Yellow open squares are the results using MOD14.

6. Calibration of the CIRC ground test model

In this section, we present the calibration results of the CIRC ground test model. Figure 4 shows the picture of the CIRC ground test model.

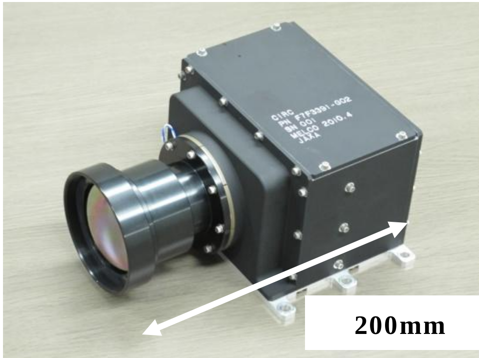


Fig. 4 Picture of the CIRC ground test model

In the laboratory experiment at JAXA Tsukuba Space center, we measured the Modulation Transfer Function (MTF) of the CIRC ground test model in a vacuum to evaluate the image capture performance of the sensor system.

6.1 Measurement setup

The schematic diagram of the experimental setup is shown in Fig. 5.

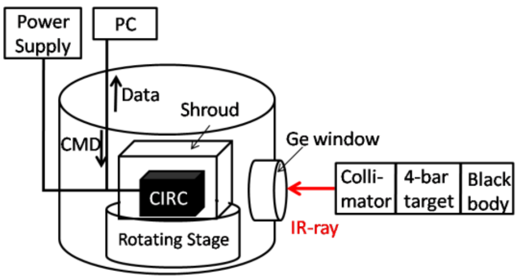
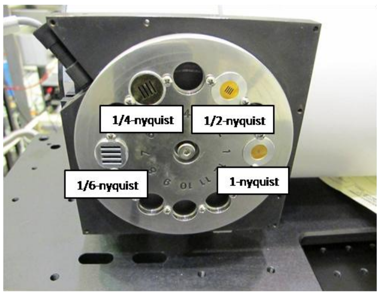


Fig. 5 Schematic diagram of the experimental setup

CIRC is placed inside of the vacuum chamber in the laboratory and surrounded by a shroud which controls the ambient temperature of CIRC by using a heater and a cooler. The pressure in the vacuum chamber is ~ 10^{-5} Torr during the experiment. The infrared-ray is emitted by the black body (CI Systems SR800) and passes through the 4-bar targets (shown in Fig.6) mounted inside of the reflective collimator system (CI Systems ILET-5-1.1). The intervals of the slits of the 4-bar targets are equivalent to 1-, 1/2-, 1/4- and 1/6-nyquist frequency. The collimated infrared-ray pass through a germanium window, which is mounted on to the side of the vacuum chamber and transmits the infrared-ray from outside of the vacuum chamber, and is detected by CIRC.



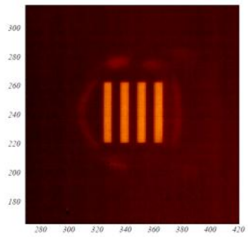


Fig. 6 (top) 4-bar target mounted on the collimator system. 1/6-, 1/4-, 1/2-, 1-nyquist frequency from the left. (bottom) image of the 4-bar target taken with CIRC

6.2 Data

We have measured MTF under a vacuum environment. The detector positions of measurements are at the center, ±5 degrees in the Cross-Track (CT) direction, and ±3.5 degrees in the Along-Track (AT) direction, shown in figure 7. In order to measure the MTF at ±3.5 degrees, the CIRC is able to be replaced to the side panel of the shroud, because only one rotating stage is set in the vacuum chamber (see figure 5). MTF for CT/ AT direction were measured by rotating the 4-bar target. The temperatures of the shroud are set to -10 to 50 degrees C.

