# MIRAGE: Calibration Radiometry System

A. Irwin, J. Oleson, Richard Robinson

Santa Barbara Infrared, Inc.
312A North Nopal Street
Santa Barbara, CA 93103

## ABSTRACT

The advent of high resolution infrared resistor arrays, has greatly increased the level of fidelity of infrared sensor testing that can be accomplished in the cost effective laboratory environment. However, the sensor output image quality depends on the uniformity of the projector array. In addition to the advanced proprietary design and fabrication process used to create a highly uniform emitter array, Santa Barbara Infrared, Inc. (SBIR) applies a high speed correction algorithm to the incoming data stream that improves the uniformity of the final infrared image. The key to this algorithm is a set of calibrated tables that are measured for each emitter element in the array. SBIR has developed a Calibration Radiometry System (CRS) which is used to quickly perform these high precision measurements for each emitter element. This paper looks at the CRS system, reviews the algorithms used for applying the correction and for making the calibration measurements. It concludes with some initial results showing the effect of the calibration tables derived using the CRS.

**Keywords**: infrared scene simulation, MIRAGE, calibration radiometry system, CRS, nonuniformity correction, NUC

## 1. INTRODUCTION

The advent of high resolution infrared resistor arrays, has greatly increased the level of fidelity of infrared sensor testing that can be accomplished in the cost effective laboratory environment. No longer does the laboratory tester have to settle for functional tests that have significant levels of uncertainty and minimal correlation to real-world scenarios. The utilization of state-of-the-art resistor array based dynamic infrared scene projectors allows the tester to simulate actual battlefield scene scenarios with unprecedented fidelity. With the on going improvement of resolution and sensitivity of today's infrared detector arrays, the challenge for the tester is to provide emitter arrays with the spatial resolution, sensitivity, and uniformity to keep pace with these detector array improvements. SBIR has introduced emitter arrays with unparalleled sensitivity in its MIRAGE infrared scene projectors[1]. Plus, SBIR and Indigo Systems are addressing the requirements for improved emitter resolution with the development of Large Area Infrared Scene Emitter (LAISE) arrays[2].

Analysis has shown that in addition to the inherent nonuniformity of the detector array, the sensor output image quality depends on the uniformity of the projector array and the relative position of the emitter image on the detector array[3]. Thus, it is essential to minimize the contribution of the emitter nonuniformity. Two apparent methods are available for reducing the spatial non-uniformities of infrared scene projectors[4]:

1. Reduction of the non-uniformities at the source, and
2. Application of nonuniformity correction procedures.

SBIR has taken great strides to potential non-uniformities in its MIRAGE resistor arrays by incorporating several advanced proprietary design and fabrication techniques[1]. However, some subtle sources of nonuniformity remain and must be eliminated through corrective procedures in the image processing software/hardware. SBIR has developed a highly automated radiometric measurement system, the Calibration Radiometry System (CRS), which automatically calibrates the infrared radiation from each pixel of the array. The details and benefits of the CRS are described in this paper.

## 2. NONUNIFORMITY CORRECTION

A simplified overview of the MIRAGE System is shown in Figure 1. The simulated scene is sent to the MIRAGE system through the Command and Control Electronics (C&CE). The scene information is encoded as a radiometric output for each of the 262,144 emitter pixels. The C&CE processes this scene information and produces the DAC value needed for each emitter pixel to generate the required radiance. Within the C&CE, multi-processing units apply NUC and other corrective algorithms to this data, in real time.

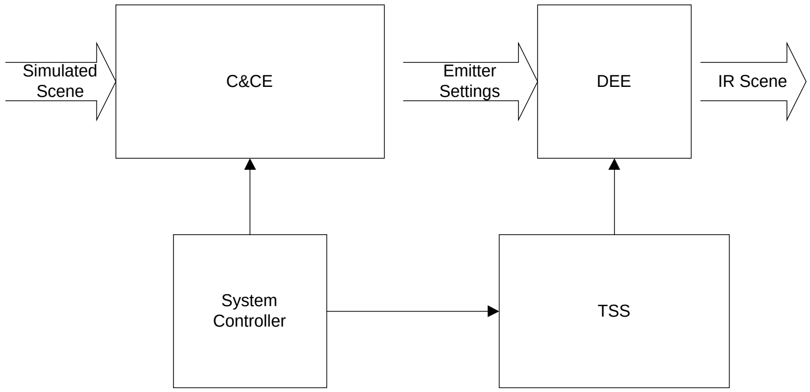


**Figure 1 MIRAGE Components**

The input value for each pixel passes through several stages of signal conditioning before it is applied to the emitter pixel. The input value is a scaled, radiometric value (16 bit integer) that passed through a NUC Stage, then an Overdrive Stage, and finally a DAC Correction Stage before the value is applied to the emitter pixel. These stages are written in ‘C’ and applied in the multiple processor stages of the MIRAGE signal conditioning system. Figure 2 shows the signal path in the MIRAGE C&CE. NUC, overdrive, and DAC corrections are applied to the scene data in real time.

