Design and Concept of The Compact Infrared Camera (CIRC) with Uncooled Infrared Detector

By Haruyoshi KATAYAMA[1)], Yoshihiko OKAMURA[1)], Yoshio TANGE[1)], and Koji NAKAU[1)]

[1)] Earth Observation Research Center, Japan Aerospace Exploration Agency, Tsukuba, Ibaraki, Japan

The compact infrared camera (CIRC) is one of technology demonstration payloads of Small Demonstration-Satellite type-3 (SDS-3). The CIRC is an infrared camera equipped with an uncooled infrared array detector (microbolometer). Microbolometers have an advantage of no requirement of cooling mechanisms such as a mechanical cooler. The main mission of the CIRC is the technology demonstration of the wildfire detection using the microbolometer. In this paper, we show the details of the design and concept of the CIRC. We also show preliminary results of feasibility study of the wildfire detection and other applications using thermal infrared images.

Key Words: Remote Sensing, Thermal Infrared Imaging, Wildfire, Uncooled Infrared Detector

1. Introduction

Microbolometers are widely used in commercial and military applications such as a night vision. Microbolometers have an advantage of no requirement of cooling mechanisms such as a mechanical cooler. The eliminating of detector cooling system can reduce the size, cost and electrical power of sensor. Although the sensitivity of microbolometers is lower than that of HgCdTe-based photonic infrared detectors, the advantage of no cooling mechanism is suitable for small satellites or resource-limited sensor systems.

For this reason, microbolometers begin to be applied for various space applications. In planetary missions, the Thermal Emission Imaging System (THEMIS) [1)] onboard Mars Odyssey spacecraft used a microbolometer focal plane array (FPA). The Longwave IR camera (LIR) onboard Venus Climate Orbiter (PLANET-C) [2)], which is scheduled to be launched in 2010, also uses a microbolometer array.

In earth observation mission, the Infrared Spectral Imaging Radiometer (ISIR) [3)] experiment tests the potential of microbolometer for application to thermal infrared imaging. The ISIR was flown as a hitchhiker experiment on the space shuttle in 1997. Recent missions to measure the atmosphere vertical profiles like CALIPSO [4)] and EarthCARE [5)] also use a microbolometer as an imaging infrared instrument. JAXA has started a research for application of microbolometer to earth observation since 2000. The Wide-Angle Multi-band Sensor - Thermal Infrared (WAMS-TIR) [6)], aboard the station-keeping test airship (SPF-II) for the stratospheric platform project, is a thermal infrared multi-band radiometer using a microbolometer FPA.

In order to demonstrate the potential of microbolometer to the thermal infrared imaging from space, the compact infrared camera (CIRC) is chosen as one of the technology demonstration payloads of Small Demonstration Satellite (SDS). The SDS program is one of activities of JAXA, to demonstrate a variety of new technologies and new missions.

In this paper, we show the details of the concept of the CIRC. We also show preliminary results of feasibility study of the wildfire detection and other applications.

2. Microbolometers

Microbolometers are detectors to detect infrared energy as minutes change of the detector temperature. A microbolometer consists of an array of pixels, each pixel being made up of several layers. Although there are several different structures from company to company, these layer are consist of IR absorbing layer, reflection layer, and readout integrated circuit (ROIC). The key technologies of the microbolometer are the IR absorber, the temperature sensor to detect the temperature change of IR absorber, and thermal isolation structures of IR absorber.

In Japan, two companies are providing microbolometers. One is Mitsubishi Electric Corporation (MELCO), and the other is NEC corporation. Uncooled infrared FPA of MELCO is a device with series PN junction diodes fabricated on Silicon-On-Insulator (SOI) wafer. On the other hand, that of NEC uses vanadium oxide as IR absorbing material. Both companies can provide a 640 x 480 large format array with 23.5 or 25μm pixel [7), 8)]. We are planning to choose one of these devices. The 640 x 480 microbolometer array is the largest format ever used in earth observations from space.

