Enhanced LWIR NUC Using an Uncooled Microbolometer Camera

Joe LaVeigne[a], Greg Franks[a], Kevin Sparkman[a],

Marcus Prewarski[a], Brian Nehring[a]

[a]Santa Barbara Infrared, Inc., 30 S. Calle Cesar Chavez, #D, Santa Barbara, CA 93103

ABSTRACT

Performing a good non-uniformity correction is a key part of achieving optimal performance from an infrared scene projector, and the best NUC is performed in the band of interest for the sensor being tested. While cooled, large format MWIR cameras are readily available and have been successfully used to perform NUC, similar cooled, large format LWIR cameras are not as common and are prohibitively expensive. Large format uncooled cameras are far more available and affordable, but present a range of challenges in practical use for performing NUC on an IRSP. Some of these challenges were discussed in a previous paper. In this discussion, we report results from a continuing development program to use a microbolometer camera to perform LWIR NUC on an IRSP. Camera instability and temporal response and thermal resolution were the main problems, and have been solved by the implementation of several compensation strategies as well as hardware used to stabilize the camera. In addition, other processes have been developed to allow iterative improvement as well as supporting changes of the post-NUC lookup table without requiring re-collection of the pre-NUC data with the new LUT in use.

Keywords: Scene Projection, LFRA, Mirage XL, LWIR, NUC, microbolometer, IRSP

1. INTRODUCTION

Non-uniformity correction (NUC) is important in the preparation of an infrared scene projector (IRSP) for projecting high fidelity images. A good NUC must be performed in the same response band as the sensor it is going to test. In the past, most long-wave infrared (LWIR) NUCs have been performed using a cooled LWIR camera. While high performance cameras in the mid-wave infrared (MWIR) portion of the spectrum are fairly common and reasonably priced, cooled large format LWIR cameras are relatively expensive. Large format uncooled cameras are far more available and affordable, but present a range of challenges in practical use for performing NUC on an IRSP. Despite the difficulties introduced by using an uncooled camera, the order of magnitude price difference between uncooled and cooled cameras justifies a careful look using the lower cost microbolometer. Initial results of a development program to use a microbolometer camera to NUC an IRSP were published previously[1]. In this paper, we report further progress made in this development program. Both previously presented and as well as new enhancements have been implemented. Previous NUC efforts have focused on deriving NUC coefficients for a particular application of the IRSP. Then NUC table was collected with a particular linearization. One of the new features is software that allows NUC tables to be modified to account for changes in the linearization. Also implemented was a capability to perform automated collection at different emitter pixel positions relative to the camera. The combination of these enhanced features allow NUC performance to remain good while driving down the equipment cost.

2. NUC SYSTEM SETUP AND PREVIOUS RESULTS

The IRSP used in this study was a Santa Barbara Infrared MIRAGE XL system[2] with a 1024x1024 array capable of producing apparent temperatures of over 550K in the 8-12 micron band. (This corresponds approximately to a 700 K

Technologies for Synthetic Environments: Hardware-in-the-Loop XVI, edited by Scott B. Mobley, R. Lee Murrer, Jr.,
Proc. of SPIE Vol. 8015, 801508 · © 2011 SPIE · CCC code: 0277-786X/11/$18 · doi: 10.1117/12.901620

MWIR apparent temperature given the spectral output curve of the array.) The specific camera used in these experiments was a FLIR Photon 640 with a standard 25 mm f/1.4 lens. The focal plane array (FPA) has a pixel pitch of 25 µm and a NEdT of ~100 mK when coupled with the f/1.4 lens used. The as-manufactured near focus distance of the camera and lens combination was 2 meters. To focus on the array at shorter distances, a custom spacer was added between the camera and lens, which reduced the near focus distance to approximately 20 cm.

The previous NUC study achieved residual non-uniformities on the order of 1.5% at moderate to high apparent temperatures (>400K)[1]. However, at low radiance levels, the non-uniformity (NU) increased to over 10%. Long period drift in the camera as well as the rest of the system including the chiller and the lab environment led to significant errors as the radiance levels dropped to near or below ambient apparent temperatures (~300K).

