A Hybrid Approach to Non-Uniformity Correction of Large Format Emitter Arrays

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ABSTRACT

Non-uniformity correction (NUC) of emitter arrays is an important part of the calibration of an infrared scene projector (IRSP), necessary to provide precise and artifact-free simulations. Producing an accurate and cost effective NUC of an IRSP is a challenge due to the complexity of the NUC process and the expense of high performance, large format infrared cameras. Previous NUC methods have typically fallen into either the sparse grid method or the flood method. The sparse grid method gives independent measurements of each emitter pixel, however, it is time consuming and becomes impractical for accurate measurements at low radiance levels, especially with lower performance but less expensive cameras such as microbolometers. Flood measurements are fast and can be applied at lower radiance, but do not allow precise measurement of the output of an individual pixel. Santa Barbara Infrared (SBIR) has developed a hybrid approach that makes use of both methods. Sparse grid methods are used at higher radiance levels to perform an initial NUC of the array. Then, a combination of flood and sparse grid data is used to extend the NUC to lower radiance levels and improve the high radiance NUC through iteration. Details of the approach and results from its application to an emitter array are presented.

Keywords: Infrared, IRSP, HWIL, Scene projection, Non-uniformity Correction (NUC), Sparse Grid NUC, Flood NUC, Hybrid NUC,

1. INTRODUCTION

Emitter array non-uniformity has been a challenge to correct since the first devices were created in the 1980s. This is partly due to the nonlinear nature of an emitter's radiant output. Further, emitter pixel drive circuitry, thermal conductance, emissivity, fill factor, and resistance (for resistive arrays) all contribute to non-uniformity. These factors are particularly troublesome at emitter temperatures near room-ambient, where many terrestrial scenes are generated.

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. Each of these steps has many variations with different degrees of effectiveness and issues. For example, sparse grid data acquisition allows for detailed evaluation of each emitter pixel, but requires specialized optics and can be time consuming. Flood acquisition, on the other hand, utilizes a faster acquisition but is limited in its ability to calibrate and correct individual pixels. Numerous other advantages and issues surround various approaches for correcting a non-uniform emitter array. This paper describes a methodology for correcting an emitter array that is both efficient and effective.

2. PREVIOUS WORK

As indicated, NUC has been performed using several different data acquisition techniques. Generally the acquisition involves either evaluating each pixel as an individual (sparse grid NUC) or as part of a broad image (flood NUC). On top of the different approaches to performing NUC, there are also different wavebands to consider. NUC has been performed primarily in the mid-wave infrared (MWIR) band owing to the availability of large format, high quality detectors. The long-wave infrared (LWIR) band, on the other hand, has historically been dominated by costly, cooled Mercury Cadmium Telluride (HgCdTe) arrays or narrow band quantum-well infrared photodetector (QWIP) devices. In recent years, microbolometer arrays have become readily available. These arrays have the advantage of being both low cost and large format. SBIR has reported methodologies and results using high NETD cameras, such as those based on microbolometers, for LWIR NUC in recent publications.

Recent work at SBIR has focused on the sparse grid approach using Indium Antimonide (InSb) MWIR cameras as well as LWIR microbolometers[2,3]. Sparse grid NUC allows for characterization of each pixel. The drawback that has been identified is camera drift during data acquisition. This drift affects both MWIR and LWIR acquisitions, though the LWIR effects using a microbolometer are more significant than those with a cooled InSb camera. Drift has been addressed in two ways. The first is frequent background correction of the camera's output. The second is an automated acquisition process which uses a large group of pixels sampled throughout the data collection as references for a drift correction algorithm. The combination of frequent background subtraction and active drift correction has significantly reduced the impact of camera drift. SBIR addressed these drift issues as reported by the authors in 2010 and 2011. The solution, focused on LWIR was directly applicable to MWIR NUC as well.

3. HYBRID NUC

Even with the drift correction methods mentioned above, there is a lower limit, below which it becomes impractical to collect data using the sparse grid method. This is due, in part, to having low signal because emitter pixels when projected onto the camera, do not fully fill a camera pixel. There is also high noise because the radiance from numerous camera pixels surrounding the peak is summed to get the total radiance from the emitter pixel being measured. Work at SBIR presented below summarizes an approach that recognizes the benefits of both flood and sparse grid methods. It utilizes them in a hybrid NUC format where flood NUC is employed at lower scene temperatures and sparse grid NUC at higher levels.

