CALCON 2015

Condition-Based Calibration of Electro-Optical Infrared (EO-IR) Sensor Systems

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Motivation

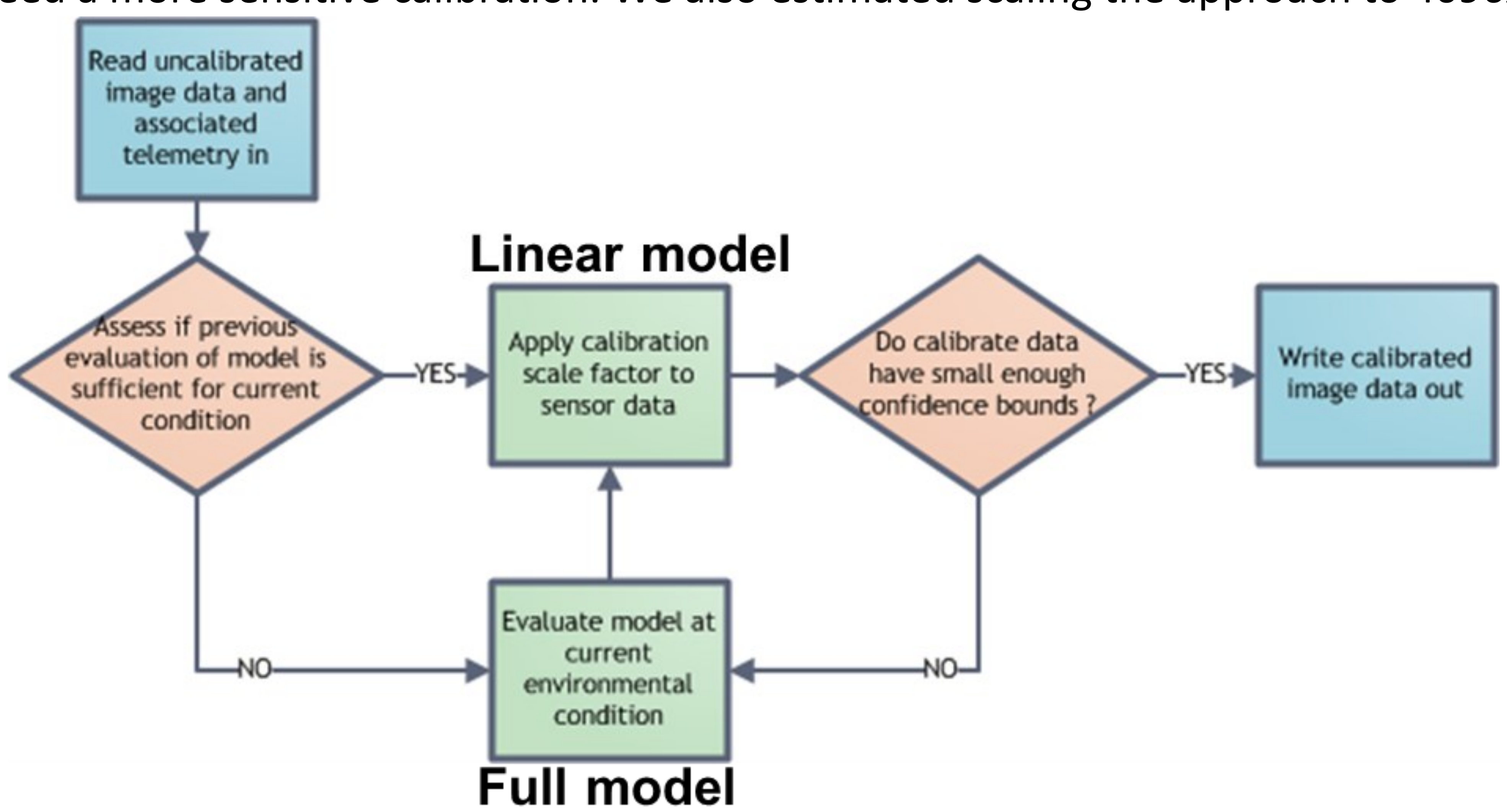
EO-IR sensors often need to provide actionable data in near-real-time, especially in early on-orbit operations (EOO) or during spacecraft anomalies. This near real-time capability requires a novel approach to applying calibration.

Objective

To demonstrate autonomous monitoring and calibration software on a flight-like processor with realistic EO-IR data, per pixel, over a wide range of operating states.

A sensor's parameters (focal plane array (FPA) temperature, FPA electronics temperature, voltage) change slowly, but we wanted to test a stressing case, similar to what might be encountered during EOO when the sensor parameters are changing very quickly. If we can calibrate in the EOO regime, then the sensor provides usable data earlier in its mission.

We selected a 64x64 pixel array as the test case, considering this size appropriate for windows within larger FPAs that may need a more sensitive calibration. We also estimated scaling the approach to 4096x4096 pixel arrays.