3. Small Demonstration Satellite type-3

The Small Demonstration Satellite type-3 (SDS-3) is a piggybag satellite of HTV/HIIB launch vehicle. The SDS-3 is scheduled to be launched in 2010. Table 1 shows a baseline specification of the SDS-3. Although the details of its system are still under discussion, the CIRC is one of possible candidates of the SDS-3 payloads. The elliptical orbit of the SDS-3 is a disadvantage for the earth observation mission like the CIRC. However, we can observe a target with different spatial resolutions from different orbital altitudes. We thus think that this orbit is suitable for our experiments.

Table 1. Baseline specifications of the SDS-3.

Size	280mm x 280mm x 500mm
Mass	< 50 kg
Bus power	> 52 W
Power supply voltage	16.8-22.4V (unstable) 5.0V (stable)
Communication	S-band
Orbit	300-1000 km elliptical orbit (TBD)

4. Mission and specifications of the CIRC

The main mission of the CIRC is the technology demonstration of the 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[1] 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.

A baseline specification of the CIRC is shown in Table-2. We set the baseline specification to meet requirements for the wildfire detection. The detector is a large format (640 x 480) to obtain wide field of view. The spatial resolution is an important factor for the wildfire detection. The baseline specification of the spatial resolution is 200m from the altitude of 450km.

Fig. 1 shows a system block diagram of the CIRC. In order to reduce the size, weight, and cost, we minimized the function of the CIRC. The optics unit of the CIRC is f/1-f/1.5 optics. We are discussing to employ an athermal optics to keep the optical performance in a wide range of temperature. This will be an advantage of the CIRC for small satellites, because we don't need an active thermal control to the optics.

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) [9] 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. The 90m spatial resolution in thermal infrared band is useful to simulate various case of a spatial resolution.

In order to check the delectability of wildfire, we obtained the wildfire data taken by ASTER. Table 3 shows the list of wildfire data we checked. These are typical wildfire data including forest fires, tundra fires, and peat fires.

Table 2. Baseline specifications of the CIRC.

Item	Characteristics
Size	< 150mm x 150mm x 300mm
Mass	< 5kg
Detector	Uncooled infrared detector
Wavelength	8 - 12 μm
Number of pixels	640 x 480
Spatial resolution	< 200 m observed from 450 km (< 0.44 mrad)
Field of View	16° x 12°
Frame rate	30Hz
Dynamic range	Hi gain : 180 K - 340 K
	Low gain : 180 K - 450 K
NEdT	0.2 K@300 K

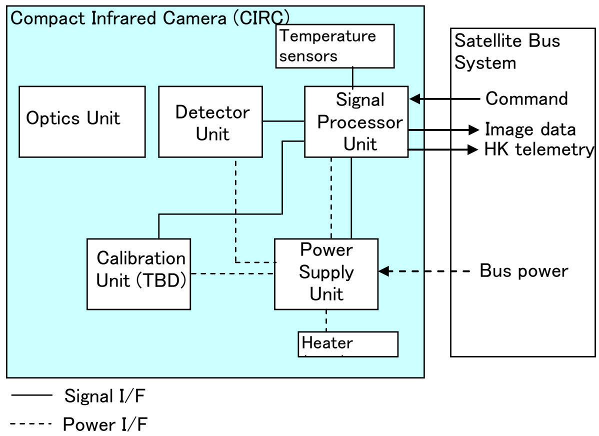

Fig 1. System block diagram of the CIRC.

Table 3. 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

5.1 Spatial resolution

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. 2 and 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. 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

[1] http://dmss.tksc.jaxa.jp/sentinel/

is higher than 3σ, where σ is standard deviation of brightness in pixels within 1km radius. Details of this algorithm will be published in 10).

