DESIGN AND CONCEPT OF THE COMPACT INFRARED CAMERA (CIRC) WITH UNCOOLED INFRARED DETECTOR

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ABSTRACT

The compact infrared camera (CIRC) is a technology-demonstration payload to be carried on the Small Demonstration Satellite (SDS). CIRC is an infrared camera equipped with an uncooled infrared array detector (microbolometer). Microbolometers have an advantage of not requiring cooling systems such as a mechanical cooler.
CIRC's main mission is technology demonstration of wildfire detection using the microbolometer. This paper presents the detailed design and concept of CIRC. We also discuss preliminary results of the feasibility study on wildfire detection and other applications using thermal infrared images.

1. INTRODUCTION

Microbolometers are widely used in commercial and military applications such as night vision. Because of recent progress of microelectromechanical system (MEMS) technology, high-resolution, large-format devices are being developed by many companies.
Microbolometers have an advantage of not requiring cooling systems such as a mechanical cooler. Eliminating the detector cooling system can reduce the size, cost and electrical power consumption of the sensor. Although microbolometers are less sensitive than HgCdTe-based photonic infrared detectors, the advantage of not requiring a cooling system is suitable for small satellites or resource-limited sensor systems.
For this reason, microbolometers began to be employed for various space applications. In planetary missions, the Thermal Emission Imaging System (THEMIS) [1] aboard the Mars Odyssey spacecraft used a microbolometer focal plane array (FPA). The array is 320 (cross-track) by 240 (along-track) with 50μm pixels. The Longwave IR camera (LIR) carried by the Venus Climate Orbiter (PLANET-C) [2], which is scheduled to be launched in 2010, also uses a 320 x 240 microbolometer array.
In Earth-observation missions, the Infrared Spectral Imaging Radiometer (ISIR) [3] experiment tests the potential of microbolometers for application to thermal infrared imaging. The ISIR was flown as a hitchhiker experiment on the space shuttle in 1997. The instrument was installed in a pressurized canister. The microbolometer used in ISIR is a 327 x 240 array providing good sensitivity (D* ~ 5e9 cmHz$^{1/2}$/Watt) in the thermal infrared region. Recent missions to measure the atmosphere vertical profiles like CALIPSO [4] and EarthCARE [5] also use a microbolometer as an imaging infrared instrument.
JAXA began research for applying microbolometers to Earth observation in 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 320 x 240 microbolometer FPA.
The compact infrared camera (CIRC) was chosen as a technology demonstration payload for the Small Demonstration Satellite (SDS) in order to demonstrate the potential of microbolometers in thermal infrared imaging from space. The SDS program is a JAXA activity to demonstrate a variety of new technologies and new missions. The mission of the SDS/CIRC project is to demonstrate the potential of the microbolometer, especially for wildfire detection but also for other applications. The second purpose of the CIRC project is the low-cost and early development of the thermal infrared imager.
This paper introduces the detailed concept of the CIRC. We also present preliminary results of a feasibility study on wildfire detection and other applications.

2. MICROBOLOMETERS

Microbolometers detect infrared energy as minute changes 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 that differ from company to company, these layers consist of an IR absorbing layer, a reflection layer, and a readout integrated circuit (ROIC). The key technologies of the microbolometer are the IR absorber, the temperature sensor to detect the temperature change of the IR absorber, and thermal isolation structures of the IR absorber.
In Japan, two companies provide microbolometers, Mitsubishi Electric Corporation (MELCO) and NEC Corporation. MELCO's uncooled infrared FPA is composed of a series of PN junction diodes fabricated on a Silicon-On-Insulator (SOI) wafer. In contrast, 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 SATELLITES

The Small Demonstration Satellite (SDS) program is a series of 100kg-class small satellites to demonstrate a range of new space technologies, from elemental to system-wide. The SDS is a piggyback satellite carried by the HIIA launch vehicle. The first satellite of the SDS series (SDS-1) will be launched in fiscal 2008 as a piggyback payload with the Greenhouse Gas Observing Satellite (GOSAT).
CIRC is a payload for the second satellite of the SDS series (SDS-2). Although the launch date of the SDS-2 is not determined yet, we have started the conceptual design of the system. Table 1 lists the baseline specifications of the SDS-2.

