Advances in Iterative Non-uniformity Correction Techniques for Infrared Scene Projection

Tom Danielson^a, Greg Franks^a, Joe LaVeigne^a, Marcus Prewarski^a, Brian Nehring^a

^aSanta Barbara Infrared, 30 S Calle Cesar Chavez, Suite C, Santa Barbara, CA 93103

ABSTRACT

Santa Barbara Infrared (SBIR) is continually developing improved methods for non-uniformity correction (NUC) of its Infrared Scene Projectors (IRSPs) as part of its comprehensive efforts to achieve the best possible projector performance. The most recent step forward, Advanced Iterative NUC (AI-NUC), improves upon previous NUC approaches in several ways. The key to NUC performance is achieving the most accurate possible input drive-to-radiance output mapping for each emitter pixel. This requires many highly-accurate radiance measurements of emitter output, as well as sophisticated manipulation of the resulting data set. AI-NUC expands the available radiance data set to include all measurements made of emitter output at any point. In addition, it allows the user to efficiently manage that data for use in the construction of a new NUC table that is generated from an improved fit of the emitter response curve. Not only does this improve the overall NUC by offering more statistics for interpolation than previous approaches, it also simplifies the removal of erroneous data from the set so that it does not propagate into the correction tables. AI-NUC is implemented by SBIR's IRWindows4 automated test software as part its advanced turnkey IRSP product (the Calibration Radiometry System or CRS), which incorporates all necessary measurement, calibration and NUC table generation capabilities. By employing AI-NUC on the CRS, SBIR has demonstrated the best uniformity results on resistive emitter arrays to date.

Keywords: Infrared, IRSP, HWIL, Scene projection, Non-uniformity correction (NUC), Iterative NUC, Hardware in the loop, MIRAGE

1. INTRODUCTION

Accurately correcting for pixel-to-pixel non-uniformities in resistive array IRSPs has been one of the greatest challenges since their introduction in the 1980's. Many approaches have been developed to correct emitter array non-uniformity [1-7]. These generally employ three basic steps: data collection, curve fitting, and generation of NUC coefficients. The three basic steps of non-uniformity correction (NUC) may be performed using an iterative approach, with each successive round of data collection producing more uniform data. Further developments in iterative NUC [8] employ a hybrid strategy for correcting array non-uniformities. In this hybrid approach, data is collected using "flood" measurements at low radiance levels (often just a few degrees above the simulated temperature floor), and "sparse grid" measurements at higher radiance levels. In flood measurements, flat field images are projected using all operable IRSP pixels and the regional radiance is recorded. In sparse grid measurements, every nth pixel in a horizontal and vertical pattern is driven while the neighboring pixels are left undriven (Figure 1). The sparse grid pattern is "walked" across the array until the radiance of each pixel has been

Infrared Imaging Systems: Design, Analysis, Modeling, and Testing XXVI, edited by Gerald C. Holst, Keith A. Krapels, Proc. of SPIE Vol. 9452, 945210 · © 2015 SPIE · CCC code: 0277-786X/15/\$18 · doi: 10.1117/12.2177456 measured. The lower-level flood measurements allow the user to correct for larger scale variations in the ambient backgrounds, while the sparse grid measurements allow the user to perform a true pixel-by-pixel measurement of the array uniformity at higher temperatures. The iterative NUC process has been highly successful, regularly producing IRSPs with non-uniformity, defined using all operable pixels as the standard deviation divided by the mean radiance, of less than 3% over a temperature range of up to 400 K.

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Figure 1: An example sparse grid pattern used to measure individual pixel radiance

A further development of the baseline iterative approach (the Advanced Iterative Non-Uniformity Correction, or AI-NUC) improves upon the successes of the iterative NUC process by generating NUC coefficients from radiance data obtained from multiple passes. This feature is especially useful for low-radiance sparse grid uniformity radiance measurements, as the measurement uncertainty of these data points can sometimes exceed the actual IRSP uncertainty. The ability to average over multiple data collection passes with the AI-NUC procedure allows the user to greatly reduce the contribution of the measurement uncertainty to the overall non-uniformity. The AI-NUC process also allows the user to select the specific radiance data subsets to be used for the NUC coefficient generation, thus permitting the removal of effects due to changes in experimental setup, camera calibration, and other factors that can complicate the process of converging to a final set of NUC coefficients.

