P5.11 APPLICATION AND DESIGN OF SATELLITE INFRARED SPECTRAL IMAGING RADIOMETERS WITH UNCOOLED MICROBOLOMETER ARRAY DETECTORS

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1. INTRODUCTION

Uncooled array detectors offer a number of advantages for space borne infrared array imaging. The elimination of detector cooling requirements can significantly reduce the size, cost and power requirements systems. Integration of the instrument to a spacecraft is much simplified due to reduced thermal management requirements. An array of detectors permits imaging without mechanical scanning. In addition an array may be exploited to provide information on the angular distribution of radiation simultaneously to spectral radiance. The potential limitation of uncooled infrared detectors is reduced sensitivity. Other issues are stability and calibration.

Over the last five years the use of infrared imaging radiometers based on uncooled microbolometer array detectors has been studied and tested. A prototype instrument was flown as a hitchhiker experiment on the space shuttle in 1997 (Spinhirne et al., 1999). The performance and application of data has been extensively studied. The hitchhiker experiment is now followed by a project to develop an engineering model of an operational imaging radiometer for low earth orbit. In addition the use of uncooled infrared array detectors for geosynchronous and other satellite applications has significant potential.

2. IR DETECTOR

The uncooled microbolometer array detector (UMAD) is a large-format (328x246 and above) device providing good sensitivity (D* ~ $5\text{x}10^9$ $\text{cmHz}^{1/2}$/Watt) in the thermal IR at room temperature. These detectors were developed in the late 1980's and early 1990's, at the Honeywell Sensor and System Development Center, using silicon micro-machining techniques to produce a monolithic array of silicon microbolometers and CMOS readout circuitry. In 1993 Honeywell demonstrated a nearly theoretical level reduction in noise with frame averaging, suggesting UMADs would display similar noise reduction with frame integration techniques and spatial averaging. In 1994 Honeywell licensed UMAD detector technology to others companies who are now providing low-cost commercial versions of these devices (Wood and Foss, 1993). Detector arrays of 640x480 size and larger are now available.

3. ISIR

The Infrared Spectral Imaging Radiometer (ISIR) program developed an infrared radiometer that flew as part of the hitchhiker complement onboard space shuttle mission STS-85 in August 1997. The ISIR instrument was the first earth observing radiometer to include UMAD technology and was built to address the applicability of these detectors as space-borne radiometric sensors. During mission STS-85 the ISIR instrument was used to obtain radiometric imagery of clouds, land, and ocean in several narrow spectral bands in the thermal infrared and provided measurements of cloud-top temperature, classification, and cloud droplet size.

The basic goal for a low earth orbit imager is one with possibly incremental increases in spatial or spectral resolution or number of bands over current AVHRR instruments. A compact imaging radiometer that offered such capabilities would find application on any number of possible multisensor missions. Hence, the ISIR instrument included thermal IR channels centered at 8.6 um, 10.8 um, and 12.0 um each with an approximate 1 um passband. A broadband channel spanning the wavelength range of 7–12 um was also included in ISIR. ISIR obtained ¼ km resolution from shuttle orbit. The AVHRR instrument uses single element detectors to provide imagery with 0.12K resolution for a 300K scene in the infrared channels (Kramer, 1994). The instantaneous field of view provides an approximate resolution of up to 1 km at nadir.

Prior to the ISIR program, no real assessment had been made of the spectral-radiometric performance of UMADs. All previous tests of sensitivity had been done broadband. ISIR used an early prototype device and the measurements shown here are not reflective of state-of-the-art devices. The measurements show an NEDT of 80mK for the broadband case current production devices offer a performance ranging between 30–50mK.

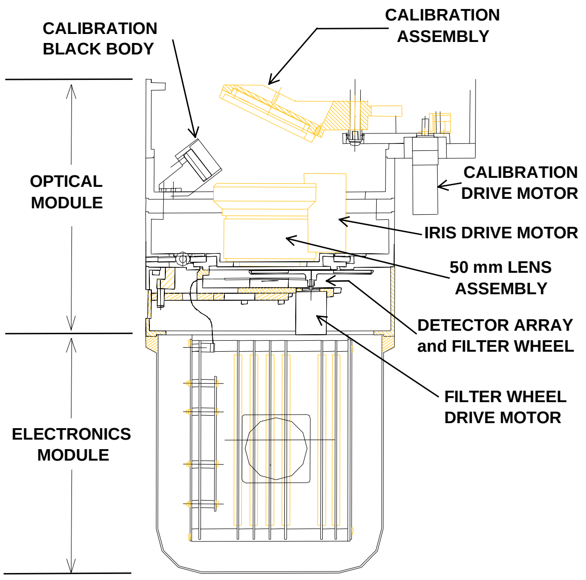

Fig. 1. Design of the Infrared Spectral Imaging Radiometer (ISIR) instrument.