Table 1. Baseline specifications of the SDS-2.

Size	700mm x 700mm x 600mm
Mass	100kg
Bus power	130W
Communication	S-band (1Mbps, 16kbps)
Attitude control	Three-axis attitude control
Orbit	Sun–synchronous orbit

4. CIRC MISSION AND SPECIFICATIONS

CIRC's main mission is the technology demonstration of wildfire detection using a microbolometer. Wildfires are major and chronic disasters affecting many countries in the Asia-Pacific region, and the situation may get worse with global warming and climate change. In the Sentinel Asia[1] project to share disaster information in near real time across the Asia-Pacific region, wildfire detection is chosen as one of the most important activities.
Table 2 lists CIRC's baseline specifications. We set the baseline specifications to meet the requirements for wildfire detection. The detector has a large format (640 x 480) to obtain a wide field of view. The spatial resolution is an important factor for wildfire detection. The baseline specification of the spatial resolution is 200m from an altitude of 600km.

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

Table 2. CIRC baseline specifications

Parameter	Specification
Size	< 100mm x 150mm x 200mm
Mass	< 3kg
Detector	Uncooled infrared detector
Wavelength	8 to 12μm
Number of pixels	640 x 480
Spatial resolution	< 200m @600km (< 0.33 mrad)
Field of View	12° x 9°
Frame rate	30Hz
Dynamic range	High gain: 180K to 340K
	Low gain: 180K to 400K
NEdT	0.2 K@300K

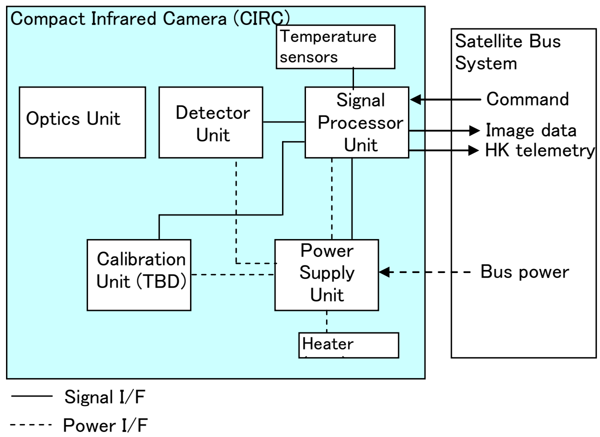

Fig. 1. System block diagram of the CIRC.

Figure 1 presents the CIRC system block diagram. In order to reduce the size, weight, and cost, we minimized CIRC's functions. CIRC's optics unit is f/1-f/1.5 optics. We are discussing using athermal optics to maintain optical performance over a wide range of temperatures. This will be an advantage of CIRC for small satellites because we do not need active thermal control for the optics.

5. FEASIBILITY STUDY OF WILDFIRE DETECTION

We used Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) / thermal infrared (TIR) [9] data to conduct a feasibility study of wildfire detection and other possible applications. ASTER has a significant advantage over previous datasets because it combines high spatial resolution (15 to 90m) and enhanced multispectral capability, particularly in the TIR. The ASTER/TIR spatial resolution is 90m, and its swath is 60km. The 90m spatial resolution in the thermal infrared band is useful for simulating various cases of spatial resolution.
In order to check the ability to detect wildfires, we obtained the wildfire data taken by ASTER. Table 3 lists the wildfire data we checked. These are typical wildfire data including forest fires, tundra fires, and peat fires.

Table 3. ASTER/TIR wildfire data analyzed

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

We made simulated images with spatial resolutions of 180m and 270m from the original ASTER/TIR image in order to investigate the dependence of wildfire detectability on the spatial resolution.

Figures 2 and 3 present simulated images of a forest fire in California and a peat fire in Indonesia. We searched the images for regions of anomalously high brightness to detect wildfires. In general, wildfire detection with satellite data uses short or medium infrared images. However, by optimizing the threshold level, we can detect a wildfire from the thermal infrared image alone.

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

This simulation demonstrated that the detectability of forest fires or tundra fires using thermal infrared images with a spatial resolution of 180m is comparable to the detectability using the MOD14 algorithm. However, a higher spatial resolution is required to detect peat fires because peat fires burn at a lower temperature than other wildfires.

