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Advanced Radiometric Imaging with Uncooled Microbolometer Cameras

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INTRODUCTION

Uncooled long wave infrared (LWIR) or thermal-infrared detectors based on un-cooled microbolometer cameras that operate without the thermal stabilization are common place within the market. These uncooled microbolometer cameras can operate with nearly the same digital sensitivity and operating range as similar TEC-stabilized cameras [1], [2]. This move toward TEC-less imaging has been driven by a variety of motivations including: reduction of camera size, instant on capability, reduction in power consumption, and reduction of camera cost.

Uncooled microbolometers are hindered by a dependence of the camera's output on the temperature of the focal plane array (FPA). Non-uniformity correction (NUC) routines that incorporate the temperature of the FPA can remove the dependence of fixed-pattern noise on FPA temperature; [3] however, these TEC-less imagers are still limited as a radiometric sensor since the output is dependent on the temperature of the FPA and other components in the camera.

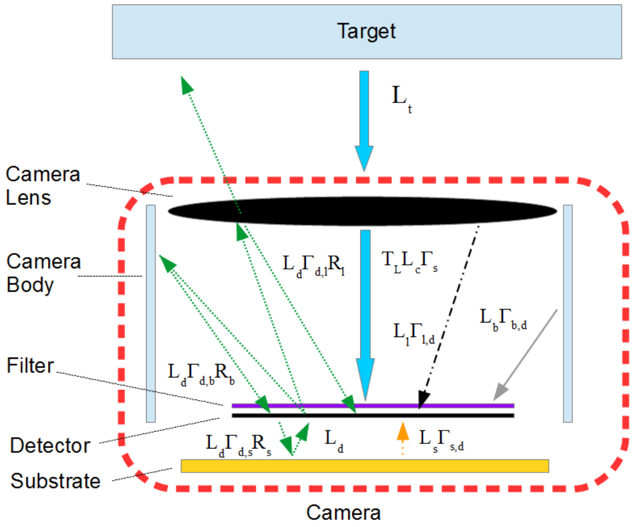


Figure 1. All components of the radiometric input to the camera. Detected signal is a combination of optical power from the detector, substrate, camera body, lens, and scene.

The result is Eq.1 where P_o represents the total optical power on the detector, Γ represents throughput or etendue, T represents transmittance, R represents reflectance, L represents radiance, and A represents area. The subscripts denote the target (t), lens (l), filter (f), camera body (b), detector (d) and substrate (s). The negative term represents the radiant emission from the detector in all directions; however, some of the power is reflected by the substrate, camera body, or lens, some is absorbed, and some leaves the camera through the lens. This leads to a power budget for the detector that is depending on the scene radiance (or temperature), detector temperature, camera temperature, and lens temperature.

Eq. 1
$$P_o = \Gamma_t T_l T_f L_t + L_{l,d}\Gamma_l T_f + L_b\Gamma_{b,d}T_f + L_d\left(R_l\Gamma_{d,l}{T_f}^2 + R_s\Gamma_{d,s} + R_b\Gamma_{d,b}{T_f}^2 - 2\pi A_d\right) + L_{s,d}\Gamma_s.$$

The result is a signal that varies with the scene, but also the temperature of the detector, camera, and lens. For highly accurate calibration, such as those in our cloud imagers, these effects must be removed.

OUR SOLUTION

The solution utilized by NWB Sensors has hits heritage in technology developed at Montana State University [4], [5], and transferred and further refined at NWB Sensors. These methods allow for the reduction of temperature dependence in un-cooled microbolometers by more than 95%. This stabilization allows for a radiometric calibration while maintaining the benefits of un-cooled cameras. In this solution the errors in camera output is corrected using the FPA-temperature, and how it has been changing to stabilize the camera output to the output that would be experienced at a reference FPA-temperature in steady state. Once stabilized a standard multi-reference blackbody calibration is taken to associated camera output with the radiometric value of the scene. This technology is a propriety set of processing techniques that allow stabilization and *subsequent radiometric* calibration of uncooled microbolometer cameras. One of the significant advantages of these techniques is that they allow stabilization of the calibration to take place through software rather than through physical stabilization of the camera's FPA temperature. With a software-based stabilization of the camera's output the usability of these uncooled cameras is increased, and a true radiometric operation can be achieved.

APPLICATION TO REAL DATA

In the following section a un-cooled microbolometer imager was placed inside an environmental in which the air temperature was varied while the camera viewed a blackbody. In the first data set the chamber temperature had a sawtooth function from 10°C to 40°C and back to 10°C in 1.5 hours. The blackbody reference was held constant during the temperature cycles, then increased by 10°C and the chamber temperature cycles repeated. This was done for blackbody temperature from 10°C up to 60°C. After these cycles as series of soak tests were performed where the chamber was held constant while the blackbody temperature was slowly changed. During this experiment the imager FPA temperature, body temperature, and lens temperature were collected with each blackbody image. In post processing our calibration techniques were applied. The FPA temperature alone was used to stabilize the data, after which a radiometric calibration was applied. Figure 2, shows the blackbody radiances (blue), calibrated data with no FPA-temperature correction (yellow), and the calibrated data with the FPA-temperature correction applied (red). It is important to note that the blue and red data are nearly overlapping during the tests. Figure 3 shows the resulting errors in each calibration with the improvement with FPA-temperature stabilization clearly apparent. The result of the calibration is quantified in Table 1 were the stabilized calibration standard error was within ±0.28 W/(m^2sr).