3. PROCESS IMPROVEMENTS

3.1 Camera Stabilization

The most challenging aspect of any NUC process is developing a good understanding of the response of the camera being used. Microbolometer cameras have several distinct differences from cooled IR cameras typically used for NUC. As well as being uncooled, they have no gating (they are always integrating) and the pixels have a limited temporal response. Microbolometers also typically have more limited thermal resolution and a more limited dynamic range than a cooled camera. The uncooled nature of the camera leads in part to the lower thermal resolution due to increased background noise. It also leads to a more difficult problem of temporal drift. These three issues: drift, temporal response and thermal resolution are the primary limitations in effectively using a microbolometer for NUC of an IRSP. All three of these issues were addressed in a previous discussion[1]. The changes made in regards to temporal response and thermal resolution have been quite direct. Some waits were extended to ensure the camera was properly settled prior to data collection and more runs were measured at low radiance levels to help improve the signal to noise ratio near the resolution of the camera. The issue that had the more significant change implemented was that of drift. Drift was found to be a major contributor to the residual non-uniformity in the previous results. Drift is particularly important in sparse grid measurements where the ratio of the collection area to the emitter area is rather high. The collection area for an emitter pixel in the sparse grid may cover 25 or more camera pixels. Furthermore, the emitter pixels usually map to a fraction of a camera pixel. This leads to the camera drift having greater than 100 times the impact on the sparse grid measurement than it would have on a flood scene of the same apparent temperature being calibrated. Two main contributors were addressed in the recent work. First, the camera body temperature was stabilized by attaching it to a temperature controlled plate. This reduced the effects of long period changes in the ambient environment. Closer investigation of some of the short period oscillations in the system were traced to instabilities in the chiller control loop. These were addressed by optimization of the chiller PID constants.

3.2 Grid positioning

One of the more challenging artifacts to deal with in NUC processing is that of sampling artifacts due to undersampling of the emitter array by the camera. These artifacts have been pervasive in sparse grid measurements and numerous methods have been developed to deal with the issue. One method used by the group at Kinetic Hardware In-The-Loop Simulator (KHILS) has been to sample with multiple camera positions, look angles and grid spacings and then averaging all of the results. The basic concept being that all the changes will introduce random small changes in the emitter locations and the average result will be a better measurement of the actual pixel radiance than the individual measurements that contain the sampling artifacts. Another methods used by Defence Science and Technology Organisation (DSTO) involves determining the point spread function of the system at each point on the camera image and then using this information to derive the radiance of the emitter. Santa Barbara Infrared, Inc. (SBIR) has developed a different approach to addressing the sampling artifacts. The NUC process at SBIR is carried out with the camera mounted to a 4 axis positioning stage. There are 3 stages with travel limited to 50mm that allow positioning to 0.1um. There is also a stage with 1m of travel used to move the camera between the scene projector and blackbodies used for calibration. The sub micron positioning stages allow precise positioning of the camera. The enhanced NUC process collects data with the camera precisely aligned in four sub camera pixel phases. In the first collection, the hunt pixel is positioned on the center of a camera pixel. The camera is then moved 0.5 camera pixels in x, and y and both x and y to collect the four phases. These collections are then averaged to reduce the sampling artifacts. This method is a bit more deterministic than the random alignment method and does not rely on good knowledge of the camera point spread function, which is not optimal for lens currently in use.

