Non Uniformity Correction Algorithm for Large Format Shortwave Infrared Imaging Array

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***Abstract*—** Preprocessing is an important field of research in optoelectronics where raw images captured from infrared (IR) imaging array are tuned by applying various algorithms. Common image preprocessing in infrared imaging are: i) Non-Uniformity Correction (NUC), ii) Bad Pixel Replacement (BPR). Non-Uniformity (NU) arises because of each individual pixel in large format detector array has unequal photo-response from its adjacent pixel even if the both pixels are illuminated by equal luminance. This NU can be corrected by applying different NU Correction algorithms. In this paper, Two Pont NUC algorithm is designed in LabVIEW tool to reduce spatial noise or Fixed Pattern Noise. This algorithm has been tested on raw data acquired from Shortwave Infrared (SWIR) linear detector which has 6000 pixel elements. The result shows that pixel's non-uniformity reduces after applying two-point correction algorithm.

Keywords - SWIR Detector, Non-Uniformities, LabVIEW, Two Point Correction

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I. Introduction

Sensing in the shortwave infrared (SWIR) range (wavelengths from 0.9 to 1.7 microns) has recently been practical by the development of Indium Gallium Arsenide (InGaAs) sensors. As SWIR light is reflective infrared light with gray information and SWIR detector is sensitive in very low light condition, SWIR detector is used where visibility in atmosphere is very low e.g. rain, fog, mist. It is also applicable in object identification.

Correcting for NU is a key problem that must be resolved in the application of infrared detectors. The NU of IR detector is an unequal response output among the pixels in large array format under the uniform illumination. At present, the most common solution for correcting the NU of IR detectors in an scientific project is the two-point NUC, where two different uniform illumination are adjusted to acquire raw data at high and low illumination from IR detector. Uniform illumination is set by using integrating sphere which has a input node where IR light source is attached and output node where detector's optical aperture is adjusted such that inkling IR illumination from circular hollow sphere is uniformly distributed to each and every area of detector's optical aperture [1]. Now, these two different data acquired at high and low illumination are calibrated to compensate gain and offset parameter of each pixel in array. These parameters are then applied in multiplicative and additive mean to correct pixel's non-uniformities.

II. Comparative Analysis of Different Issue for NUC Algorithm

As there are many algorithms available to correct pixel's NU. But those algorithms have some constraint for example, i) what is input scene? Stationary or in motion, ii) constant or variable integration time, iii) processing time requirement, iv) complexity etc. based on these parameter, effective algorithm has to be choose for better performance. Here, some literature study is presented to analysis various issues of NU and thus, optimum NUC algorithm is selected based on the analysis.

The first issue is, to obtain good quality of image from target object, integration time of detector needs to be tuned as per target object information. But if integration time is changed, dynamic range and detector's responsivity are affected and thus, already compensated NUC parameters are no longer valid and needs to be recalibrated again for different integration time. The proposed algorithm present in [2] is based on adaptive adjusting integration time and neural network correction. In this, first estimation of one point calibration is achieved by adopting linear regression technique, and then neural network algorithm performs non-uniformity compensation. Scene based non-uniformity correction used where the scene is random and constantly in motion relative to the detector. Algorithms like neural network based on constant statistics, temporal high pass filter etc., were not able to handle the problem of ghosting artifacts and object degeneration. Integration time has to be appropriate for ensuring quality of image. Author has explained about two point calibration algorithm in which 12 groups of correction parameters are stored in external flash by using least mean square adaptive filter algorithm to adjust integration time iteratively and then to widened dynamic range, super framing technique proposed, but those are not real time.

Two-point calibration method variants blackbody method and integration time method. both methods applied on LWIR and MWIR cameras and compared in [3] and concluded that NUC and BPR should be performed every time camera is powered up or any parameter like integration time, lens temperature or scene content is changed.

The improved TPC algorithm overcomes the influence of nonlinearity of the detector's response to enlarge correction precision and dynamic range is described in [4] and concluded that if dynamic range of detector increases, two-point correction precision reduces quickly. Sometimes multipoint correction is used but it increases complexity and cost of the system. In this, FPGA and DSP are used as the real time processing elements.

Based on literatures, comparison analysis is presented in Table 1.

Table 1: Comparative Analysis of available NUC methods

Parameters	Scene based	Calibration based
Effectiveness	More when scene is random and in motion	More when scene is stationary or slowly varying
Processing Speed	Low	High
Complexity	High	Low
Limitation	Need more time for processing raw images.	If integration time changes, calibration parameters will no longer be valid and need to be re-calibrated for different integration time.

III. DETECTOR SPECIFICATIONS

Shortwave Infrared 6000 pixel elements detector made of Indium Gallium Arsenide (InGaAs) material to detect incoming IR photons in SWIR ranges from 0.9µm to 1.7µm is used. CMOS Readout Integrated Circuit (ROIC) is connected with InGaAs array by indium bumps which generate all internal biases and signals to the sensor. 14-bit ADC is integrated in ROIC.

