A 2-Color 1024x1024 Dynamic Infrared Scene Projection System

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ABSTRACT

We report on the design and testing of a 2-color dynamic scene projector system based on the MIRAGE-XL infrared scene projector. The system is based on the optical combination of two 1024x1024 MIRAGE-XL resistive arrays. Algorithms derived for 2-color operation are discussed and system performance data is presented, including radiometric performance, sub-pixel spatial co-registration and compensation for spectral cross-talk.

Keywords: MIRAGE, IRSP, Scene Projection, 2-color, HWIL, hardware-in-the-loop

1. INTRODUCTION

In recent years, 2-color focal planes have been put to use in seeker applications in order to improve target discrimination. With the introduction of such systems comes the need to test them. Hardware in the loop (HWIL) testing has been used in many applications as a way to engage in high fidelity testing of a complete seeker system. The addition of a second color to the seeker requires additional complexity in order to provide an accurate representation of the desired radiance to the seeker in the two bands of interest. When the sensors are tested in a hardware-in-the-loop (HWIL) environment, this requirement for radiometric calibration, spatial alignment, and temporal accuracy are in turn imposed on the projection systems used for testing[1].

If left uncorrected, the spatial misalignment and radiometric overlap can lead to significant band-to-band and band-to-truth simulation errors[1,2,3,4]. Since 1999, Santa Barbara Infrared (SBIR) has been delivering one-color infrared scene projector (IRSP) systems used to provide high fidelity imagery for HWIL testing. Moving to a 2-color system imposes additional requirements on these systems to ensure the band-to-band accuracy is acceptable for testing. The basic components of a 2-color system include two 1-color emitter systems, a collimator and a dichroic beam combiner. In principle, such a system would simply require the output of the two one-color systems to be aligned such that they are overlapped through the beam combiner. In practice, this simple ideal becomes more complex.

There are two main issues requiring significant effort to address. The first issue is spectral overlap of the two bands. In the event that the two spectral bands to be simulated are relatively close, the situation may arise such that they cannot be completely optically separated and the system under test (SUT) will see contributions to the radiance of one band from the output of the other band's emitter array. Due to this spectral overlap, the measured radiance of the two bands is not independent. In order to correct for this effect, some method of spectral compensation must be employed.

The second issue is sub-pixel spatial co-registration of the two bands. The insertion of a beam combiner affects the optical path of each band differently. Perfect co-registration of both bands at every pixel is generally not possible. In order to overcome pixel alignment issues, a form of electronic co-registration has been implemented. The spectral and spatial correction features will be discussed briefly below and the results of initial testing be given.

2. SYSTEM DESCRIPTION

2.1 General System

The 2-color system consists of a 2-color collimator with a dichroic beam combiner and two infrared scene projection (IRSP) systems based on the MIRAGE-XL design by Santa Barbara Infrared (SBIR), a HEICO company. Figure 1 shows a block diagram of the 2-color system. Figure 2 shows a block diagram of the collimator and some images of the completed system. The two IRSP systems described here are derivatives of the MIRAGE-XL system produced by SBIR[5,6]. MIRAGE-XL is a 1024x1024 resistive emitter array capable of operating at 200Hz and producing apparent

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temperatures up to 675K in the mid-wave infrared (MWIR) band and up to 550K in the long wave infrared (LWIR) band. Each MIRAGE-XL is composed of three subsystems: the Digital Emitter Engine (DEE), the Thermal Support System (TSS) and the Command and Control Electronics (C&CE). The DEE contains the emitter array, Dewar, and close-support electronics. The TSS is composed of the power supplies, gauge controllers, and chiller needed to power, monitor, and cool the system. The C&CE is a computer with custom image processing boards that receives images from a scene generator then processes and formats that imagery to be sent out to the DEE.