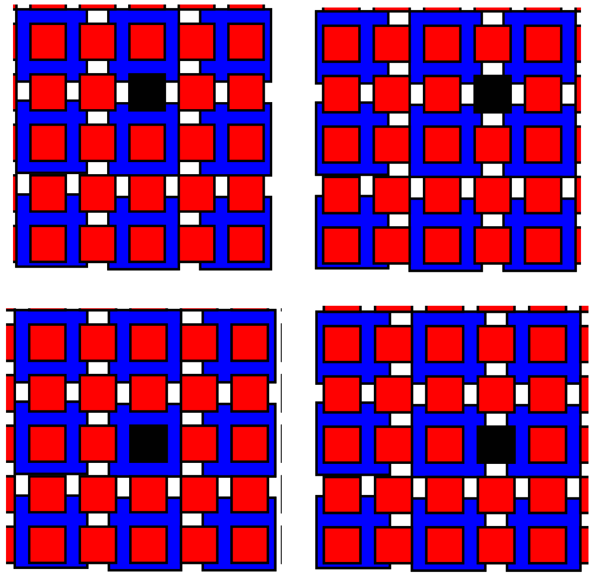

Figure 1. Multiple sampling of the emitter:camera phase. The emitter hunt pixel (shown in black) is initially centered on the camera pixel shown in blue (bottom left image). After a full uniformity map is measured, the camera is then moved over half a camera pixel so that the hunt emitter falls between two camera pixels (bottom right). The camera then moves up half a pixel (upper right) and finally left half a camera pixel (top left) to complete collection in all four phases.

3.3 Coefficient Calculation

The NUC process follows a standard procedure[3,4]:

1. Calibrate the camera
2. Measure the radiance of each pixel using the sparse grid method
3. Perform drift correction
4. Generate NUC coefficients

Details of the first three steps can be found in the previous work as well as other discussions, which better detail the sparse grid measurement methodology[1,3,4]. The other significant development has been in the calculation of NUC coefficients. The non-uniformity correction used in the MIRAGE-XL IRSP system is a piecewise linear correction with 16 segments. A lookup table for each segment contains gain and offset corrections for each pixel in the array. The new capabilities in NUC table generation have the capability for performing iterative NUC as well as modifying NUC tables to accommodate changes to the post-NUC linearization file. Both of these features are based on the same concept. Because the NUC table used during a post NUC collection is known, as is the input drive level for each grid point, it is a straightforward calculation to derive the post-NUC drive that generated the radiance measured. Ideally, iteration would not be necessary. If the pixels all followed a known curve, measuring a few points on that curve would give enough information to allow precise interpolation and an excellent NUC to be derived. In reality, there are some characteristics of resistive arrays that make having an iterative capability desirable. The first issue that iteration can be of use in solving is that of outlier pixels. Some arrays have pixels that exhibit significantly different radiance output when compared to the average pixel. When measuring, the same camera settings must be used for all pixels. Ideally, the camera would be configured such that the average radiance generated an easily measurable signal (filling half the camera pixel well for instance) while the brightest pixels do not saturate the camera. If there are significant outliers, these two criteria cannot be met simultaneously. Allowing iteration greatly improves the NUC for these outlying pixels. The first set of NUC coefficients typically bring the pixel response down to a level that is within the optimized dynamic range of the camera. Subsequent iterations allow more accurate correction by avoiding any problems of saturation.

The second issue that iteration can help address is large scale structure in the residual non-uniformity. Some IRSPs exhibit large scale structure even after a careful sparse grid NUC. This structure can be due to variations digital-to-analog converter (DAC) response or large scale variations introduced during emitter processing. Often these structures have residual features with magnitudes that are lower than the residual NU measured. Despite being smaller in magnitude than the average error over the array, these large scale structures are often visible after NUC has been applied. The reason these structures are visible is that they amount to coherent changes over a large portion of the array. Although a single point measure like the sparse grid will not show the features, they may still stand out when viewed by a human. In an array with 2% residual NU, a 1% variation of a single pixel would never be noticed. However, 1 % change for an entire DAC would stand out. Iteration can help reduce these errors by making small optimizations after an initial pass has gotten the response close to the same across the array.

4. RESULTS

The results presented in the following section are based on the NUC of a 1024x1024 MIRAGE-XL array. The array went through three iterations of the NUC process. The overall result of the new process was an improvement across the entire range. Table 1 shows the pre and post NUC non-uniformity at several drive levels after a single iteration. Figure 2 shows pre and post NUC uniformity measurement images from the first iteration. The overall statistics show a marked improvement, however there is some large scale structure noticeable in the image. Both the structure and image show improvement after two more iterations. Table 2 shows the statistics after three iterations. The average non-uniformity has been reduced to around 2%.

Table 1 Array statistics after a single NUC iteration.