2. SYSTEM DESCRIPTION

AI-NUC has been developed and validated using three MIRAGE-XL (large format: 1024 x 1024 pixels) and one MIRAGE-H (small format: 512 x 512 pixel) emitter arrays. AI-NUC was employed in the mid-wave infrared band (MWIR) for all of the MIRAGE-XL systems, and in both the MWIR and long-wave infrared band (LWIR) for the MIRAGE-H system. The MWIR measurements were performed using a liquid nitrogen cooled Indium Antimonide (InSb) MWIR camera, while the LWIR measurements were performed using a micro-bolometer array corrected for camera drift employing previously-developed techniques [2].

Figure 2 shows a block diagram of the IRSP interfaced to the CRS. The CRS computer controls the camera, 3-axis stage, and blackbody source. The CRS computer also interfaces to the MIRAGE Command and Control Electronics (C&CE), which allows it to control the IRSP image projection. IRWindows4 includes test libraries that conduct camera calibration and automated IRSP uniformity data collection. While the IRSP array is imaged with the camera

in focus, the blackbody used for calibration is deliberately set off-focus so the camera records the radiance without imaging any structure or minor non-uniformities on the blackbody surface.



Figure 2: System block diagram of IRSP interfaced with CRS. The camera is calibrated on the blackbody with the blackbody surface slightly out of focus. The camera images the IRSP with the array in focus.

3. PROCESS IMPROVEMENTS WITH ADVANCED ITERATIVE NUC

AI-NUC incorporates improvements to the well-established iterative NUC technique to improve overall nonuniformity and the signal-to-noise ratio at lower drive levels. These improvements include updates to the algorithm used to derive the NUC table coefficients, and enhanced user access to the radiance data. Common to both baseline iterative and AI-NUC is the requirement that the actual drive values sent to each emitter pixel during data collection are available to the algorithm. The standard iterative NUC process involves the following steps:

- 1. Collect initial radiance data
- 2. Generate a table of NUC coefficients from the radiance data
- 3. With the NUC table applied, collect 'next pass' radiance data
- 4. Generate an updated NUC table based on the radiance data
- 5. Repeat steps 3 and 4 until target non-uniformity is reached.

With each 'pass' at NUC table generation in iterative NUC, the algorithm takes as its input the NUC table from step 3 to determine the actual drive values sent to each pixel, and adjusts the gain and offset accordingly.

The AI-NUC process follows a similar procedure to iterative NUC:

- 1. Collect initial radiance data
- 2. Generate a table of NUC coefficients from the radiance data
- 3. With the NUC table applied, collect 'next pass' radiance data
- 4. Select appropriate radiance data from all collection passes
- 5. Generate an updated NUC table based on selected data
- 6. Repeat steps 3-5 until target non-uniformity reached

Included in the radiance data of AI-NUC are the actual drive values sent to each pixel for each collection pass. Including the pixel drive values in the radiance data eliminates the need to utilize the previous NUC table as a parameter during NUC coefficient generation, and ensures that each data point collected can be used during the generation of any subsequent NUC tables.

The Advanced Iterative approach offers clear advantages in deriving the NUC coefficients, especially in the case of lower-radiance sparse grid measurements. At these radiance values, the measurement uncertainties can be at least as large as the non-uniformities that the user is attempting to correct. Because these measurements have such a low signal-to-noise ratio, converging on a final set of NUC coefficients is difficult, as statistical outliers can have a significant impact on the fitted coefficients. In the case of iterative NUC, the user must collect multiple data points at these drive levels for each collection pass in order to prevent measurement noise from being a significant component of the NUC coefficients. AI-NUC mitigates this requirement, as the user has access to all data collected at these drive levels. This reduces the time needed to complete each collection pass. With AI-NUC, the only point at which multiple data points at these drive levels is required is during the final pass, when they are necessary to demonstrate that a sufficiently small residual non-uniformity has been achieved.