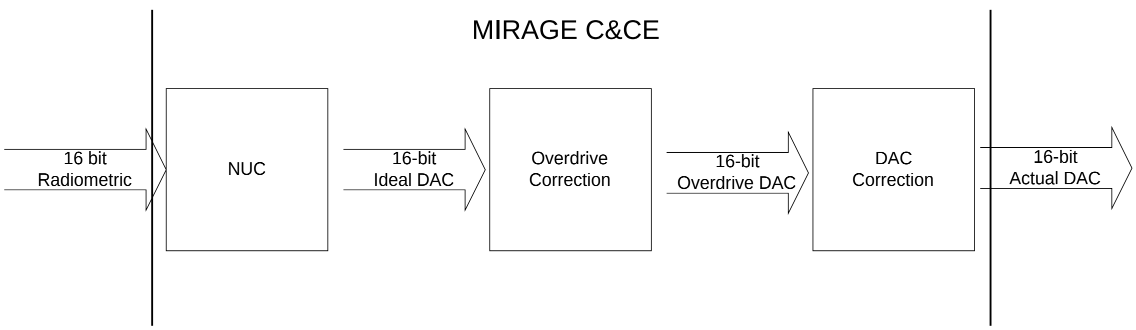


**Figure 2 Signal Conditioning Stages**

The NUC process, which is the most complex, involves different correction data for each pixel in the emitter array. For each pixel, the input value is used as a lookup into a table of corrective values. Each element has a correction table of up to 32 entries. Each entry consists of a scaling factor and an offset that is applied to the input, and each entry is associated with a particular range of appropriate input values. The ranges are not fixed, so that the table may have variable resolution across its operating range (as desired).

| Radiometric Ranges |
|---|
| Upper Limit 1 |
| Upper Limit 2 |
| … |
| Upper Limit n (up to 32 entries) |

| Element m Multiplier | Element m Divisor | Element m Offset |
|---|---|---|
| Range 1 mult. | Range 1 divisor | Range 1 offset |
| Range 2 mult. | Range 2 divisor | Range 2 offset |
| … | … | … |
| Range n mult. | Range n divisor | Range n offset |

**Figure 3 NUC Process Coefficient Table**

The range table is common to all elements, but the coefficients are unique for each emitter element (as shown in Figure 3). The coefficients are derived from data collected using the Calibration Radiometry System. Each entry in the table is calculated from measurement taken at a specific calibration point. The process of collecting this calibration data is discussed in the next section.

The Overdrive Stage applies a scaling function used to greatly reduce the settling time of the emitter pixel. This is invariant over all the emitter elements and is procedural in nature rather than data dependent.

The DAC Correction Stage is a 16-bit x 16-bit look up table that corrects the non-monotonic characteristics of the DAC. The lookup values are defined in advance and invariant over all emitter elements

## 3. NONUNIFORMITY CALIBRATION

A simple overview of the CRS approach is that a thermal-camera (starring array) matches the radiant output from the emitter array to the output of a reference blackbody at the temperature of the calibration point. Each pixel in the emitter array has its drive individually adjusted until the radiant output matches the blackbody source. The components used to perform this calibration are shown in the following figure.