Radiance [W/(cm2sr)]	LWIR App T (K)	PreNUC NU	1 Iteration NU
0.00175	307	10.3%	5.5%
0.00238	316	12.1%	2.4%
0.00460	343	13.1%	1.4%
0.00792	376	12.2%	1.7%
0.01272	415	11.1%	2.3%
0.01887	456	10.1%	2.7%
0.02251	478	9.5%	3.1%
0.02655	501	9.0%	3.1%
0.03069	523	8.6%	3.4%
0.03461	542	8.1%	3.5%
0.03864	562	6.6%	3.6%
0.04366	585	5.2%	3.9%

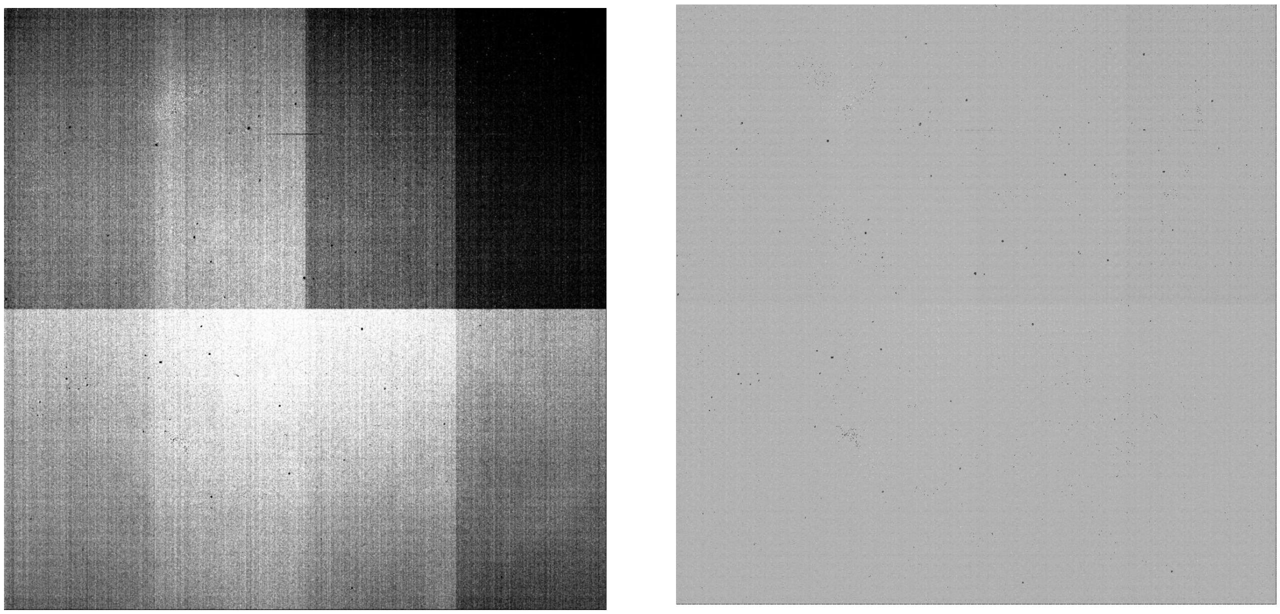

Figure 2. Collection point 3 NUC Results after a single iteration Pre NUC and post NUC composite images after one iteration from the third band in Table 1. The NU is significantly improved, however there is some large scale structure apparent in the DAC blocks. This NU is improved after three iterations as seen in Figure 3.

Table 2 Post NUC non-uniformity after three iterations.

Radiance [W/(cm2sr)]	LWIR App T (K)	PreNUC NU	3 Iteration NU
0.00175	307	10.3%	4.6%
0.00238	316	12.1%	2.0%
0.00460	343	13.1%	1.3%
0.00792	376	12.2%	1.2%
0.01272	415	11.1%	1.3%
0.01887	456	10.1%	1.7%
0.02251	478	9.5%	1.9%
0.02655	501	9.0%	2.1%
0.03069	523	8.6%	2.3%
0.03461	542	8.1%	2.4%
0.03864	562	6.6%	2.5%
0.04366	585	5.2%	2.9%