3.1 Basic Concept

Performing NUC at very low radiance levels is often a difficult process. Due to camera expense and the relatively large format (up to 1024x1024) of emitter arrays, NUCs are often performed using a camera with lower resolution than the emitter being corrected. In these cases, an emitter pixel typically subtends between 10% and 20% of the area of a camera pixel. Thus the radiance at the camera is five to ten times lower than it is at the emitter. In order to mitigate some sampling errors, cameras are defocused slightly, exacerbating the problem. When trying to present a background scene near ambient, apparent temperatures a few degrees above the substrate temperature (typically 0C) are required. For a sparse grid, if all the emitter pixel radiance were focused onto a single camera pixel, it would lead to a radiance equivalent of less than 1C on the camera. Signal to noise is further reduced because the algorithms sum the camera pixels surrounding the peak. Although the signal added in these pixels is significant enough to warrant measuring, the additional radiance is small compared to the peak while the noise added is comparable to that of the peak pixel. Massive averaging is a potential solution, but it is very impractical. The NUC procedures developed by SBIR and reported previously were based on sparse grid measurements. For collections using a microbolometer and an array substrate temperature of 0C, the NUC collections had a lower limit of around 35-40C.

Flood based NUCs are another option for correcting emitter arrays. A flood NUC turns on all the pixels at the same drive and captures the entire image at once. This greatly improves data collection times. The problem with flood based NUCs using a lower resolution camera is that they do not address each pixel individually. Because of this, an excessively bright or dark pixel might influence its neighbors. SBIR has developed a hybrid method that uses flood based collections at lower radiance levels but attempts to mitigate some of the under-sampling issues. In order to minimize these effects, an initial sparse grid data set is collected and a NUC is generated from that data. That NUC was then used to collect secondary sparse and flood data. These secondary data sets are then used to generate an improved NUC table. The initial NUC tends to improve uniformity significantly, especially for pixels that deviate significantly from the average. The most noticeable remaining sources of non-uniformity tend to be large scale variations such as differences between digital to analog converters (DACs) and column amplifiers. Ideally, the NUC based on the sparse grid measurements corrects the outliers and provides a good starting point, by deriving correction coefficients at temperatures slightly higher than those used for flood. Then the NUC based on flood measurements corrects any large scale structure that is evident below the level at which it is practical to collect sparse grid data.

Although there are many artifacts that can be corrected by flood NUC, there are others that can cause the flood NUC to introduce errors. One such case is that of no-functional or "dead" emitter pixels. Because the individual emitter pixels are not resolved in a flood NUC, one emitter can influence its neighbors. In the case where all the pixels are relatively close in radiance, this is usually not an issue. An outlier may not get corrected quite enough and its neighbors might be slightly over corrected, but these errors are typically on the order of the residual non-uniformity, if an initial NUC has been applied prior to the flood data collection. In the case of dead emitter pixels, they can influence their neighbors and cause them to be significantly over-corrected. In order to prevent this over-correction from occurring, while attempting to maintain as much information about the array response as possible, a dead pixel correction procedure was developed.

In this procedure, a dead pixel map is used, in conjunction with an estimate of "lost" radiance from the dead pixels, to correct the camera image prior to interpolation to generate individual pixel radiance. The procedure is as follows:

1. Collect flood NUC data
2. Collect a high density distortion map across the array
3. Collect an inverse sparse grid (a flood image with a grid of off emitters to simulate dead pixels)
4. Subtract the inverse sparse grid from the flood image to create a correction image
5. For each dead pixel:
    a. Locate the 16 closest points in the inverse sparse grid
    b. Discard the highest and lowest radiance points of the 16 and the take the remaining 14 points and calculate an average radiance loss for the pixels turned off in the inverse grid
    c. Out of the 14 closest points selected above, choose the pixel that is nearest to the relative camera pixel location as the dead pixel being corrected.
    d. Take the 5x5 camera block surrounding the selected grid point in the correction image, normalize its sum to that of the average of the 14 calculated above and add those radiance values to the flood image, effectively using measured loss of the nearby inverse sparse grid image as a proxy for the lost radiance due to the dead pixel
6. Interpolate the corrected flood image to yield individual pixel radiance

Figure 1 shows the results of the bad pixel correction. The image on the left had not had bad pixel correction performed, while the image on the right has had the correction performed. The bad pixel correction is quite good at removing artifacts due to the dead pixels for single dead emitters and small clusters. Larger clusters can still leave some artifacts after the correction, however these are typically much smaller in magnitude than the initial artifacts due to the dead pixel. Also, the residual artifacts in the corrected image typically fall within the dead area of the larger clusters so the errors affect pixels that are already dead.

