BIRD IR SENSOR DYNAMIC ADAPTATION FOR HIGH TEMPERATURE EVENT RECOGNITION

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ABSTRACT

Existing now spaceborne sensors are able to provide information on fire risk as well as to monitor burned areas. However, existing spaceborne sensors – mostly meteorological satellite sensors - used for active fire recognition suffer from serious limitations, such as saturation effects in the mid infrared channel. They present snapshots of fire occurrences only. The global change research and disaster management community expects from new and dedicated spaceborne fire observation sensors quantitative information on fire characteristics. The German Aerospace Center (DLR) and its industrial partner OHB-System, have been working on new spaceborne fire missions since 1994 [FIRES, 1994]. The first of them is DLR small satellite mission BIRD (Bi-spectral IR Detection), a technology demonstrator which will be launched mid of 2001. BIRD uses mid infrared range (MIR) at 4 µm and thermal infrared (TIR) at 9 µm solid state pushbroom imagers with real time digital signal processing providing an adaptive and very high dynamic range in radiometry for the High Temperature Event (HTE) recognition in the sub-pixel domain. The paper describes the physical background and the main technical solutions of the dynamic adaptation approach implemented within the BIRD-IR-Sensors.

INTRODUCTION

The observation of high temperature events from Space is a main task of the BIRD small satellite mission. That is an interesting part of remote sensing and is important for global monitoring of environmental processes. This mission connects the application of new line array IR Technology working in the mid infrared range (MIR) and the thermal infrared range (TIR) with important scientific tasks on the field of remote sensing, [Goldammer, 1993 and Jahn, Briess, Sandau, Skrbek, 1994]. The IR sensor (Hot Spot Recognition Sensor HSRS) is designed on the base of a push broom scanner concept with engine cooled MCT (Mercury Cadmium Telluride) line arrays. The observation and parameter retrieval of High Temperature Events (HTE) in the sub-pixel range requires a precise sensor design based on a flexible real time signal adaptation control mechanism.

HIGH TEMPERATURE EVENTS RECOGNITION DYNAMIC REQUIREMENTS

To retrieve the temperature and the extension of a HTE from spaceborne observation the Dozier method can be applied, [Dozier, 1981]. This method is based on the deviation of the received radiation from the Planck’s law within two spectral channels. This deviation is given by the existence of two different the temperatures within a ground pixel area – the HTE temperature and the background temperature.

Wildfires – as one typical HTE - in their initial stage may occupy only a small portion of a pixel, making their signal comparable or even smaller than natural variations of the background signal. The detection of small forest fires (down to 0.001 of the pixel area) requires a sufficiently high signal-to-noise ratio in the MIR channel as well as a separation of
fire signals from natural variations of the MIR radiation. On the other hand, the sensor should not be saturated by a strong signal from large HTE occupying the whole pixel. Accordingly to these two very contrary performance requirements the BIRD IR sensors must provide:

- a Noise Equivalent Temperature Difference (NEΔT) of < 0.5 K for MIR and a NEΔT of < 0.3 K for TIR, on one hand,
- no saturation for “at sensor entrance” - temperatures of 1200 K, on the other, what means a very large dynamic range of the MIR sensor of about 20 bit and of about 16 bit for TIR.

To meet these requirements cooled array detectors, sophisticated detector exposition time control, and real-time signal processing are necessary. Only a pushbroom sensor solution - providing a sufficient pixel dwell time for the mentioned real-time processing and sensor control – allows to meet this large radiometric dynamic range [Skrbek, Lorenz, 1998].

Based on experimental results from airborne data acquisition over natural and artificial HTE, the following additional requirements must be fulfilled by the MIR and TIR sensor channels for a reliable HTE detection and HTE parameter retrieval, [Lorenz, Skrbek, Zhukov, 1999]:

- the calibration errors of inter-channel geometrical displacements as well as the inter-channel geometric stability should not exceed 0.1 - 0.2 of the MIR/TIR linear pixel size,
- the relative shape difference of the point spread functions (PSF) of the MIR and TIR channels should not exceed 10 – 20 % within the pixel size of these channels.

Furthermore, the BIRD MIR and TIR channel shall meet the following technical design rules:

- the detector line array has to be cooled to 80 – 100 K,
- the detector array cooling must be performed by a closed cycling Stirling cooler,
- the detector array must be mounted in a dewar which is equipped with an IR entrance window acting as a optical band filter,
- a cold shield has to be used between the IR entrance window and the detector array, which is necessary to avoid the illumination of the detector array by background radiance coming from the space outside of the Field of View (FOV) of the sensor,
- the design of the pushbroom sensor lens must be conducted in a way that the cold shield works as the field stop.