Figure 3 shows examples of fitting output pixel radiance vs. input pixel drive value curves to measured data points for the standard Iterative NUC procedure (left) and the AI-NUC procedure (right). Both iterative and AI-NUC approaches characterize the pixel radiance vs. drive relationship and adjust individual pixel gain and offset values to match the radiance target provided by the user. In the iterative NUC procedure, the coefficients are determined using a second-order polynomial fit to the pixel radiance at the NUC drive point in question and the pixel radiance at the neighboring NUC drive points. For AI-NUC, a second-order polynomial fit is also used, however, in this case, the gain and offset for each NUC breakpoint is established using the radiance data from several previous collections. The algorithm uses the data points clustered around each drive point, as well as the data points collected at the neighboring drive points, to perform a chi-squared minimization to determine the best fit. This minimization reduces the impact on the final fit parameters of any 'outlier' data points.



Figure 3: Example pixel drive vs. radiance curves fitted to a second-order polynomial for Iterative NUC (left) and AI-NUC (right). Each pass of data collection contains multiple data collections near 37000 and 40000 pixel drive.

4. RESULTS FROM ADVANCED ITERATIVE NUC

As is the case with Iterative NUC, AI-NUC delivers a high level of post-correction uniformity at high temperatures, easily meeting the target requirement of <3% residual non-uniformity. For each of the arrays used in the development of AI-NUC, AI-NUC also successfully converges on a set of NUC coefficients that delivers a non-uniformity of <3% at lowest sparse grid drive levels.

Figure 4 shows the non-uniformity in the MWIR band for one of the MIRAGE-XL systems before and after the AI-NUC has been applied. Following the approach of iterative NUC, the initial pre-NUC non-uniformity is measured for drive levels that employ sparse grid data collection only. For a simulated temperature floor of 285 K, the AI-NUC technique converges on a set of NUC table coefficients at an apparent temperature of 320 K, with a final nonuniformity within the specified 3% target. At higher drive levels, the non-uniformity improves greatly, reaching levels of 0.5%. For each of the arrays used in the development of AI-NUC, non-uniformities under 1% at the higher drive levels are typical.



Figure 4: Pre-NUC and post-NUC non-uniformity for a MIRAGE XL array that has undergone AI-NUC. Following the hybrid NUC approach, both flood and sparse grid measurements were used.

Figure 5 graphically displays the pixel-by-pixel radiance of the array from Figure 4 at an apparent MWIR temperature of 384 K before and after AI-NUC is applied. AI-NUC successfully corrects for all effects from array processing, as well as pixel-to-pixel emissivity variations. While the post-NUC non-uniformity in this figure is well within the requirement at 1.4%, additional iterations would likely reduce this value even further.



Figure 5: Radiance data for an apparent MWIR temperature of 384 K in a MIRAGE-XL array without NUC (left) and with AI-NUC (right). Greyscales for the images have been matched.

Figure 6 shows imagery in the MWIR band from a generated scene as projected by another of the MIRAGE-XL arrays used for AI-NUC development and validation. This array was also corrected to a non-uniformity of less than

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3% for all measured radiance levels. The DAC-to-DAC and column-to-column variations in the pre-NUC imagery on the left are greatly suppressed by the applied NUC, presenting an extremely clear IR target signature on a well-resolved background.



Figure 6: MWIR scene generator imagery projected on a MIRAGE-XL system without NUC (left) and with AI-NUC (right).

5. SUMMARY

The AI-NUC algorithm incorporates important improvements in the both the core algorithm and data management in order to achieve higher levels of post-correction uniformity in IRSP images than have been previously demonstrated. Utilizing data from multiple collection runs helps eliminate measurement error and deliver a more robust NUC table by minimizing the effects of statistical outliers on the fit. The increased level of access to all data used in the NUC process also allows the user to increase the level of uniformity by allowing the user to identify and remove spurious data points. These developments have been used successfully in the development of multiple MIRAGE IRSPs.

6. **REFERENCES**

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