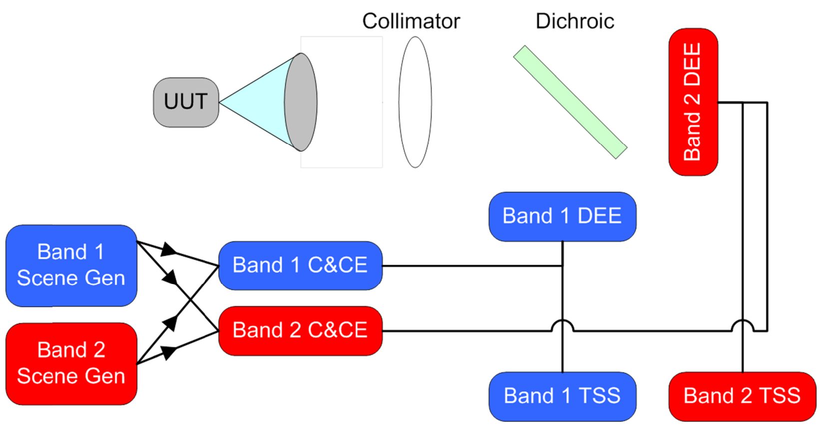

Figure 1: 2-color system block diagram.

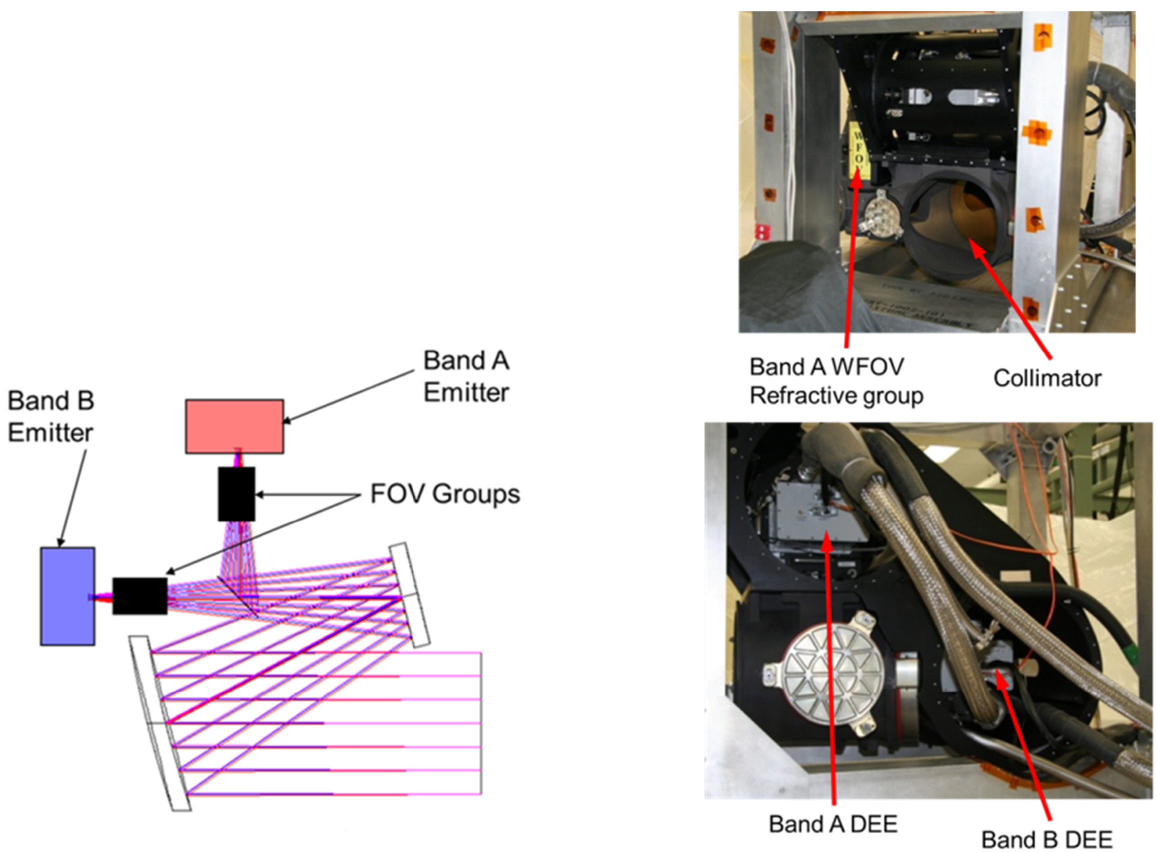

Figure 2. Block diagram (left) and images (right) of the 2-color system, showing the collimator and two emitter arrays.