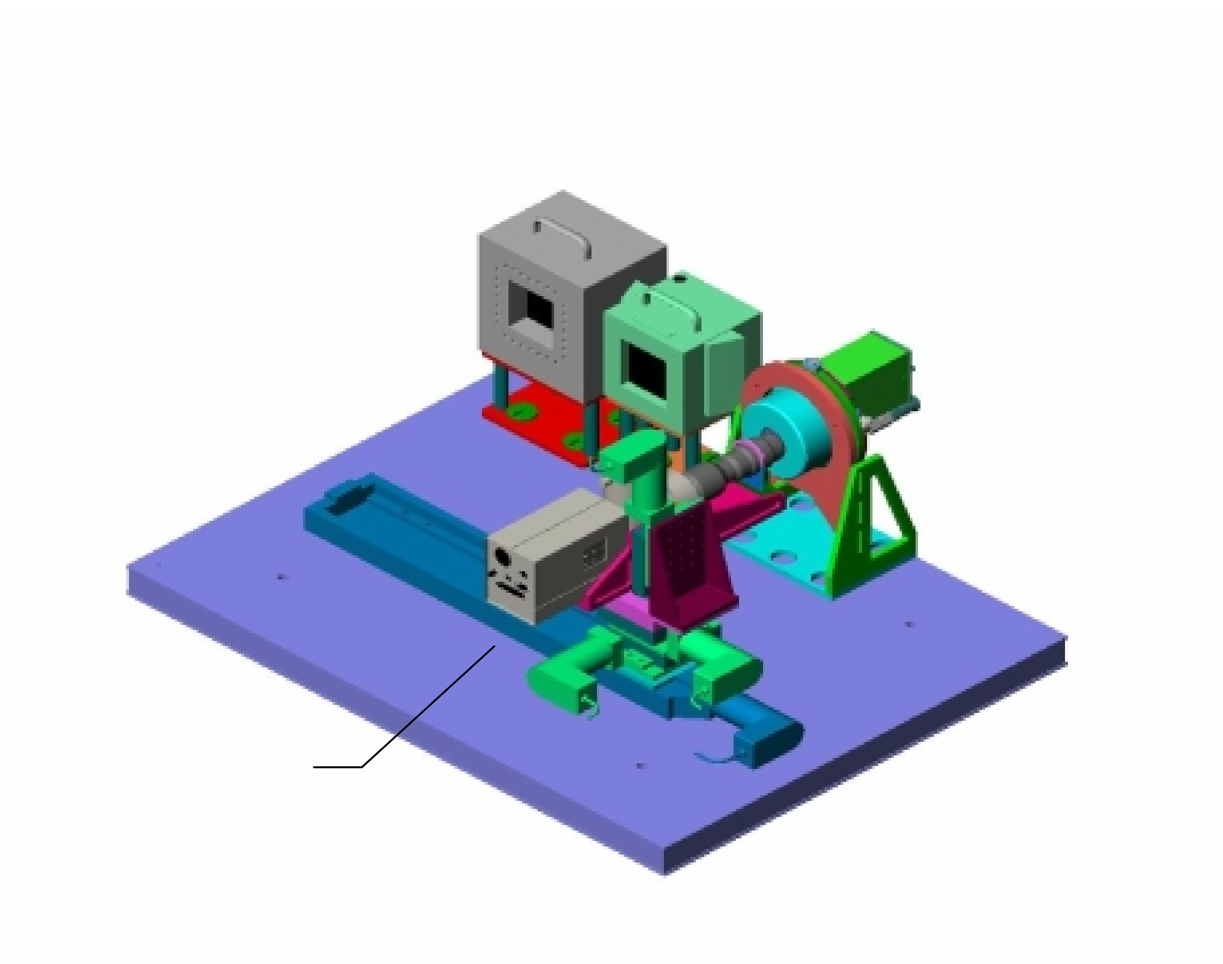

**Figure 4 Calibration Radiometry System**

An optics bench holds a high precision, motion control system (four stages) used to position a 320x240 InSb camera between the CEE being calibrated and two reference blackbodies. The blackbodies have operating ranges of 0 to 100 $^{o}$C with 0.001 $^{o}$C resolution and stability and 50 to 600 $^{o}$C with 0.1 $^{o}$C resolution and stability. The camera can also be moved in front of the emitter (in all 3 axes) to a precision of 0.01 mm. Finally, the camera has a microscope lens for focusing onto small regions of the emitter. A computer (not shown in the diagram) directs the calibration process. It is used to coordinate the motion tables, configure the camera, setup and monitor the blackbodies, collect data, process the results, and produce the final calibration tables.

Since a thermal camera is subject to drift, it is calibrated using a blackbody just before measuring the emitter output. One motion stage is used just to move the camera between blackbodies and the emitter array being calibrated.

The microscope optics map one emitter pixel onto 16 camera pixels (a 4x4 array). Because of the large number of emitter pixels (512x512) compared to the number of camera pixels (320x256), the camera is moved across the face of the emitter, taking measurements at different positions. The region of the emitter that is measured at each camera position is called a tile.

