COMMERCIAL THERMAL INFRARED CAMERA APPLIED TO SMALL SATELLITE IN JAPAN

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Introduction: The thermal infrared camera became an essential instrument for planetary science in Japan since the Japanese Venus climate orbiter Akatsuki mounted the Long-wave Infrared camera (LIR). LIR has discovered a large stationary gravity wave at the cloud-top of Venus [1]. Same camera of LIR was mounted to Hayabusa-2 spacecraft investigating Ryugu asteroid as TIR [2]. TIR contributes to not only estimate thermal inertia of the surface but also decide landing site of the spacecraft. We believe that the thermal infrared camera contributes to future planetary missions but Akatsuki and Hayabusa-2 mission. When it observes atmosphere of Mars, temperature distribution of dust storm soaring into the sky [3] can be obtained. When it observes impact flashes on the Moon, unknown feature of the flashes will be thermally clarified. The detector of our cameras is the uncooled micro-bolometer array (UMBA) which detects wavelengths from 8 to 14 μm. The detector does not need a cryogenic system and enables a camera to be lightweight, hence it meets to future small-sat missions for planetary science. We have developed newly UMBA cameras and some were experimentally launched as a payload of the 50 kg class satellite in Japan [4]. The smallest UMBA camera we have ever developed (shown in Fig.1) was launched by Rising-2 satellite. In this mission, a commercial product was uniquely applied in order to compress the development cost; nevertheless ability of the camera was kept high. In addition, period from mission proposal to the launch was only three years. This camera can be flexibly applied to any planetary missions with inexpensively short-term development. In this presentation, we report ability and initial result of the camera on orbit.

Instrument: We applied the UMBA detector called HX3100 made by NEC Co Ltd. in Japan to the camera. It is newer detector than that of LIR for Akatsuki and TIR for Hayabusa-2. The UMBA has large pixel inhomogeneity called an on-chip Fixed Pattern noise (OFPN) in each pixel. The inhomogeneity can be partially removed from an image by calibration data acquired at the time of activation. The residual component can be eliminated from the image by subtracting a shutter image. Therefore, NEC provides not only the detector but also an electrical camera module containing a mechanical shutter system and

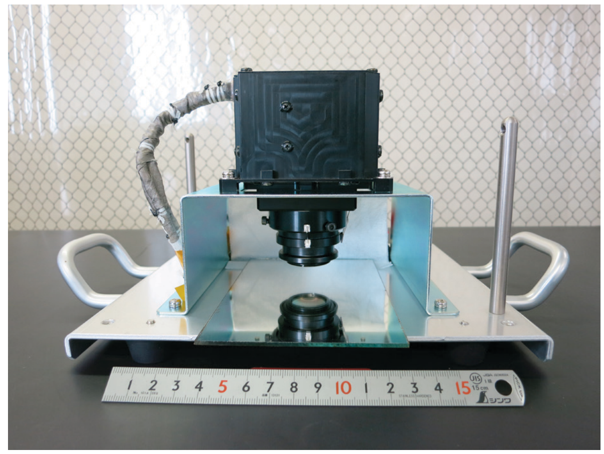

Fig.1. Thermal infrared camera mounted to Rising-2 satellite

substrates for the calibration and readout signals from HX3100. The sequence to eliminate the inhomogeneity was preinstalled to the FPGA in the camera module. When the detector is turned on, a Peltier device in the module starts temperature control of the UMBA and acquiring calibration data automatically with shutter close status. After calibration of OFPN, the UMBA provides image stream with 30 Hz as a video graphical array (VGA). Thus, the camera module attains 0.1 K of a noise equivalent temperature difference (NETD) at the room temperature.

The limited edition of the camera module which is provided by NEC, which endures vibration environment based on the military standard in United States numbered MIL-STD-810E so that the camera module could be operated at a vibration environment on a helicopter. The toughness against the vibration is benefit for the launch of the spacecraft. Hence, the limited edition was applied to Rising-2 mission. The commercial camera module should be modified suitable to vacuum environment with high solar radiation conspicuously different from air environment. The mechanical shutter system that prevents sunlight input is uneasy to work in vacuum environment because the motor used in the system is for air condition. Therefore, we decided to remove the shutter system from the module. The shutter is also used for calibration of the detector. The UMBA should be calibrated by using a deep space instead of a shutter image at the time of activation. Since the UMBA cannot be protected from solar radiation by the shutter, the attitude of the spacecraft should be strictly controlled to avoid the solar radiation from inputting to the detector.

Wet-type electrolytic capacitors that may rupture in the vacuum environment do not meet to the spacecraft use. Hence, we replaced them to the Tantalum capacitors which endure in vacuum environment. Digital Signal Processor (DSP) and a field-programmable gate array (FPGA) on the substrate for the camera module are major heat source in the camera module. A radiator with fins attached to the devices was suitable for heat dissipation only in an air convection environment. The fins were replaced to a heat sink newly designed to work in space. Adhesives for space use are applied to a commercial Germanium lens and a housing case of the camera that blocks the solar radiation.

Results on orbit: Rising-2 satellite has been successfully launched on May 24, 2014. The first light of thermal infrared camera was successfully acquired on June 25, 2014. Unfortunately, a trouble has been occurred in the main control unit of the satellite bus-system on 26 June. Since then, the satellite could not be controlled outside of the coverage of the ground station located at Sendai city in Japan. Since the main control unit has been shut down to avoid serious troubles except for satellite operation within the coverage, observation area of Rising-2 is limited to Asia. An example of the observation is shown in Fig.2. A typhoon can be seen in the image as a dark vortex. Since temperature is kept low in the upper atmosphere, the higher cloud-top at the typhoon looks dark in the image. The contrast can be converted to the brightness temperature using blackbody images that have been acquired before the launch in laboratory [6][7]. The result indicates the temperature of the cloud-top at the typhoon is ~230 K, that is consistent with the result which has been acquired from the Japanese meteorological satellite called Himawari. We could successfully operate the commercial thermal infrared camera in orbit just as expected.

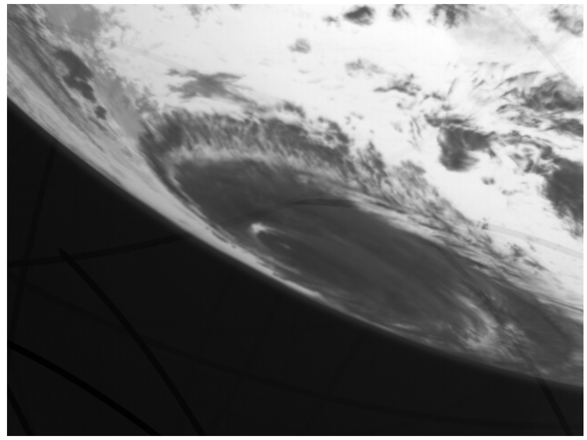

Fig.2. Typhoon observed by the thermal infrared camera on board Rising-2 (August 8, 2014, above south-east Asia)

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