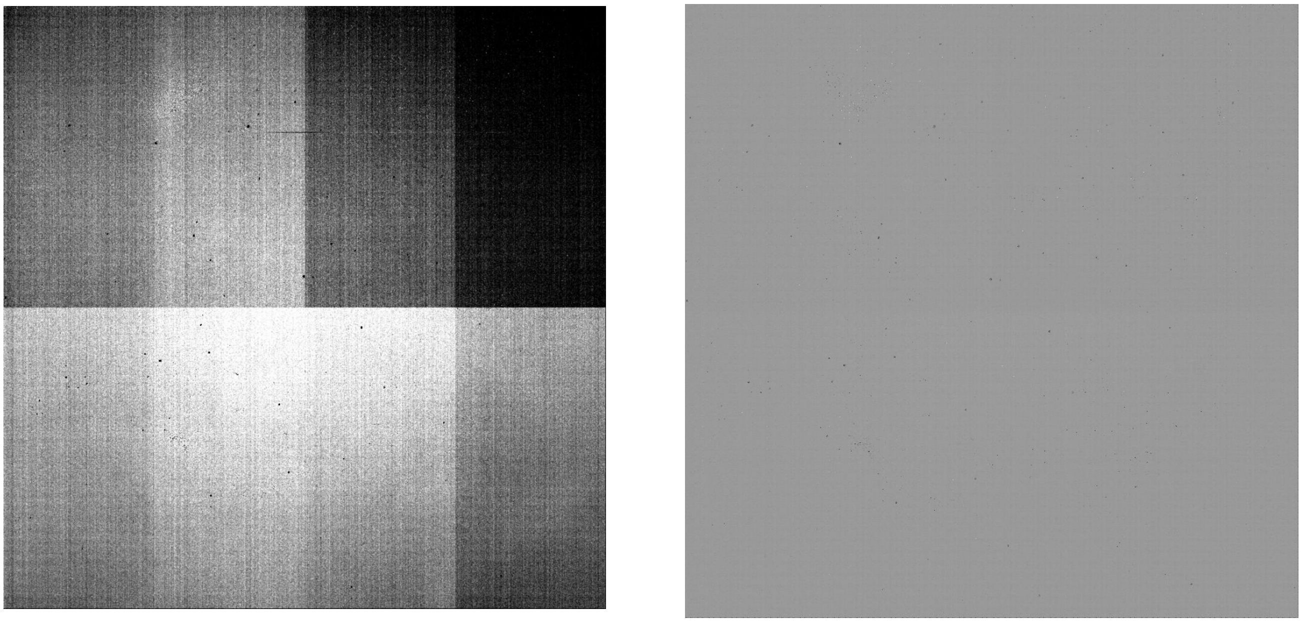

Figure 3. Collection point 3 NUC Results Pre NUC and post NUC composite images after three iterations from the third band in Table 2. the NU is significantly improved. Both images use the same stretch to generate the grey scale.