2.2 2-Color MIRAGE-XL System

All of the differences between a 2-color system and a standard MIRAGE-XL are in the command and control electronics (C&CE). The new 2-color C&CE provides support for the new features required for 2-color testing. 2-color testing requires an accurate scene be projected in both bands of the system under test (SUT). In order to provide an accurate scene, the projectors must produce accurate radiance and have both scenes be spatially co-registered. Figure 3 shows a comparison of the old and new C&CEs.

The additional 2-color requirements discussed in the introduction require more field programmable gate array (FPGA) resources than can be supported on the standard MIRAGE-XL system. In particular, the spectral compensation requires the data streams for both colors to be processed by each half of the system, effectively doubling the bandwidth requirement of the timing and input processor (TIP) card. Also, neither the translation and rotation processor (TRP), nor the reprogrammable pixel processor (RPP) have the resources free to implement the 2-color spatial correction; therefore, 2 new cards were added to the system. The TIP2 card which replaces the TIP, provides more than double the input bandwidth of the original TIP card. In addition to performing all of the original TIP functions, the TIP2 card also performs the 2-color spectral correction. The output of the TIP2 is a single color drive which reduces downstream bandwidth by a factor of two. Also added is a RPP4 card which replaces both the TRP and RPP cards, providing all the functionality of both as well as hosting the 2-color spatial correction. This functionality includes translation and rotation processing and 2-color spatial correction, as well as, non-uniformity correction (NUC) and Scene Accelerator (aka "overdrive"). Figure 3 shows a comparison of the single color and 2-color C&CEs.