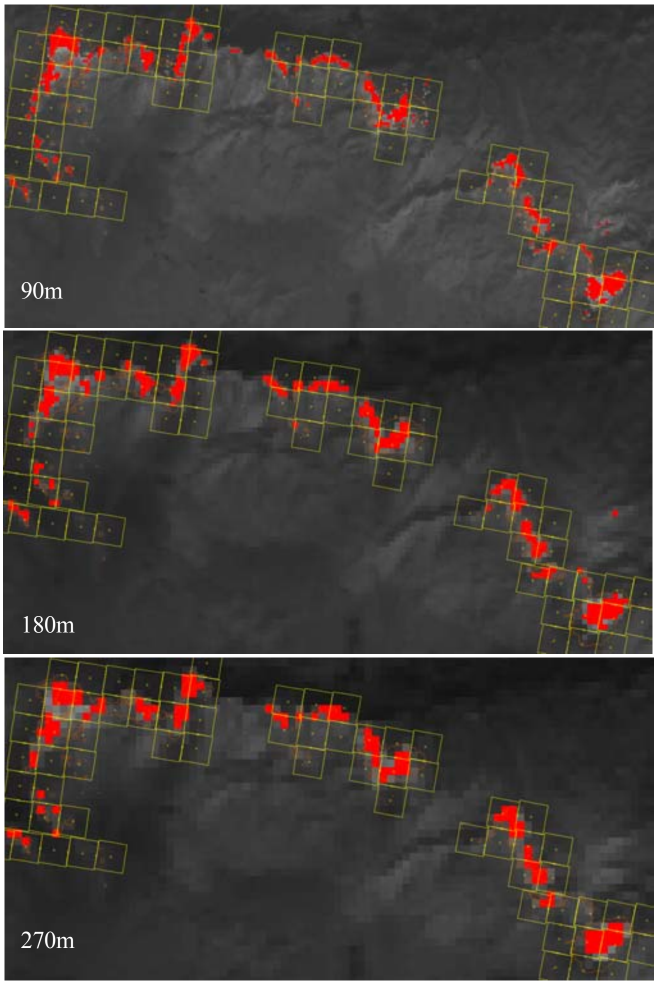

Fig 2. ASTER/TIR images of forest fire in California on October 26, 2003. The spatial resolutions are 90m (top), 180m (middle), and 270m (bottom). Red filled squares are the results of wildfire detection using thermal infrared data only. Yellow open squares are the results using MOD14.

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 spatial resolution of 1km.

From this simulation, we find 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.

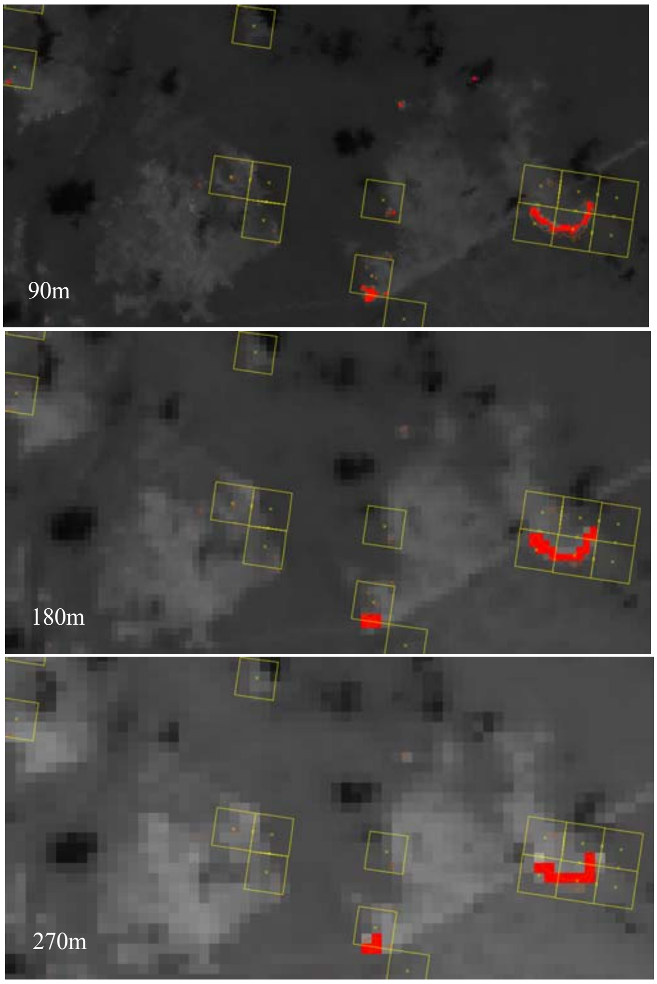

Fig 3. ASTER/TIR images of peat fire in Indonesia on October 12, 2006. The spatial resolutions are 90m (top), 180m (middle), and 270m (bottom). Red filled squares and yellow open squares are the same in Fig. 1.