Although further improvements of the detection algorithm are needed, especially for peat fires, we find that 200m spatial resolution is adequate for wildfire detection. The detectability of wildfires should depend on the burning area. In addition, “false” wildfires may be detected in cities due to various heat sources like heat power plants. We therefore plan to apply this algorithm to various other datasets and check the detectability.

5.2 Dynamic range

The sensor dynamic range is also important for detecting wildfires. If the burning temperature is too high, the sensor output may saturate.

Figure 4 depicts a histogram of the radiation temperature of a wildfire acquired by ASTER/TIR in the 11µm band. The radiation temperature of 370K is the saturation level of the ASTER/TIR. This implies that the dynamic range needed for CIRC is 400K.

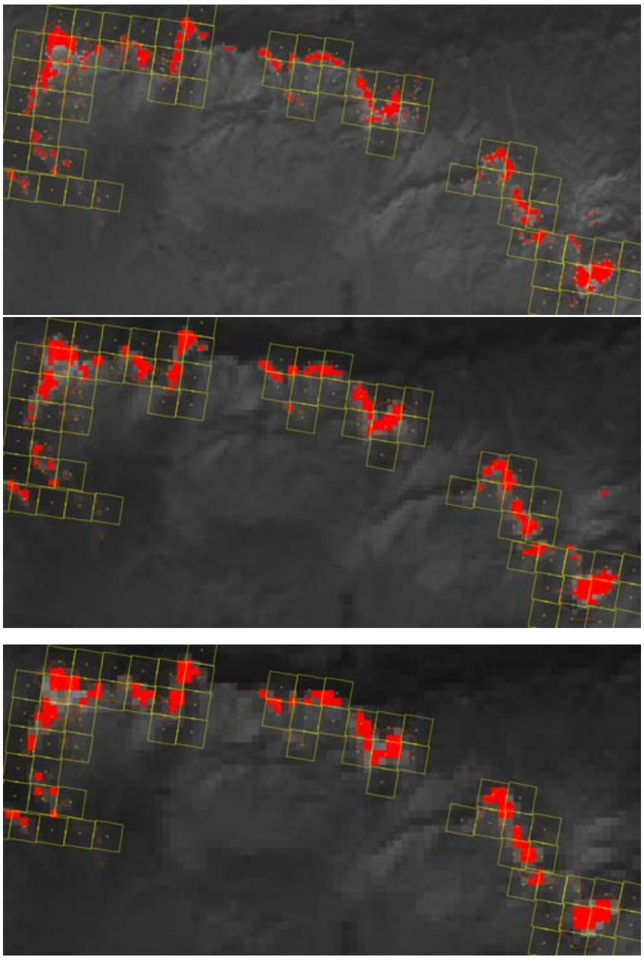

Fig. 2. ASTER/TIR images of forest fire in California on October 26, 2003. The spatial resolutions are 90m (top), 180m (middle), and 270m (bottom). Red filled squares are the results of wildfire detection using thermal infrared data only. Yellow open squares are the results using MOD14.

6. OTHER POSSIBLE APPLICATIONS

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

Figure 5 presents an image of Mt. Merapi volcano, Indonesia, acquired by ASTER on June 6, 2006. We can see fumes and volcanic ash at the crater and its surrounding area from the VNIR image. Figure 6 shows TIR images around the crater with different spatial resolutions. The two streaks are relics of a 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 with wildfire detection, the visibility of these features depends on the scale of the observation target. We will continue this kind of work to investigate the feasibility.