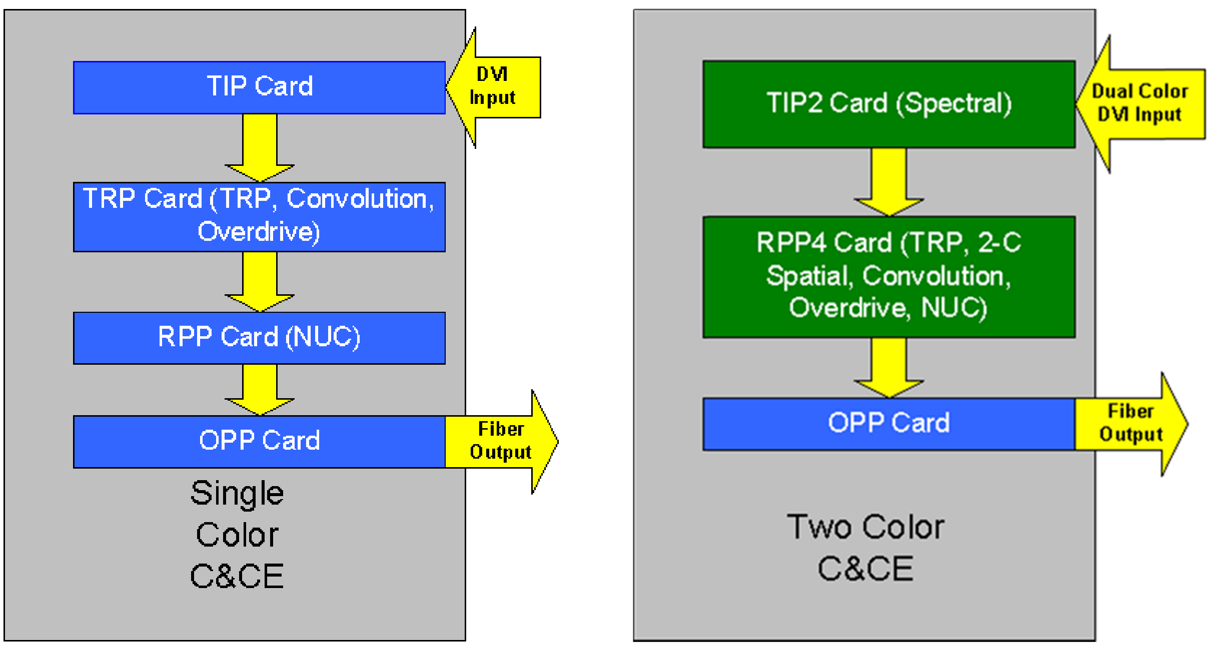

Figure 3. Comparison of single color and 2-color MIRAGE-XL C&CEs.

If the two spectral bands of the SUT are sufficiently far apart, a dichroic beam combiner can be practically produced to combine the two colors without significant excitation of one band from the emitters of the other. However, if the two bands are closer together, producing a suitable beam combiner may be costly or impossible. In such cases, energy from one band may bleed into the other causing an error in radiance. In order to provide accurate radiance, a spectral band compensation must be made. In order to correct for the additional radiance from the out of band emitter, the in band emitter must know the commanded drive of each pixel in the out of band projector and what proportion of that radiance will leak into the desired band for that commanded drive. Thus, each C&CE must receive all the scene data for both its own band as well as the opposite band. Both scenes must be separately processed by both C&CEs in order to provide the spectral compensation. This doubles the input bandwidth requirement of the C&CE. The original MIRAGE-XL TIP processor operated in its full 1024x1024 frame mode at a maximum of 200Hz. The TIP2 card has twice the bandwidth of the original TIP card and includes the capability to perform the spectral compensation calculations on each pixel. Once those calculations are done, only the corrected drive for each band need be further processed, so the bandwidth of the rest of the system need not be doubled.

In addition to providing accurate radiance in both bands, the system must ensure that the scenes from the two bands overlap properly. The typical desire for this is to achieve scene co-registration to better than 1/4 of a pixel. Producing an optical system that aligns each pair pixels from two 1024x1024 arrays to such an accuracy is not practical. Alignment of a single pair of pixels is straight-forward, but with different optical paths for the two including distortions and slight variations in field size, aligning the entire array is virtually impossible. In order to provide accurate, overlapping radiance from the two bands, a spatial correction must be made. In order to properly locate radiance sources with better than 1 pixel accuracy, an interpolation must be performed. This correction is performed in real time based on a spatial calibration.

Two spatial algorithms are required in a 2-color system: the TRP function and the 2-color spatial correction. In both cases, input simulation data pixels must be mapped to output pixels to be displayed by the emitter array. Due to discrete nature of the input and output data, there cannot, in general, be a perfect one-to-one mapping of input pixels to output pixels; therefore, some sort of compromise must be made. There are two options for performing the spatial correction: a) doing a nearest-neighbor and nearest-correct-pixel replacement in the output data, or b) performing an interpolation. Nearest neighbor pixel replacement prevents blurring of the input image, but can lead to sampling artifacts and registration errors. Interpolation allows proper registration, but leads to blurring. For the standard 1-color MIRAGE-XL system, the interpolation method was selected for the translation and rotation function.

Two-color spatial correction has similar limits to translate and rotate with similar artifacts depending on the choice of algorithm. Performing both functions independently would cause the errors from the respective artifacts to be compounded. Consider the worst case scenario using interpolated functions: If a single input pixel were illuminated and then its located after translation and rotation were shifted half a pixel in both the vertical and horizontal directions, it would end up at the corner of 4 pixels and its radiance would be evenly spread amongst those four pixels. If those four were then moved half a pixel up and over, due to the 2-color spatial correction, the initial radiance of that one pixel would be spread into 9 pixels. The potential for this additional blurring makes performing the two corrections independently undesirable. The 2-color MIRAGE-XL system described here avoids the additional blurring by performing the TRP and 2-color spatial correction in a combined algorithm that interpolates only after both corrections have been made. This algorithm was discussed in detail in 2010[7].