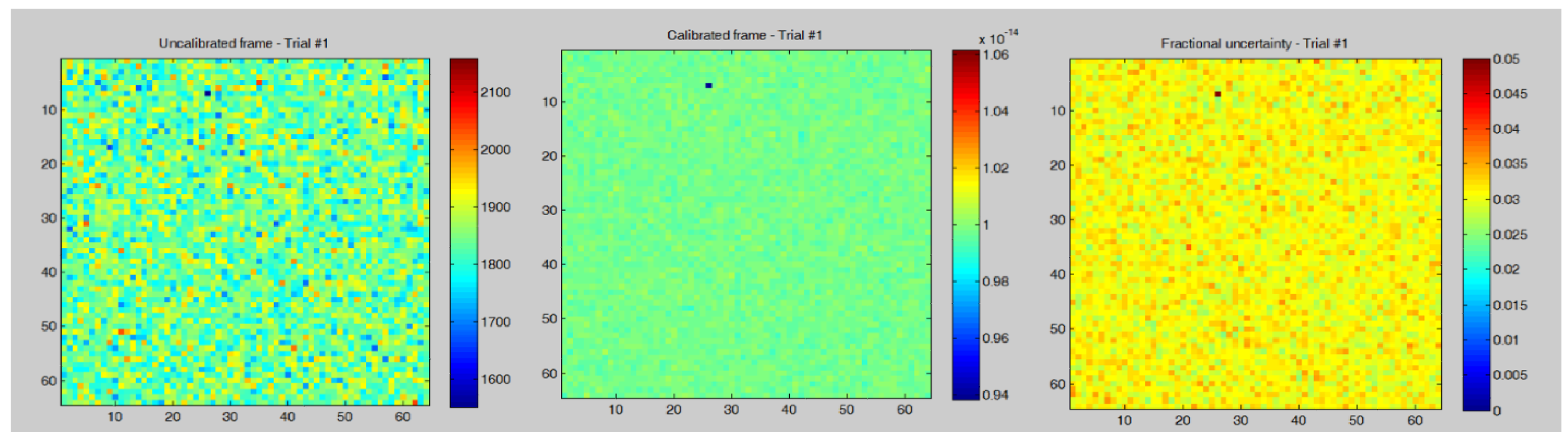
Method

1. Simulated 64x64 pixel EO-IR data run through FTI Sensor Model to add conversion efficiency and dark current as functions of the sensor parameters, 80% quantum efficiency, bad pixels, no radiation hits, 12 bit digitization, and 100 count DC offset.
2. Train calibration Gaussian Process Model on 100 frames.
3. Put calibration model and logic for applying it on Athena II single board computer (SBC) with auxiliary hardware/software for mimicking operation in a flight environment.
4. Send validation sensor data to SBC at 30 Hz.
5. Apply the calibration model in one of two methods. Adjust the fractional uncertainty, the ratio of the second order to first order determinant of the linear model accuracy, to influence whether to: (i) re-evaluate whole model {$O(220^2)$ operations} or (ii) linearly interpolate local model {$O(4^2)$ operations}. Linear extrapolation is much faster than model evaluation, but may be slightly less accurate.
6. Output is calibrated imagery data and calibration uncertainty measure per pixel, which can be visualized in FTI's Integrated Sensor Analysis Toolkit (I-SAT®).

Results

- **Calibration approach runs in real-time for 64x64 pixel, 30 Hz imagery**
- All data collected from turn-on available in 10-13 minutes
  - At startup, SBC takes 6.5 min to compute full model for all pixels for the 1st frame (mostly I/O)
  - Data could be buffered during initial calibration period
  - If all subsequent frames use the linear model, takes 3.5 min to process buffered frames and catch up, then process in real time
  - If subsequent frames use a very stressing case of full model for 4.2% of pixels per frame and linear model for rest, SBC takes 6.7 min to catch up
- After that the algorithm runs in real-time
  - When frame only use linear model, SBC processes at 183 Hz—6x faster than collecting data
  - When frames use full model for 4.2% of pixels, SBC processes at 53 Hz—twice faster than collecting data
- Full model and linear interpolation of local model result in similar calibration accuracy, relative to truth irradiance levels input into the FTI Sensor. Calibration to <3% of simulated input irradiance for all sensor conditions

Raw, calibrated and calibration uncertainty



- Extrapolation to a 4096x4096 pixel, 30 Hz imagery case shows approach is not directly scalable to large focal planes (large data storage requirement and too slow calibration with tested SBC hardware)
  - TB data storage requirement, 16 hr initial full model calibration, 18 sec linear model interpolation…
- However, a modification grouping similarly-behaving pixels to use fewer models, or advanced multi core processors, would reduce memory size and processing time
- Traditional calibration could be applied to full 4096x4096 array while this Gaussian process approach could be used in a window for more responsive calibration to sensor's environmental conditions

This document has been cleared for public release under approval number 377ABW-2015-0497.