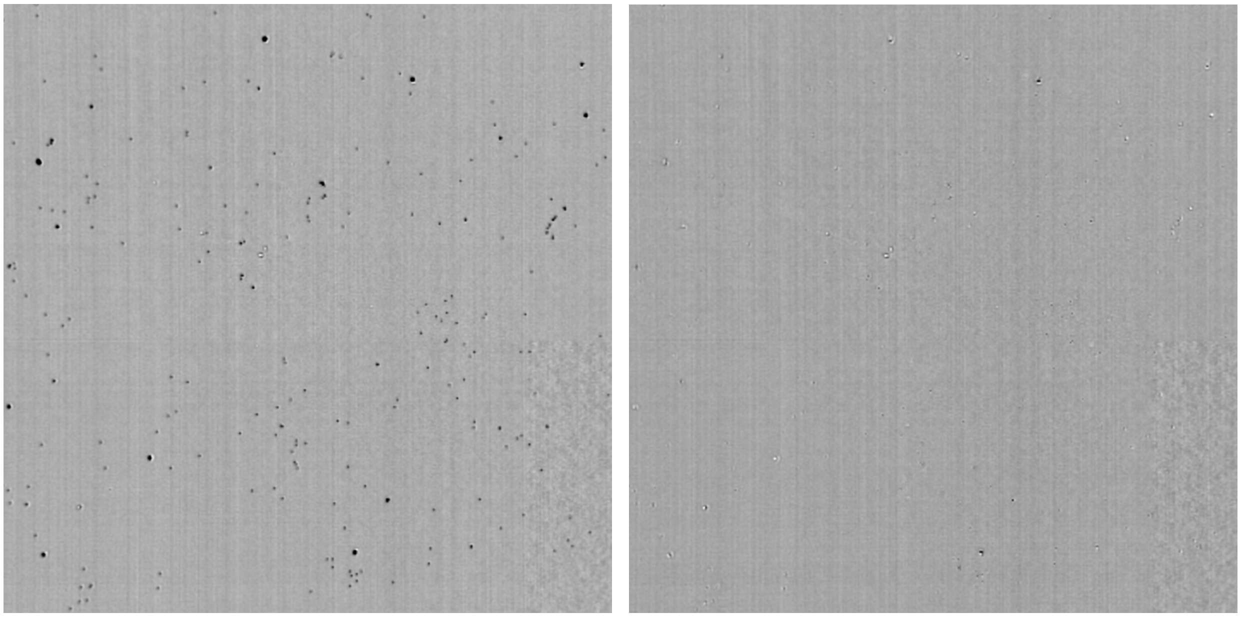

Figure 1 Comparison of flood NUC with and without bad pixel correction. The image on the right was processed with bad pixel correction. The image on the left has no bad pixel correction. Both were collected at 7.6% of maximum drive. The image greyscale is set to approximately +/- 7% of the mean radiance. Much of the remaining structure is seen as vertical stripes the traverse the entire emitter. These are residual artifacts from slowly varying column noise in the camera.

3.2 Experiment

The IRSP used in this study was a Santa Barbara Infrared MIRAGE-H system[1] with an 800x800 array capable of producing apparent temperatures of up to 550K in the 8-12 micron band. The camera used 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 NETD of ≈50 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 than the as manufactured near focus distance of 2 meters, a custom spacer was added between the camera and lens, which reduced the near focus distance to approximately 20 cm.