3. SYSTEM PERFORMANCE

The unique nature of the 2-color system made performance verification challenging in several areas. Performance of each of the subsystems was measured in turn. Key performance metrics are presented below. The collimator was optimized for the LWIR region of the infrared (IR) spectrum. Testing of a 1024x1024 array requires an imager of comparable resolution. The camera selected for system test and validation was a FLIR Photon 640 microbolometer camera. Although microbolometers are not as sensitive as cooled LWIR cameras, they are more ubiquitous and significantly less expensive than the cooled cameras. SBIR has spent several years developing non-uniformity correction algorithms to make use of microbolometers for radiometric testing of emitter arrays [8,9] and those algorithms along with the experience gained in their development were applied to make the camera suitable for the validation tasks. The system validation falls into three categories: Radiometric, spectral and spatial, which are presented below.

3.1 Radiance

Providing an accurate radiometric image is the primary goal of any IRSP system. For a 2-color system, the radiometric performance of each band's subsystem must be measured. The primary radiometric performance metrics of IRSP systems are maximum apparent temperature, operability and non-uniformity, as measured after a non-uniformity correction (NUC) is applied. Table 1 gives the key performance metrics for bands A and B of the system. Figure 4 shows the operability map of each of the two bands and Figure 5 shows the combined operability map. Figure 6 shows an example post-NUC uniformity image for each band and Table 2 shows the statistical results of the NUC for both bands.

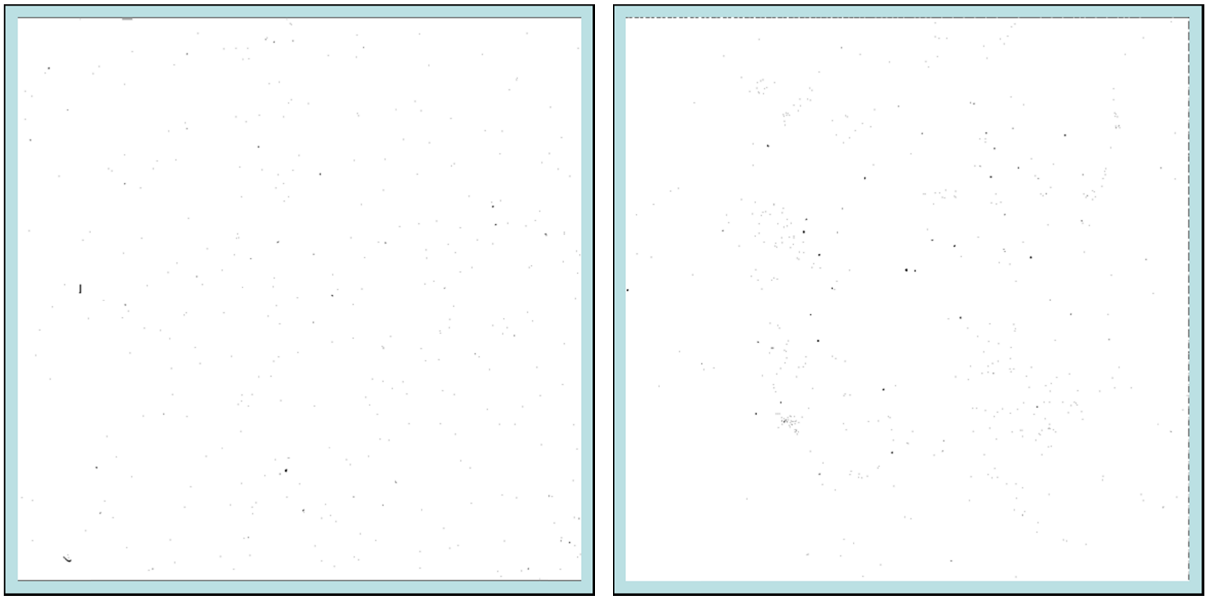

Figure 4. Operability maps of Bands A (left) and B (right).