To fulfil the imaging and field stop conditions Re-Imager lens solutions and Direct-Imager lens solutions are possible, however the Re-Imager solutions are more mass-, space- and cost-expensive, what is the appropriate one for a small satellite mission.

**BIRD IR PUSHBROOM SENSOR DESIGN**

The BIRD IR sensor MIR and TIR line detectors are arrays of MCT loophole diodes hybridised on a silicon CMOS multiplexer chip. The MCT components mixture ratio of both detector arrays are different but the MIR and TIR array lay out are identical. The MCT arrays are completed by Silicon read-out and sample & hold circuits. All this is housed under a sealed cap containing the cold shield as well and is covered by the IR-window. The detector and the readout circuit have to be cooled to 80K. They are located on the top of the cold finger of the Stirling engine within a common dewar as integrated solution.

The staggered MCT line arrays of the MIR and TIR channel consist of 2 x 512 diodes is hybridised onto a silicon CMOS Multiplexer chip – both with an identical lay out. Each of the 30 µm x 30 µm pixels is connected to the read-out circuit (direct injection) with a common stare time control. The drain diode current is integrated on three different selectable capacitors. The voltage of the capacitors is scanned into a sample circuit at the beginning of
each read-out cycle. The output signals of these circuits are connected to the multiplexer which supplies four signal output lines of the detector.

The pushbroom scan produces a smearing effect because of the movement of satellite. To minimise smearing errors caused by this movement the integration time must be smaller than the dwell time (less than or equal to 0.1 of the dwell time).

Two control mechanisms for signal dynamic adaptation are implemented by the detector manufacturer /GEC Marconi, UK/ in the readout electronics of the line array detector:

- control of integration time, and
- control of charge collecting capacity.

These functions and the relative long dwell time of the pushbroom sensor are used to provide the real-time BIRD IR sensor dynamic adaptation.

Besides the control of the integration time and the collecting capacity, the sensitivity and the SNR can be optimised by controlling of the detector’s voltage operating point.

If saturation is close to take place - due to the imaging of a high temperature event - the MIR sensor integration time has to be decreased and/or the integration capacity must be adjusted to ensure a signal level within the operating range of the detector electronics.

A “hot event detection filter procedure” - which is applied to the digitised detector output signal - has to recognise the highly illuminated pixels in real-time frame (within a part of the pixel dwell time). However, this operation is complicated by the fact that the output signals of the detector have a large pattern noise and a non-linearity of the sensitivity characteristic. In any case, a high speed floating point signal processing is necessary to conduct this real-time operation. A single task processing system is used to perform in each BIRD IR channel:

- synchronising of the line controller for scene scanning,
- data access to accumulator memory,
- exposure control,
- adjustment of operating points,
- measuring of the scanline-related housekeeping data,
- generation of the data structure for transmission.

The main components of optics and electronics are the same for both IR channels and they are mounted on a common optical bench: The dual band optics are based on the same optical materials (ZnS, ZnSe) and lens lay out, geometric identical detector lay out, and a sampling synchronised by the electronics are necessary for an exact sampling. By this design approach a stable temperature behaviour should be reached.

The IR dual band optics consists of the same material for both spectral channels but each of them has special coating. Together with an athermalisation of the design in the temperature working range a good thermal stability can be expected. Calculations of the thermal behaviour of the optics show that we get a distortion in the order of 0.006mrad at the FOV borders calculated in the temperature range of +20°C/-15°C (working range +10°C.) Fig.1 shows that that the calculated imaging differences (distortions) between the both optics are negligible.

Both optics and detector housing (dewar and cooling engine) are adjustable mounted on an invar optics bench. This is a very compact design and is in accordance with the strong restrictions of the mass budget of the satellite.
Modularity and low cost design are the base of all components of BIRD. But a high geometric accuracy and stability of all channels were a fundamental design goal. The BIRD IR sensors called also Hot Spot Recognition Sensors (HSRS), [Skrbek et al., 1996 and Skrbek, Lorenz, 1998], - are mounted together with the Wide-Angle Optoelectronic Stereo Scanner (WAOSS) working in the visible and with the star sensors on a common BIRD payload platform.
The platform consists of two carbon fibre (CF) honeycomb panels which is connected to the satellite structure.
The CF honeycomb structure ensures a high stiffness and thermal stability of the platform and good thermal conductivity to dispose the thermal power of the instruments. The stability of this platform with the payload instruments of the Structural Thermal Engineering Model (STEM) has been measured under realistic environmental conditions. It was shown that a deviation less than +/- 0.3mrad of the axes between the instruments of WAOSS and HSRS occurs. That is about one IFOV(instantaneous field of view) of the IR sensors (0.65mrad). A calculated deformation of the both spectral HSRS heads against each other is below 0.01mrad. However these results are a good base to minimise radiometric errors after re-sampling.

REFERENCES