To uniquely identify the energy from each pixel, only a partial set of the pixels are turned on and calibrated at any one time. Every third pixel, or one in a 3x3 array is isolated. This subset is called a sparse array, and there are 9 sparse array patterns for each camera position.

The drive to each emitter pixel is adjusted so that the average camera reading from that emitter pixel matches the camera reading of the blackbody. This is an iterative process where the System Control Computer takes the measurement values from the camera, calculates the new DAC values necessary to correct the temperature measurement errors, and then sends those values out to the DACs.

With each translation of the camera moving ½ the camera's field of view, four measurements will be made of each pixel in four different regions of the camera. The PC collects these measurements and after all the scanning has been completed, a table value for each pixel is calculated. This process averages the measurements from 64 different camera pixels for each emitter pixel, further minimizing the nonuniformity effects of the camera, lens, and blackbody.

A simplified algorithm overview is:

```
For each temperature in the curve:
    Set the blackbody to the calibration value
    Move the camera to look at the blackbody
    Measure each camera pixel and store as the reference set
    Move the camera to the emitter array (in the dewar)
    Calculate distortion map
    For each tile (overlapping camera region):
        Move the camera to the region
        For each pixel pattern (sparse array patterns):
            Set the drive to each pixel in the pattern to the initial value
            Measure each camera pixel
            Identify the 16 camera pixels for each emitter pixel
            While emitter measurement do not match the reference set
                Adjust the drive to each emitter
                Measure each camera pixel
            Next emitter measurement test
        Next pixel pattern
        Save the emitter pixel drive map
    Next region
    Average the overlapping values of the emitter drive maps
    Save the final emitter drive map for this temperature
Next temperature
Assemble final NUC table
```

***Practical Issues***

In the process of working with the CRS system, several points have become critical to repeatability and precision. The first is alignment due to mechanical/geometry effects of the equipment. The second is image distortion, due to optical effects. The third is the environmental effects of the calibration lab on the system.

The alignment of the system changes over time due to simple thermal expansion of the equipment. As the camera is moved to each tile position, a reference pixel is turned on and the camera is centered on the corresponding tile. And, just before the pixel measurements are taken, the pixels are illuminated brightly enough for their position to be identified and the measurement region defined. Only then is the calibrated drive applied, and the total energy is measured.

To compensate for distortion, whenever the camera is moved to the array (typically just after the camera is calibrated at the blackbody), the camera is alligned on a specific tile where a very sparse grid of points is illuminated and the position of each point is identified in the camera. These points are used to calculate a distortion map. This distortion map is used when identifying the regions expected for each pixel in a sparse array. The typical optical distortions (barrel, pincushion, trapezoid, etc) and some geometric distortions (rotation) are corrected with the distortion map.

Additionally, only the central region of the camera is used for calibration. By eliminating the camera edges, optical effects due to the high magnification lens and edge effects of the camera's focal plane array are reduced. The trade off is longer times for calibrating the entire array.

Environmental effects, such as IR reflections and room temperature drift, are dealt with using traditional methods. A shroud surrounds the measurement system to reduce reflection. The camera is calibrated with the blackbody just before measurements are made to reduce the impact of any room or optics long-term temperature drift.

## 4. RESULTS

At this stage, we've begun applying initial NUC tables to our emitter arrays. Below are two set of images captured using two different IR cameras. Each shows an image before and after the NUC correction table has been applied. The variation between the left half of the image and the right half of the image is due to the construction of the emitter chip. A different DAC is used to drive the left half of the chip than is used on the right half of the chip. The difference in drive is approximately 1% of the peak scene brightness (There is an aximuth inversion between the optics used for the two images, so that the darker half appears on the right side of the emitter in Figure 4L, and on the left side of Figure 5L).

Each pixel is individually corrected, meaning all 262,144 correction tables are being processed to create the images in real time (at a frame rate of 200 Hz).

The corrected image shows the overall brightening of half the image, matching it to the brightness of the other half. The distinct line down the middle of the image (at the junction of the two emitter halves) disappears in the corrected image.

The remaining vertical streaks are nonuniformities in the 0.1% range. Routines and operating procedures that address very subtle error sources are being developed to eliminate these artifacts.