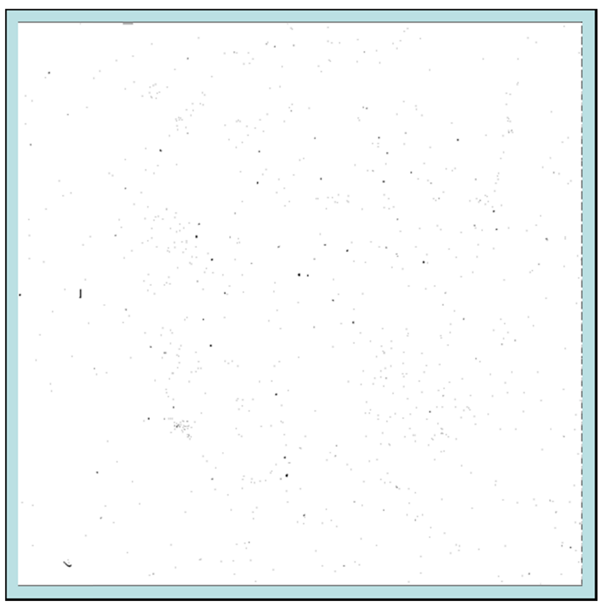

Figure 5. Operability of the combined system.

Table 1. Radiometric performance of individual bands.

Parameter	Band A Value	Band B Value
LWIR Max T	553K	590K
Operability	99.75%	99.79%
Rise Time	4.1 ms	4.1 ms
Fall Time	2.7 ms	2.5 ms
Minimum dT	22 mK	19 mK