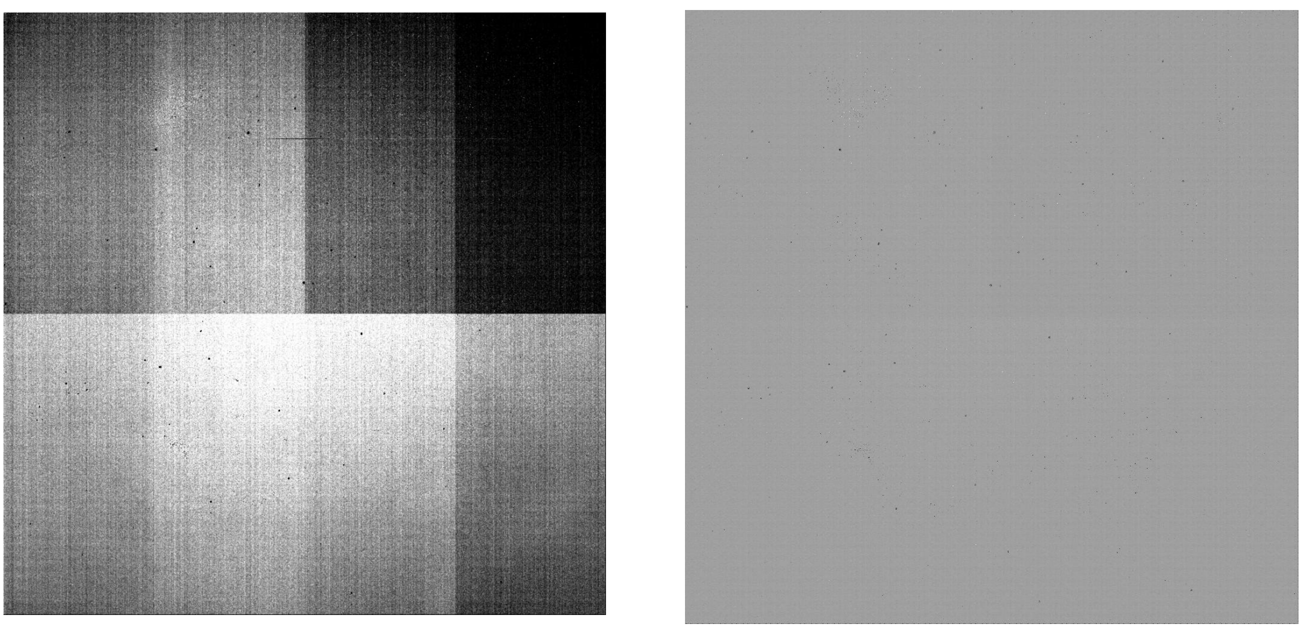

Figure 4. Collectin point 6 NUC Results Pre NUC and post NUC composite images after three iterations from the sixth band in Table 2. the NU is significantly improved. Both images use the same stretch to generate the grey scale.

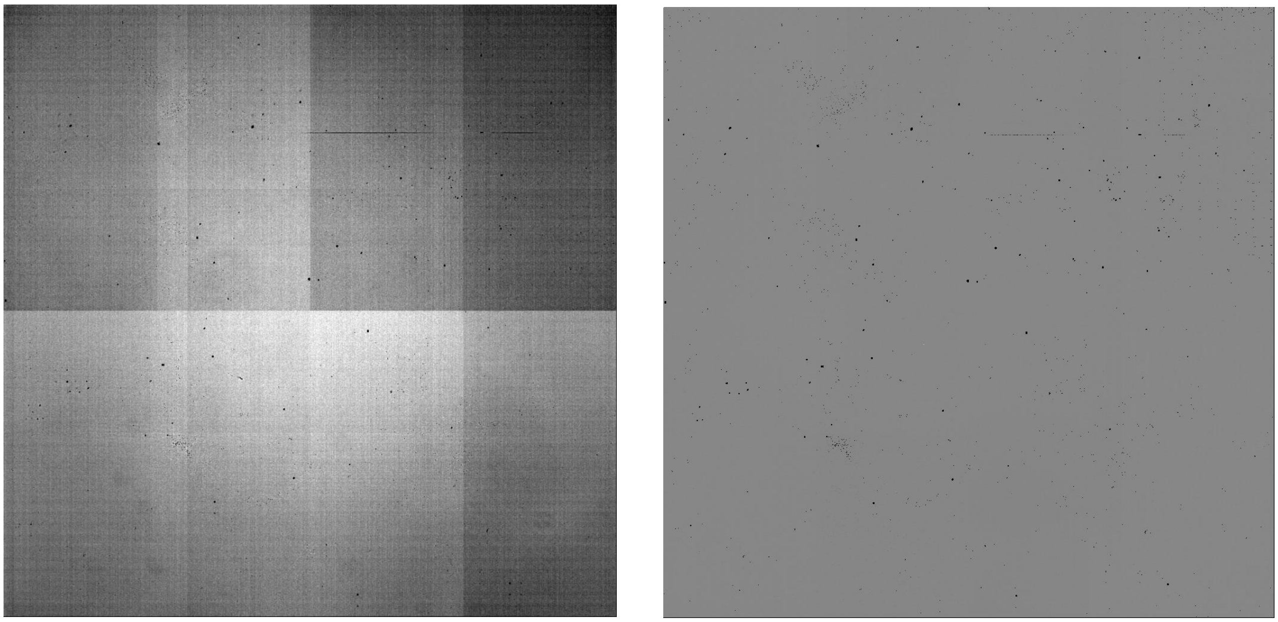

Figure 5. Collection point 11 NUC Results Pre NUC and post NUC composite images after three iterations from the eleventh band in Table 2. the NU is significantly improved. Both images use the same stretch to generate the grey scale.