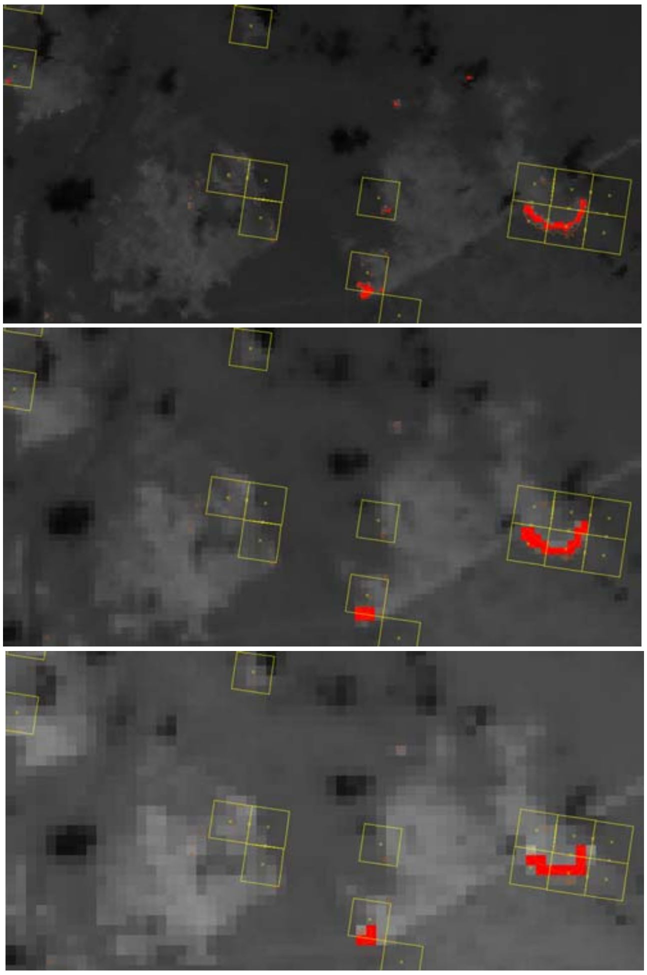

Fig. 3. ASTER/TIR images of peat fire in Indonesia on October 12, 2006. The spatial resolutions are 90m (top), 180m (middle), and 270m (bottom). Red filled squares and yellow open squares are the same as in Fig. 1.

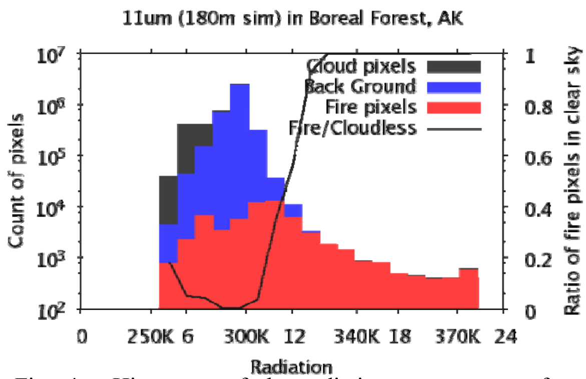

Fig. 4. Histogram of the radiation temperature of a wildfire acquired by ASTER/TIR in the 11μm band.

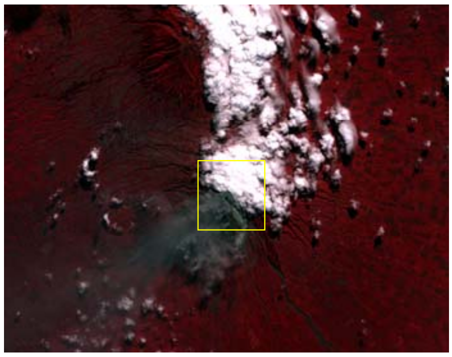

Fig. 5. ASTER/VNIR image of Mt. Merapi Volcano, Indonesia, acquired by ASTER on June 6, 2006.

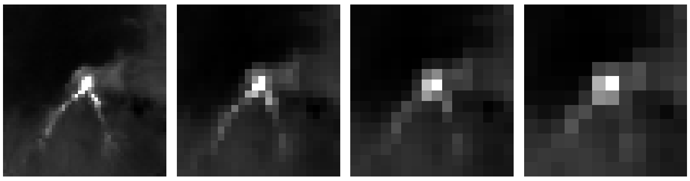

Fig. 6. ASTER/TIR images of the crater of Mt. Merapi. The spatial resolutions of images are 90m, 180m, 270m, and 360m from left to right.

7. SUMMARY

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

We set the baseline specification to meet requirements for wildfire detection and other applications. The feasibility study indicates that the CIRC baseline specification is adequate for these purposes. We will start to develop CIRC this year based on the specifications.

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