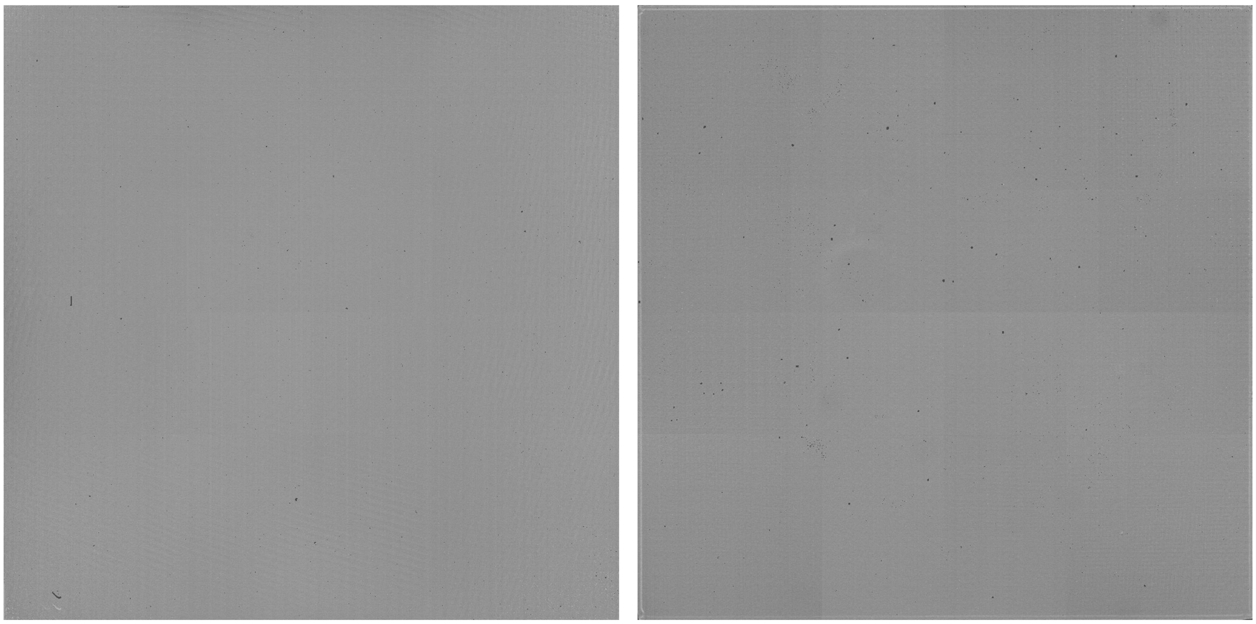

Figure 6. Post NUC images for band A (left) and band B (right) at approximately 430K apparent temperature.

Table 2. Post-NUC non-uniformity of the two bands as a function of LWIR apparent temperature. %NU is measured as the standard deviation of the radiance over the mean.

Band A		Band B	
App. T	NU	App. T	NU
309	3.1	309	2.6
335	0.8	317	1
365	0.9	344	0.8
407	0.9	377	0.6
452	1.1	416	0.5
500	1.2	458	0.5
508	1.2	480	0.5
517	1.2	502	0.4
525	1.3	524	0.4
534	1.4	544	0.5
539	1.6	564	0.5
545	1.9	588	1.4

3.2 Spectral

Testing the spectral correction algorithm and calibration presented a challenge. A suitable customer furnished 2-color SUT was not available at the time of system delivery, so the system had to be validated with the single band microbolometer mentioned above. In order to simulate a 2-color system, images from the two bands were collected through two spectral filters which allowed enough radiance overlap such that the spectral correction algorithm would be required and hence, could be used and then validated by limiting the cross-talk between the two bands. Data was collected from the two filter bands using each of the two emitter systems. From that data, a calibration curve was derived and applied to the system. The spectral correction was then tested by commanding a series of images with varying overall radiance as well as relative radiance between the bands. The results of the tests are given in Table 3.

Table 3. Results from spectral correction

Band A Error Pre-correction		Band B Radiance level		
		30%	60%	90%
Band A Radiance level	30%	17.7%	34.8%	48.0%
	60%	8.2%	16.2%	22.3%
	90%	4.8%	9.5%	13.2%

Band B Error Pre-correction		Band A Radiance level		
		30%	60%	90%
Band B Radiance level	30%	7.3%	15.8%	27.2%
	60%	3.6%	7.9%	13.5%
	90%	2.4%	5.3%	9.0%

Band A Error Post-correction		Band B Radiance level		
		30%	60%	90%
Band A Radiance level	30%	4.2%	0.0%	4.4%
	60%	1.2%	2.0%	3.7%
	90%	-0.7%	-0.2%	0.4%

Band B Error Post-correction		Band A Radiance level		
		30%	60%	90%
Band B Radiance level	30%	0.9%	0.0%	0.7%
	60%	0.0%	0.0%	0.1%
	90%	0.1%	0.5%	0.0%

3.3 Spatial

Testing the spatial correction was the most difficult portion of system validation, in large part because the system required calibration and validation at three different fields of view. Cost is always a consideration and the three fields of view would each require a separate, custom lens for optimal calibration and validation. In an effort to be more efficient, a concept to use the field selection lens groups as fixed focus lenses for the camera was put forth. The thought was to use the next more narrow field of view lens group from one of the paths as the primary camera lens. The stock lens is removed and the camera body mounted to a 3-axis motion control stage to allow for positioning and focus of the image. Using the lens group for the mid field of view (MFOV) to view the wide field of view (WFOV) allowed slightly more than 1/4 of the emitter array to be imaged at a time. With the lens fixed, the camera body was moved to image each of the 4 quadrants of the array for calibration and later validation. The intent was to use the same concept with the narrow field of view (NFOV) lens to view the collimator in MFOV mode. However, this was not practical due to a lack of sufficient radiance through the NFOV lens group due to its high f/#. A standard SBIR f/5 reflective collimator was used to view the NFOV and could view the entire field in one image. That same collimator was used with the MFOV, viewing the 4 quadrants in turn as with the WFOV. Figure 7 shows the results from the NFOV test. Slight distortions combined with extrapolation of the calibration points at the edge of the field caused a few of the pixels on the edges to exceed 0.25 pixel co-registration error. However, most of the field had less than 0.1 pixels of spatial error.