The non-uniformity correction used in the IRSP 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 NUC coefficients for each pixel are derived by interpolating radiance data collected at various drive levels. The most recent generation of the NUC software developed at SBIR allows for iteration on a previous NUC, as well as modification of a NUC table to match a changed post NUC look-up table. This procedure involves using the input NUC table and post-NUC LUT to calculate the "raw" drive sent to the emitter for a give input drive value. The new post-NUC LUT is used in reverse to calculate the equivalent input drive under the new LUT that would have produced an equivalent raw drive sent to the array. This procedure is used for each pixel at every drive for which radiance data was collected. This produces a drive versus radiance response curve for each pixel based on the new LUT. This drive versus radiance response curve is then interpolated to extract the drive which gives the desired radiance at each breakpoint desired in the new NUC table. These drives are then used to calculate the gain and offset for each pixel in each segment of the NUC table.

Initial pre-NUC data was collected by sparse grid measurements for apparent temperatures in the range of 340K to 500K. The pre-NUC non-uniformity is given in Table 1. A NUC table was produced based on this initial sparse grid data. Next, post NUC sparse grid data was collected over the range of 350K to 500K and flood data was collected over temperatures from 280K to 320K. A second NUC table was then produced that included the flood data. Then, a second round of post-NUC measurements was performed.

Table 1 shows the non-uniformity at various radiance levels. The measured post-NUC non-uniformity will be an underestimate due to the sampling of multiple emitter pixels by a single camera pixel.

Linear Drive	Average Rad. (W/cm2sr)	LWIR App. Temp. (K)	Pre-NUC NU (%)	Post-NUC NU (%)	Method
100	0.00016	281.0	4.9%	2.6%	Flood
200	0.00033	282.1	3.8%	1.4%	Flood
400	0.00065	284.0	4.0%	0.8%	Flood
800	0.00131	287.8	4.8%	0.4%	Flood
1600	0.00261	295.1	4.7%	0.2%	Flood
2500	0.00412	302.7	4.8%	0.2%	Flood
5000	0.00816	321.0	4.9%	0.2%	Flood
10000	0.01634	351.2	8.3%	0.9%	Sparse Grid
20000	0.03278	398.2	9.2%	1.0%	Sparse Grid
40000	0.06521	468.5	7.1%	1.5%	Sparse Grid

4. RESULTS

The hybrid NUC method made significant improvements over the entire radiance range of the array. DAC differences and column variations are measurably better as shown in Figures 2 and 3. Making meaningful measurements at low radiance levels using the sparse grid method would not be practical with a microbolometer. The flood NUC measurements typically take about 2 minutes including the bad pixel correction, while a comparable sparse grid collection would take several hours. Table 1 summarizes the data collected. It gives the statistics for pre and post NUC uniformity measurements made at various radiance levels. Finally, Figure 4 shows an example image with and without NUC applied.

The hybrid sparse-flood NUC presented above shows clear improvement in the imagery at lower radiance values. Its success suggests there may be a way to reduce NUC measurement time if the NUC can be customized for a particular application. For example, in testing with terrestrial backgrounds, flood NUC could be used for radiance values up to the approximate ambient temperature of the scenarios being tested. Assuming the sensor under test did not have a significantly higher spatial resolution, the flood NUC should be adequate for the relatively uniform background. For higher radiance levels contained in smaller areas of the scene, the NUC would be based on the more appropriate sparse grid data. The above argument does not apply for simulations of space backgrounds, where the ambient is typically kept as low as possible in a cryogenic chamber. Usually these facilities have high performance cameras available to perform NUC at low levels. That said, even in those situations, there comes a time where the sparse grid radiance measurements become impractical and a hybrid flood approach may be better than ending the NUC collection at the higher levels.