A schematic of the ISIR instrument is shown in Figure 1. Frame averaging is used to obtain the 0.12K sensitivity requirement. Time delay integration (TDI) is employed in ISIR to continuous imaging of 320 pixel cross track. Images are acquired at 30 Hz and successive rows of detectors are integrated in a time-delayed sequence, adding the signals from the pixel elements that originate from the same earth location. Hence, TDI requires that the image motion due to the forward motion of the platform across one pixel row and the frame readout rate be synchronized. In the absence of correlated noise, TDI improves the signal-to-noise ratio by the square root of the number of pixels used in the averaging process. For ISIR the spectral bands were selected by filters mounted on a rotating filter wheel. Radiance calibration was through an internal black body target that was viewed as part of the imaging sequence. Laboratory measurements and analysis of ISIR on orbit data in comparison to airborne radiometers demonstrate that a 0.12 K brightness temperature accuracy was obtained.

Shown in Figure 2 is an example of 10.7 um imagery collected during the ISIR shuttle flight of STS-85. This figure includes a compilation of 6 individual image frames. Each of these frames was acquired while operating in a mode that used 40 pixels in the TDI process and the images were registered during post-processing. Additionally, these data have been calibrated in units of brightness temperature and a color scale indicating the range of observed temperatures is shown. Cooler temperatures of course tend to indicate higher cloud-tops but this is dependent upon the optical depth of the cloud under consideration. Measurement on ST-85 included some direct cloud height measurements by the Shuttle Laser Altimeter.

The image data were collected at a rate sufficient to provide overlap from one image to the next. This allows for a relative registration to be performed wherein one component of an image pair is selected as the reference to which the other component image is registered. Image-processing techniques are used to determine the relative translation of each image and a geometric transformation based on the determined displacement is applied. An alternative approach to registering the data is to do so based upon the altitude, orientation, and forward motion of the spacecraft. However, this is less practical because clouds at different altitudes require different transformations and thus registration requires apriori knowledge of cloud height.

4. COVIR

The Compact Visible and Infrared Radiometer (COVIR) instrument is being developed with the goal of providing an operational imager for small satellite missions dedicated to earth and climate monitoring (Lancaster et al., 2001). Small satellite missions continue to increase in priority at NASA as they hold the potential for improved

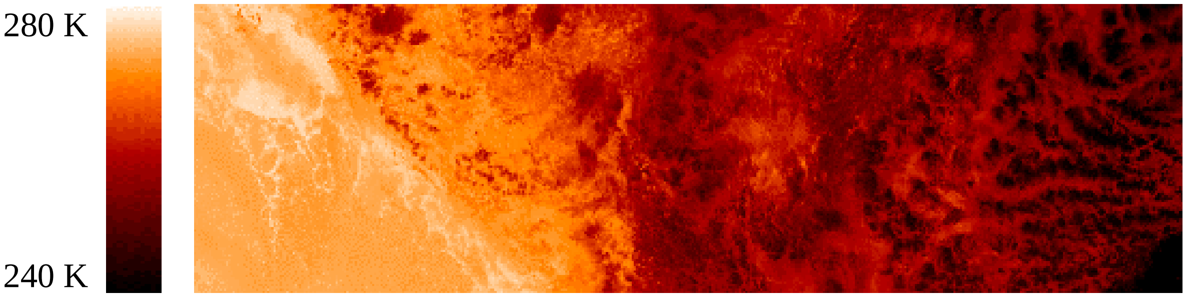

Fig. 7. Imagery acquired with the ISIR instrument of an optically thick cloud scene spanning several kilometers in altitude.