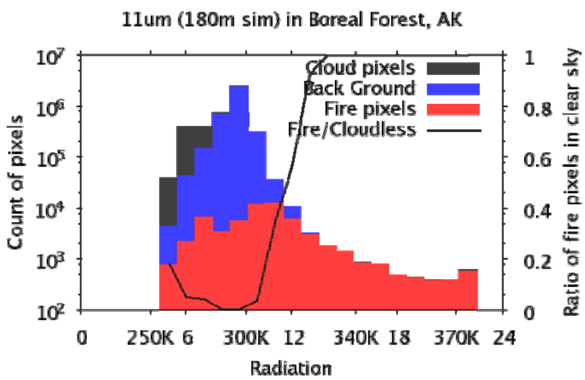

Fig 4. A histogram of the radiation temperature of a wildfire taken by ASTER/TIR 11μm band.

5.2 Dynamic range

For the detection of wildfires, the dynamic range of sensor is also important. If the burning temperature is too high, the output of sensor is saturated.

Fig. 4 shows a histogram of the radiation temperature of a wildfire taken by ASTER/TIR 11μm band. The radiation temperature of 370K is the saturation level of the ASTER/TIR. This implies that the dynamic range needed for the CIRC is 400K-450K.

6. Other possible applications

The other CIRC mission is to demonstrate the possibility of microbolometers as a thermal infrared imager to other observation targets like volcanoes or heat island phenomena in a city.

Fig 5. shows the image of Mt. Merapi volcano, Indonesia taken by ASTER on June 6, 2006. We can see fumes and volcanic ash at the crater and its surrounding area from the VNIR image. Fig 6. shows TIR images around crater with different spatial resolution. Two streaks are relics of the pyroclastic flow. We can see these features from the images of 90m and 180m spatial resolution. However it is difficult to resolve from 270m or 360m spatial resolution.

As well as the wildfire detection, the visibility of these features has a dependency of the scale of observation target. We will continue this kind of work to check the feasibility.

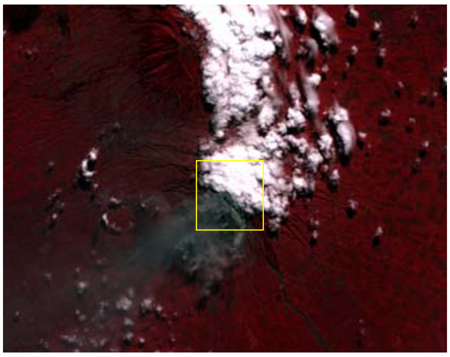

Fig 5. ASTER/VNIR image of Mt. Merapi volcano, Indonesia taken by ASTER on June 6, 2006.

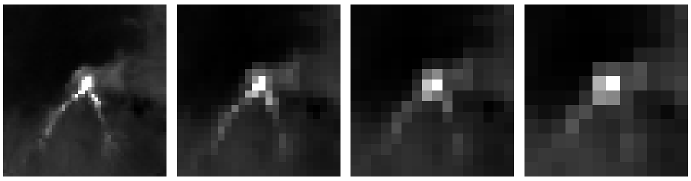

Fig 6. ASTER/TIR images of the crater of Mt. Merapi. The spatial resolutions of images are 90m, 180m, 270m, and 360m from left to right.

7. Summary

The compact infrared camera (CIRC) onboard the Small Demonstration Satellite type-3 (SDS-3) is a thermal infrared imager using microbolometer. The main mission of the CIRC is the technology demonstration of the wildfire detection using the microbolometer.

We set the baseline specification to meet requirements for the wildfire detection and other applications. The feasibility study shows that the CIRC baseline specification is almost suitable for these purposes. We start the development of the CIRC based on the specification this year.

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