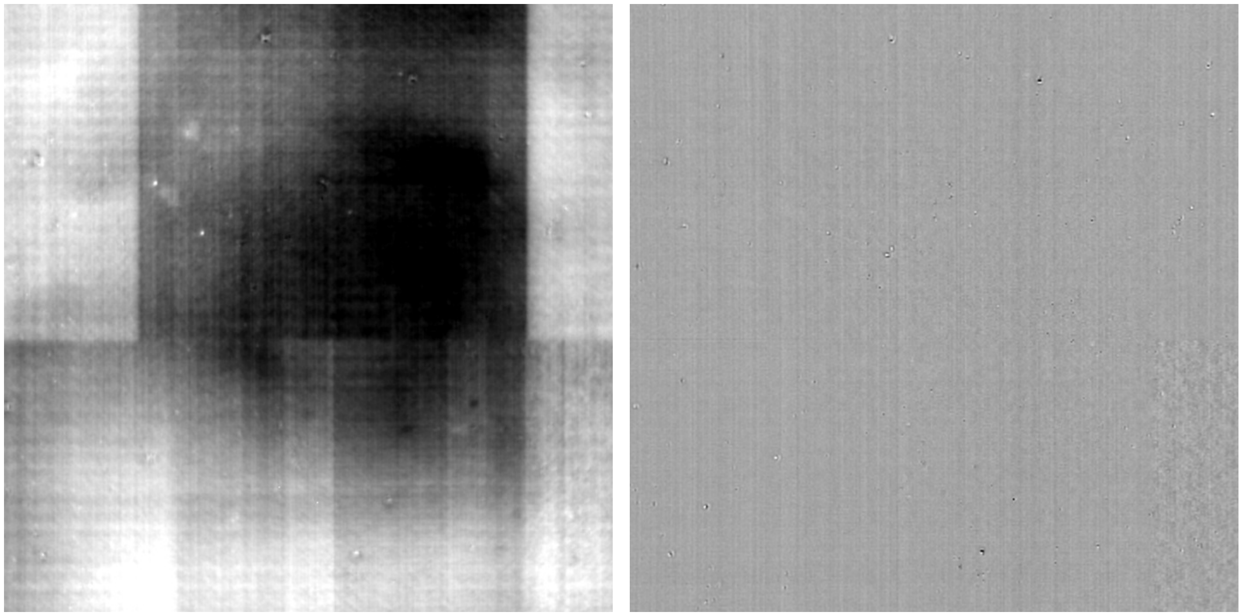

Figure 2 Flood NUC results. The image on the left was collected after applying NUC based only on sparse grid data collected at high radiance levels. The image on the right was collected after completion of the entire hybrid NUC process. Both images were collected at approximately 7.6% of maximum radiance and both are displayed with the same greyscale.

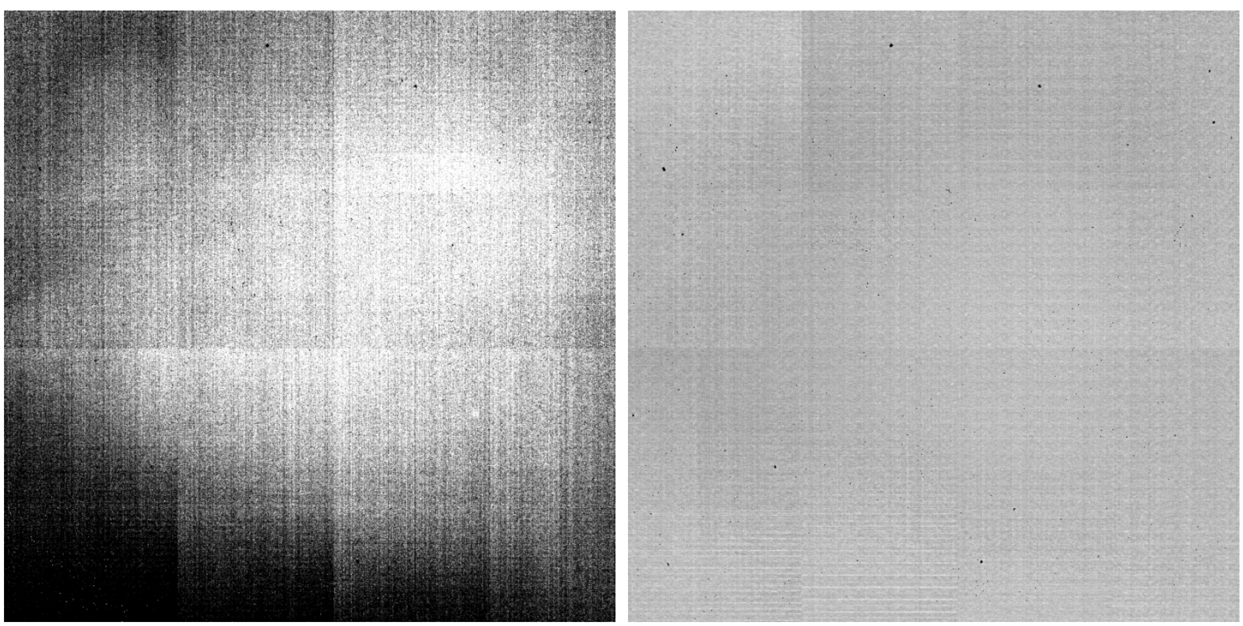

Figure 3 Pre and Post-NUC images at 30% of maximum radiance. These images were collected with the sparse grid NUC method. The image on the left is the pre-NUC data, the image on the right is the post-NUC data.