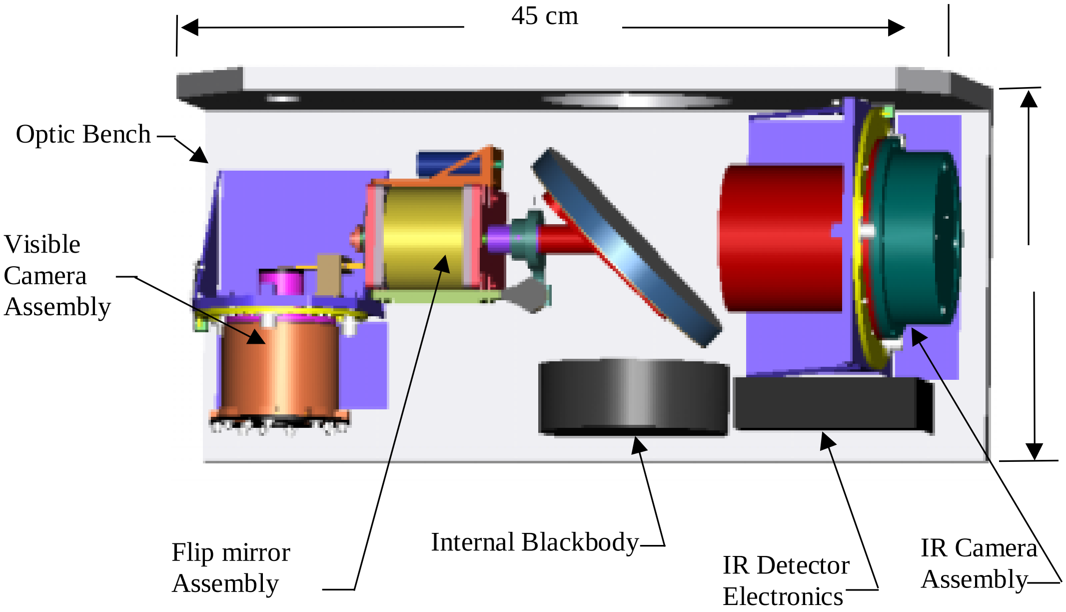

Fig. 3. A solid body model of the Compact Visible and Infrared Radiometer.

temporal coverage of the earth environment through multiple missions and an opportunity for increased scientific yield through the deployment of different complements of mission instrumentation.

The spectral selection for ISIR was achieved with the use of a filter wheel. Using this approach the scene imaged onto the entirety of the detector was sampled simultaneously in a single channel and sequentially in each of the four channels. Although the COVIR instrument operates on this same principle it departs from this approach by incorporating a strip filter array within the UMAD detector package. Hence, as the instrument platform advances the image scene moves sequentially from one filter to the next. An instantaneous field of view (IFOV) of 15 degrees is contained in the cross-track direction of the detector and 11 degrees in the along-track direction.

The design of COVIR consists of one visible and one infrared camera, a flip-mirror mechanism and internal blackbody for calibration, and the optics bench support structure on which they are mounted. A solid-body model of these subsystems is shown in Figure 3. The view toward the Earth is made through the top direction. For ease of accommodation the optics bench consists of a structural "L" bracket on which all components remain mounted to the sidewall regardless of the platform. The primary subsystem of the COVIR instrument is the infrared camera. It is built around a Lockheed Martin Infrared Systems (LMIRS) SIM200 imaging module incorporating a LAM 2D-class infrared focal plane array. This imaging module includes the UMAD in its package on a focal plane front-end board, a video signal processing and control card, and a power supply card. The IR is imaged through a fast, F/0.8, 55mm focal-length compound lens is made up of one zinc selenide and two germanium optical elements. This configuration provides an IFOV of 0.833 mrad/pixel; equivalent to ¼ km ground resolution when operated at Shuttle orbit altitude and ½ km resolution when placed in polar orbit at 600 km altitude. A flip mirror mechanism is used to provide rapid two point calibrations. This mirror is mounted at 45 degrees to the motor shaft of a single-axis direct drive stepping motor. The mirror is made up of a lightweight aluminum foam core that has been plated with nickel, polished, and coated with gold for high reflectivity in the IR bands. This mirror rotates 90 degrees and settles in less than ¼ second. During normal operation the mirror will be regularly rotated to view the Earth, a port for viewing cold space, or an internal blackbody. When viewing the Earth scene the pointing is repeatable to within 20 urads. Regardless of the target the number of optics in the optical path remains constant.