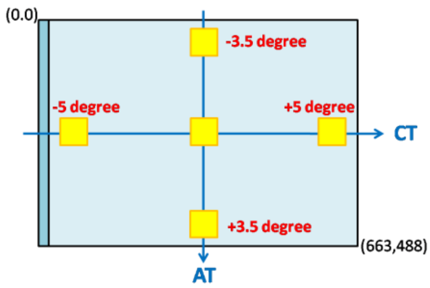


Fig. 7 The positions of MTF measurement

6.3 Procedure of analysis

We have taken 4-bar target image for each frequency. By using the image, we obtained MTF. MTF is defined as shown below;

$$MTF = (V_{max} + V_{min}) / (V_{max} - V_{min}),$$

where V_{max}, V_{min} are peak and a bottom of digital number of 4-bar image. (see Fig. 8)

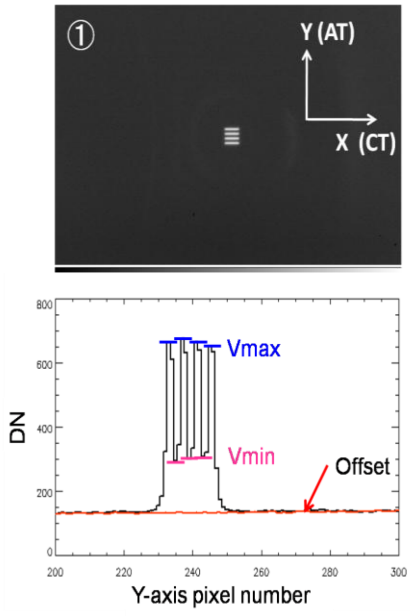


Fig. 8 (Top) Image of 4-bar target at the detector center. (Bottom) DN of 4-bar target. We correct the offset (red line), and calculate MTF with Vmax and Vmin shown in blue line.

6.4 Result

We have measured MTF for CT/AT direction at 5 detector positions. Main results are shown in figure 9. CT-direction at the detector position has same trend with several temperature. Athermal characteristics at nyquist frequency measurement are shown in Fig. 9 middle(CT) and bottom(AT). CT direction MTF at the detector center and ±5 degrees are constant regardless of temperatures. CT at ±3.5 degrees and AT direction MTF has gradient, lower in low temperature environment.

7. Discussion and Conclusion

Results of MTF measurement are summarized as follows;

- MTF is lower at low temperature environment
- The variation of AT-direction MTF is large

Possible reason for small MTF at low temperature case is due to the gap of focal length. Although an alignment of focal length of CIRC ground test model was adjusted in atmosphere, focal length changes due to the variation of reflective index in the vacuum environment. The variation of AT-direction MTF is also due to the misalignment of focal length. We are planning to adjust focal length of CIRC PFM for vacuum environment.

We measured the MTF characteristic of CIRC, which is one of the important image capture performance parameters of the optical sensor systems, and confirmed the athermal characteristics of the CIRC. We input the results to development process of CIRC PFM. In a future experiment, we will measure the radiometric performance of the CIRC ground test model. Through these experiments, we establish a prelaunch calibration method

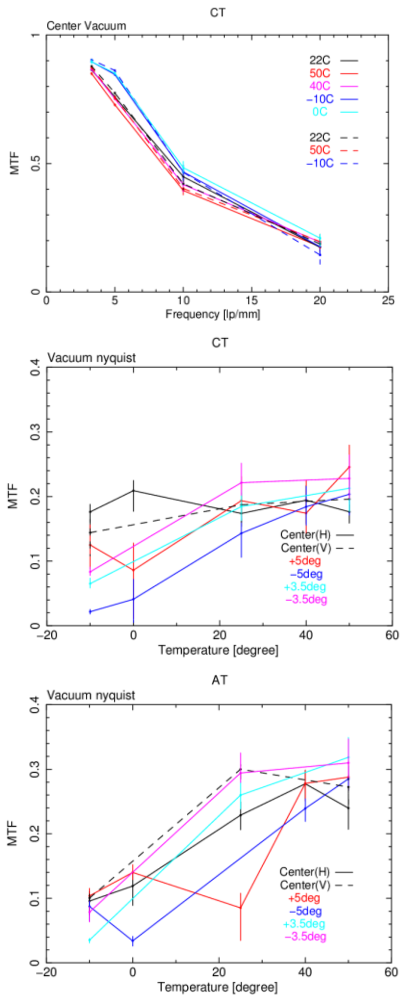


Fig. 9 (Top) Results of CT-direction MTF measurement at the detector center. In the room temperature (black), low temperature (blue) and high temperature (magenta or red) environment results are shown. (Middle, Bottom) Athermal characteristics at nyquist frequency at CT/AT-direction. Difference in color shows the detector position; center is in black, +5 degrees is in red, -5 degrees is in blue, +3.5 degrees is in cyan, and -3.5 degrees is in magenta, respectively.

for the CIRC PFM onboard ALOS-2 and CALET.

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