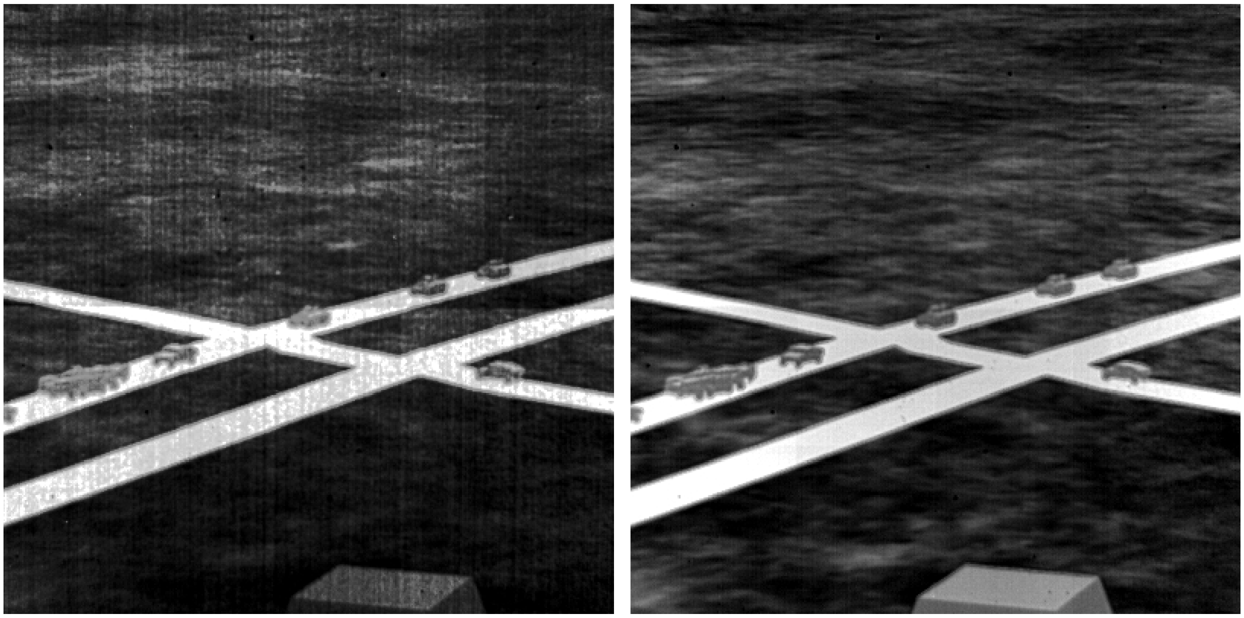

Figure 4 Example image. This figure shows an example image captured with and without NUC applied. The uncorrected image on the left shows visible non-uniformity, including DAC variations as well as column variations. In the corrected image on the right, these artifacts have been suppressed to the point that they are not visible.

5. SUMMARY/CONCLUSIONS

Non-uniformity correction at low radiance values can be very difficult to accomplish cost effectively due to a low signal to noise ratio in the measuring system. While the sparse grid measurement technique is useful for achieving the best NUC at the individual pixel level at high radiance levels, at lower levels the technique becomes impractical. Flood NUC has been used in the past as a very fast way to perform NUC. However, the errors at the individual pixel level were larger because the camera system typically averaged the radiance from multiple nearby pixels. The hybrid technique developed by Santa Barbara Infrared, and described above provides a combination of the two methods in an effort to make use of the best properties of both. Imagery at radiance levels below the limit for practical sparse grid measurements is improved after flood data is used to produce a NUC at lower radiance values. This technique can help reduce the cost of performing a quality NUC by allowing a lower performance, and hence, less expensive camera to be used for NUC data collection.

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