The internal blackbody assembly of COVIR provides a source for frequent two-point calibrations when combined with views to cold space. For proper calibration of the imagery data, knowledge of the temperature of this blackbody must be achieved to within an accuracy of 0.1^{o}C, and uniformity must be maintained across an approximate 15cm aperture. A two-phase, copper/water sinter wick device developed by the semi-conductor industry for cooling high heat density IC's is used as the iso-thermalizing baseplate for the blackbody assembly. To this baseplate a honeycomb structure is epoxied and painted with a high-emittance black paint. Experimentation with straight-cut and bias-cut honeycomb structures, as well as flat and glossy black paints has shown little dependence of the performance of this blackbody on these parameters. These same laboratory measurements have also shown that this novel design to a spacecraft blackbody does indeed provide the required radiometric accuracy.

Operation of the visible camera included in COVIR departs significantly from the approach taken with the infrared camera. Whereas the IR camera is a pushbroom imager that uses a 2-D array, the visible camera employs continual readout of four linear arrays. In order for the visible imagery to be used together with that of the infrared camera in a multi-spectral analysis, the two sets of data must be registered to within about ¼ pixel. This means that the pixels of the two detectors must share common fields of view and that the readout of the visible detector must be clocked to the infrared detector. The visible camera optics have been designed to provide the same 0.833 mrad/pixel IFOV for the 21 um pixels of the visible detector and only the center 327 of them are used to build up continual imagery. Ten pixels on both ends of the linear arrays are masked to provide a dark current reference.

The COVIR electrical system consists of the electronics assembly and drive motors along with the necessary wiring connectors and cable harnesses to connect these subassemblies to each other. The microbolometer array detector that is the heart of the infrared camera is supplied with various associated electronics. The objective of COVIR is to produce an engineering model radiometer. As such, these associated electronic cards remain in their commercial format, meeting military specification, and no effort has been made to optimize or limit the circuitry included on them for space flight. For a free-flyer mission much of the IR camera circuitry would be removed to reduce the associated risk of failure of parts that are not pertinent to this application. Combined, the COVIR electronics assembly consists of 7 printed-circuit boards and three camera-electronics signal processing boards. The printed circuit boards include a TDI processing board, a house keeping and digital I/O board, and a board for control of various heaters and TEC power supplies. Also, there is the visible camera interface board, a control DSP board and a power supply board.

5. GEOSYNCHONOUS

Uncooled infrared array detectors have significant potential for imaging radiometer applications from geosynchronous orbit. Small instruments could be developed for specialized and general applications that require higher resolution or more rapid repeat imaging. Large-format UMAD arrays offering 1024 x 1024 pixels are now being developed (Tsao et al. 1999). An issue is whether sufficient sensitivity can be obtained for geosynchronous applications. Studies indicate that with frame averaging, similar to that demonstrated for our LEO instruments but direct rather than TDI, sufficient sensitivity for cloud observations can be readily obtained. The influence of correlated noise is a limiting factor, but such pattern noise can be largely eliminated by masking and dither techniques. An additional requirement, as for LEO applications is a fast optical design. System studies indicate that practically sized instruments are possible. A special study has been made on an imager for rapid detection of volcanic eruptions.

6. SUMMARY

The use of uncooled infrared detectors for space borne imaging has been demonstrated by the shuttle ISIR hitchhiker experiment. The Compact Visible and Infrared Radiometer instrument is now being developed at the NASA Goddard Space Flight Center with the goal of providing an operational design for visible and infrared imagery for small satellite missions dedicated to earth and climate monitoring. Use of an uncooled microbolometer array detector as a pushbroom multiwavelength image sensor allows the size, cost, and weight of the instrument to be reduced through the elimination of a cooler. The COVIR instrument is being developed as part of the NASA Instrument Incubator Program (IIP) as an engineering model. The goal of the IIP is to develop laboratory prototype instruments that can be rapidly upgraded to meet flight standards and integrated into a spacecraft. The target spacecraft for the COVIR instrument is a sun synchronous, polar orbiting earth satellite at a nominal altitude of 600 km. The COVIR instrument may be tested on a shuttle flight in 2003. Although it is not being developed expressly as a shuttle instrument, a flight provides an ideal opportunity to test the instrument capabilities under space flight conditions.

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