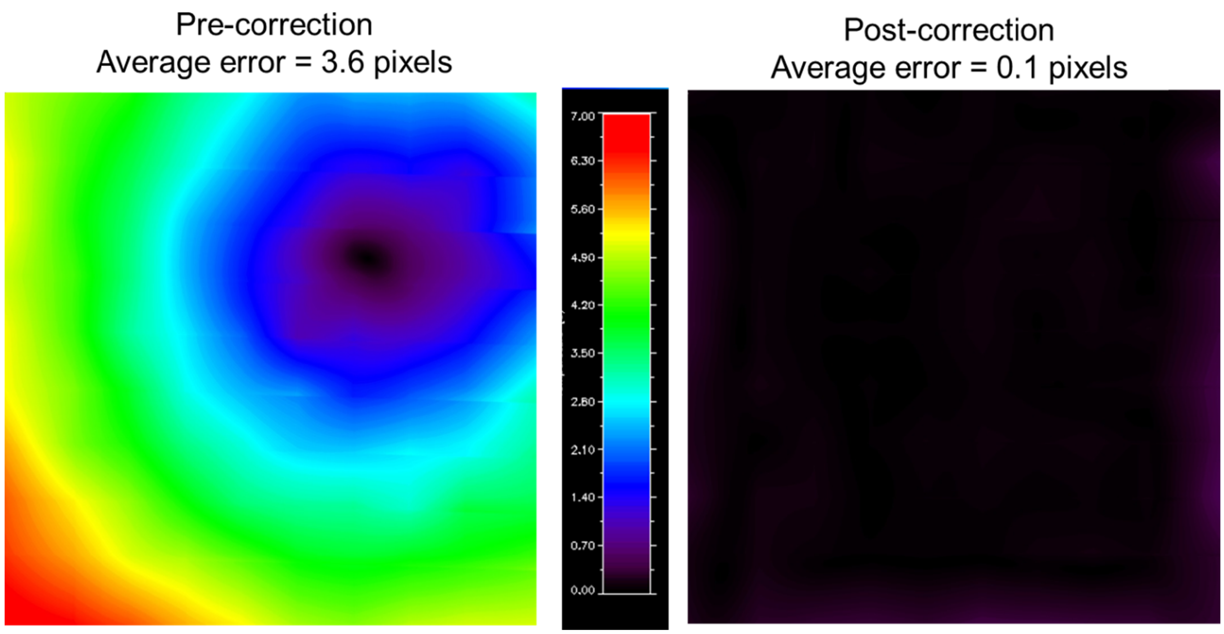

Figure 7. Image of spatial overlap errors before (left) and after (right) spatial correction. The post correction image greyscale is 10x that of the pre correction image. The average pre-correction error is 3.6 pixels and the average post-correction error is 0.1 pixels. Post-correction errors are dominated by the distortion near the edges of the field.

4. SUMMARY

A high fidelity 2-color IRSP system has been developed SBIR. C&CE upgrades have provided increased bandwidth, allowing 2-color spectral and spatial corrections to be implemented. The system has been tested and found to achieve LWIR apparent temperatures greater than 550K, with post-NUC non-uniformity less than 2% on average in both bands. Spectral correction has been demonstrated to reduce cross-talk between bands limiting cross-talk from the out of band emitter to less than 1% of the commanded radiance. Spatial co-registration was shown to be better than 0.1 pixel on average, though a few pixels near the edge of the array exceeded the 0.25 pixel goal.

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