**Figure 5 Uncorrected (L) and Corrected (R) Image Acquired Using a 320x240 InSb Camera**

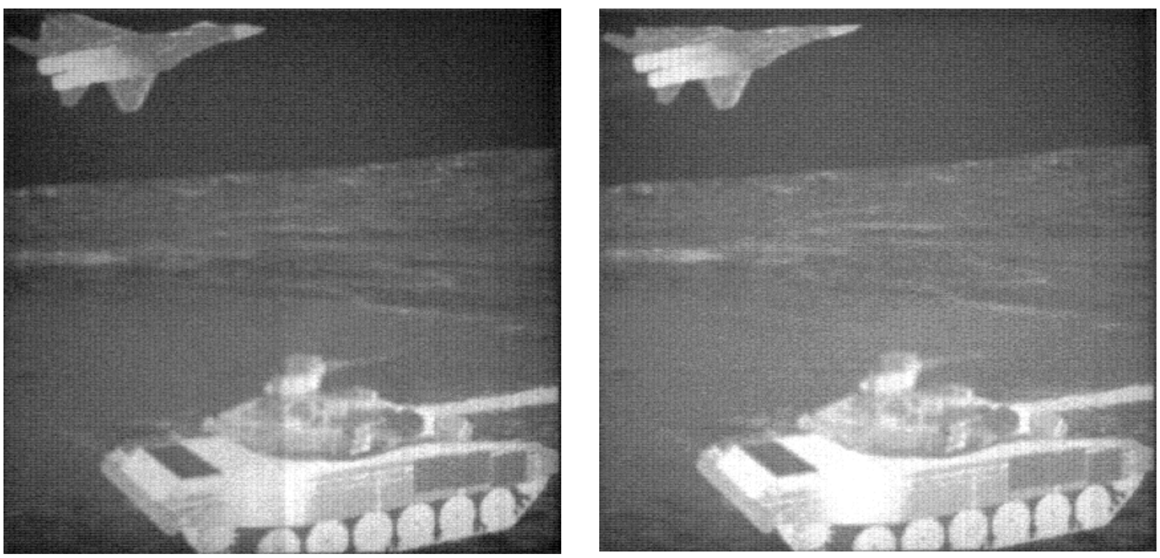

**Figure 6 Uncorrected (L) and Corrected (R) Image Acquired Using a 512x512 PtSi Camera**

## 5. CONCLUSIONS

As described in the introduction, there are two methods used to remove nonuniformity in spatial sources. The MIRAGE scene projection system eliminates the majority of the nonuniformity through advanced proprietary design and fabrication processes. Initial measurements show uncorrected non-uniformities of less than 5% (sigma/mean).

The second method of nonuniformity correction is by applying scaling factors that are derived from a radiometric calibration. As has been describe, there are several sources of error that must be corrected within the calibration system, before the results can be accurate enough to remove the final emitter non-uniformities. The Calibration Radiometric System addresses these problems by using highly stable thermal sources and components, applying algorithms to correct for changes in alignment and distortion, and to process the data collected in such a way as to achieve very precise corrections to the emitter array. Currently, uniformity corrections are being made to less than 1%, and improvements in the algorithms expect corrections to be made that will limit nonuniformity to 0.1%, or less.

## 6. REFERENCES

[1] Steve McHugh, Jon Warner, Mike Pollack, Alan Irwin, Santa Barbara Infrared, Inc; Ted Hoelter, Bill Parrish, and Jim Woolaway, Indigo Systems Corp., "MIRAGE Dynamic IR Scene Projector Overview and Status," *Technologies for Synthetic Environments: Hardware-in-the-loop Testing IV*, Proc. SPIE 3697, 209-222 (1999).

[2] Steve McHugh, Santa Barbara Infrared, Inc.; B.Parish, J.T. Woolaway, Indigo Systems Corp.; J. Oleson, Santa Barbara Infrared, Inc. "MIRAGE: Large-Format Emitter Arrays, 1024x1024 and 1024x2048", *Technologies for Synthetic Environments: Hardware-in-the-Loop Testing V*., Proc. SPIE Vol. 4027 (2000)

[3] Brian P Beecken, Homas J. McElmurry, and Thomas R. Greenlee, "The impact of a scene projector array on the nonuniformity of a test article's output image," *Technologies for Synthetic Environments: Hardware-in-the-loop Testing IV*, Proc. SPIE 3697, 366-378 (1999).

[4] O.M. Williams, "Search for Optimal Infrared Projector Nonuniformity Correction Procedures," *Technologies for Synthetic Environments: Hardware-in-the-loop Testing IV*, Proc. SPIE 3697, 352-365 (1999).