CURRENT TRENDS

- Un-microbolometer cameras are becoming smaller and more compact.
- Benefits include: reduced power consumption, instant on capability, lower cost.
- As the cameras become smaller the sensitivity to detector and camera body temperature increase.

CURRENT PERCEPTIONS

- Un-cooled cameras cannot provide the stable imaging required by thermography and scientific imaging.
- Market potential for TEC-less cameras limited to semi-radiometric applications ±5°C.

OUR SOLUTION

- Lock the camera output to the output at a reference steady state FPA temperature
- Reduces FPA-temperature dependence by over 95%
- Allows for precise radiometric calibration

BENEFITS

- Stabilization of the camera's output without stabilization of its temperature.
- Open markets were radiometric output is required to uncooled cameras
- Entirely software based which can be easily integrated into existing solutions

TECHNICAL BENEFITS

- Unprecedented calibration accuracy achieved with TEC-less microbolometer cameras.
- Maintains the benefits of low-power operation
- Wide ambient temperature range
- Once stabilized a radiometric calibration can be applied

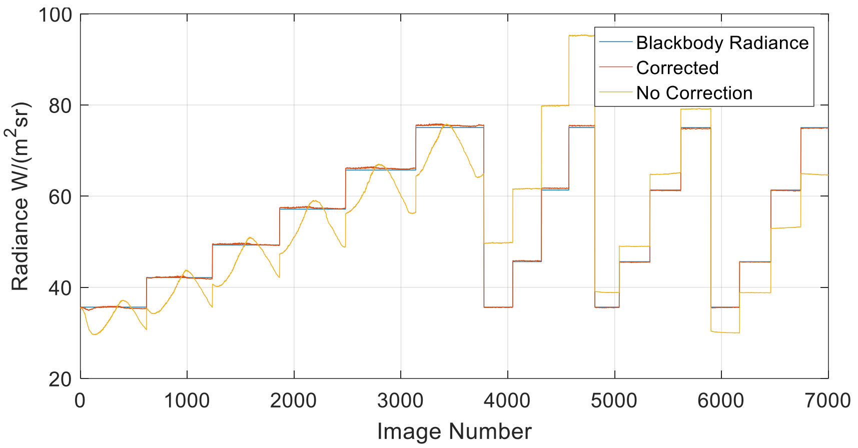
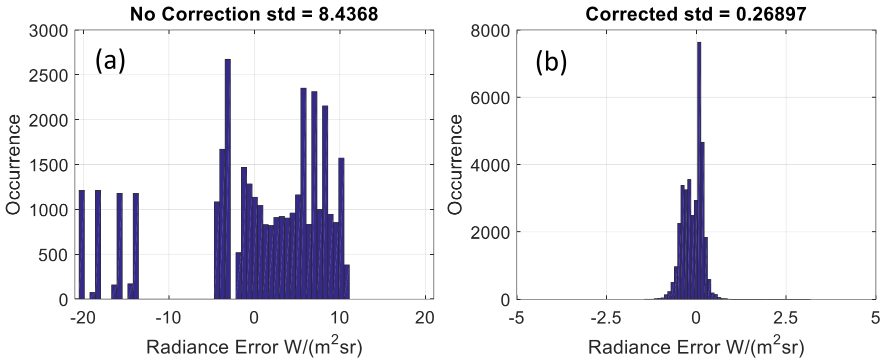


Figure 2. Plot of the calibration results showing the blackbody temperature (blue), derived blackbody temperature using the FPA-temperature dependent calibration (red), and derived temperature without compensating for FPA temperature (yellow).


No Correction std = 8.4368

Corrected std = 0.26897

Figure 3. Histogram of the resulting derived blackbody radiance errors without FPA-temperature-dependent stabilization (a) and with FPA-temperature dependent stabilization (b). Note the x axis is over a much smaller range for the corrected data.

Table 1. Summary of the calibration accuracy

Calibration	σ_t (time)	σ_s (spatial)	Combined σ_r	Calibration Bias L_b
Uncorrected	8.44 W/(m^{2}sr)	0.071 W/(m^{2}sr)	8.44 W/(m^{2}sr)	0.23 W/(m^{2}sr)
FPA-Temp Corrected	0.27 W/(m^{2}sr)	0.067 W/(m^{2}sr)	0.28 W/(m^{2}sr)	-0.09 W/(m^{2}sr)

OUR TEAM

We have years of experience in developing radiometrically calibration thermal imaging systems.

Additionally, we have years of experience developing calibration routines for unique sensors and systems.

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