5. DISCUSSION

One issue that remains in NUC processing is how best to describe the results. Conceptually, everyone wants the same thing: the same radiance out for a given input. However, the various measurement errors and other artifacts introduced by the NUC process limit how close a NUC can come to this ideal. The most common method used to describe the residual non-uniformity is by reporting the sigma over mean. While this is a good description of the overall NUC performance, not all of the pixels fit in a normal distribution, and even though the overall distribution may be close to normal, there may be other structure in the image that is lost when using a single number to describe the merit of the NUC. Therefore, a better performance threshold is needed to determine when a NUC is good enough to be acceptable. Defining a useful figure of merit for a NUC can be quite application specific. That makes development of a common process rather difficult as each application has different thresholds for the various artifacts that remain in the residual non-uniformity of the radiant output of the array. The common practice of reporting the standard deviation over the mean is often not enough to specify an acceptable end product. Some applications may be sensitive to coherent artifacts that are smaller than the standard error, but still visible. Others may be sensitive to outliers should the residual non-uniformity not follow a normal distribution. The sensitivity of the application to the distribution of the post-NUC radiance must be considered and an acceptance criteria developed prior to the NUC process.

The progress to date described in these proceedings is part of a continuing effort to develop an uncooled LWIR NUC capability. The efforts described above focused on overcoming the limits of the camera and improving the ease of use and utility of the software used to generate the NUC coefficients. Other steps are available to make further improvements. On the hardware side, the limited thermal resolution remains one of the most significant system limitations. The most direct method for improving the resolution is to increase the number of photons to the camera pixels. A possible improvement would be to move to an f/1 lens, which would effectively halve the NEdT and hence improve the performance by a factor of two. Typical off the shelf lenses are optimized for viewing scenes in the far field. The lens used in the measurements described here was a commercial lens that had been mounted with a spacer to reduce its minimum focal distance. The lens showed a modest amount of distortion in the outer edges of the image but it did not significantly affect the sparse grid measurements. Another off the shelf lens with an 18mm f/1.1 lens was tried, also using a spacer to decrease the minimum focus distance. This lens with the spacer produced enough distortion to degrade the measurements to such an extent that the lens was not useable. Moving to a truly useful f/1 lens will likely require a custom lens design. Finally, the search continues for an automated process to properly address the outliers in the residual non-uniformity distribution.

6. SUMMARY

Santa Barbara Infrared Inc,, a HEICO company, has developed a LWIR NUC capability based on an uncooled microbolometer camera. Camera drift, thermal resolution and temporal response time all cause significant difficulties in the NUC process and require correction strategies. Drift correction, camera stabilization and additional waiting periods address the worst of the camera drift and temporal response issues. Multiple collections at specific phases between the camera and emitter pixels reduce sampling artifacts. In addition, other process improvements have allowed an iterative solution to be applied, which improves the general distribution and deals with the problem of pixels that fall outside the optimal dynamic range of the camera during the pre-NUC data collection.

REFERENCES

[1] LaVeigne, J. et al., “LWIR NUC using an uncooled microbolometer camera”, Proc. SPIE 7663 (2010)

[2] Oleson, J., et al " Large Format Resistive Array (LFRA) Infrared Scene Projector (IRSP) Performance & Production Status," Proc. SPIE 6544, (2007).

[3] Sieglinger, B., et al. " Array non-uniformity correction -- new procedures designed for difficult measurement conditions," Proc. SPIE 5092, (2003)

[4] Sieglinger, B., et al., “Procedures and recent results for two-color infrared projection”, Proc. SPIE 6208, (2006)