IV. TWO POINT CORRECTION (TPC) ALGORITHM

From Literature study of different NU correction algorithm, two point NUC is proved to be most practical method and requires fewer resources to implement and give better result compared to other methods.

The output of pixel is proportional to the number of photoelectrons accumulated at the pixel over the integration time, as given by Eqn. (1). To perform the non-uniformity correction, the sensor output is acquired at two different illuminations or at two different integration times by exposing the system with a uniform illuminator such as integrating sphere. To achieve this, first set of image data I_1 is recorded at lower illumination and second set of image data I_2 is recorded at higher illumination. Fixed number of image frames, at each illumination are taken and averaged to reduce the temporal noise. For the i^{th} pixel in the linear array, the measured signal Y_i (detector response) is given by the following linear relationship,

$$Y_i = a.X_i + b_i \tag{1}$$

Where, 'a' and 'b_i' are the gain and offset non-uniformities associated with the i^{th} pixel respectively. 'X_i' is the irradiance received by the i^{th} detector pixel. Thus, after NUC correction, the above equation can be expressed as,

$$X_i = a_i^{'}.(Y_i - b_i) \tag{2}$$

Where, $a'_i = \frac{1}{a_i}$

Defining,

$$a'_i = \frac{(I_2 - I_1)}{(I_{2i} - I_{1i})} \quad , \quad b_i = I_{1i}$$

I_{1i} and I_{2i} are i^{th} pixel intensities at lower and higher illuminations respectively. I_1 and I_2 are the spatial averages of the image frames at lower and higher illuminations respectively and are defined as,

$$I_1 = \frac{1}{N} \sum_{i=1}^{N} I_{1i} \tag{3}$$

$$I_2 = \frac{1}{N} \sum_{i=1}^{N,} I_{2i} \tag{4}$$

N is the total number of pixels in an array. Thus, the corrected output of the pixel i^{th} is given as,

$$X_i = \frac{(I_2 - I_1)}{(I_{2i} - I_{1ij})} * (Y_i - b_i)$$

V. DESIGN OF NUC ALGORITHM

TPC algorithm shown in Fig. 1 is designed in LabVIEW tool. This algorithm calibrates gain and offset parameters of each pixel in array and corrects non-uniformity. Illumination based TPC technique is used to perform NUC. In illumination based technique, Correction parameters are calculated based on two different set of frames acquired on high illumination and low illumination with constant integration time.

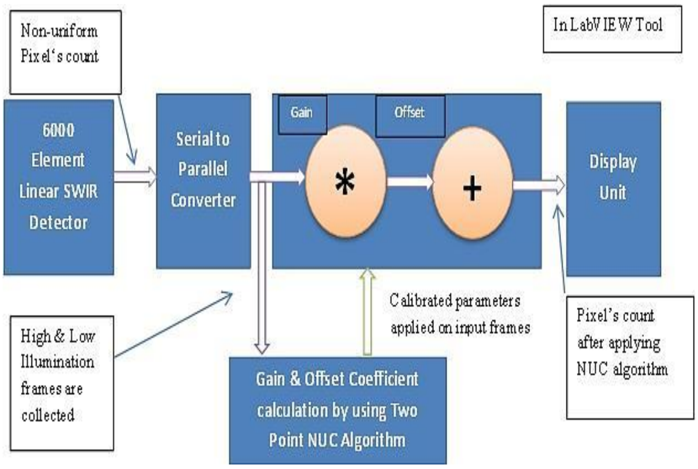

Figure 1. TPC NUC Design in LabVIEW

Serial to parallel converter module converts 14-bit 6000 pixel serial data which is coming from detector to NI's PCI6552 data acquisition card into parallel form to process it. Each pixel's gain and offset is calibrated based on acquired frames at high and low uniform illumination and stored in array. NU raw data are acquired in LabVIEW and TPC NUC algorithm is applied on it by multiplying gain coefficients and adding offset coefficients with raw pixel. NU Corrected data is displayed on wave former in LabVIEW.

Performance parameter called as Photo Response Non-Uniformity (PRNU) is used to evaluate the performance of the algorithm. This is defined as standard deviation (SD) of the corrected FPA signal divided by the mean signal (mean). Mathematically it can be expressed as,

$$PRNU = SD/\,Mean = \frac{1}{\bar{\bar{X}}} * \frac{\sqrt{\sum_{i=1}^{N}(Xi-\bar{X}))^2}}{N} \quad (5)$$

Where N is the number of pixels in an array, X_i is the output of the pixel (i) and $\overline{X}$ is the spatial mean of the pixel in array.

VI. Experimental Setup and Results

To prepare experimental setup for acquiring uniform illumination, detector's optical aperture must be covered by integrating sphere's aperture. Moreover, no any light source is emitted to detector's any area for proper experimentation.

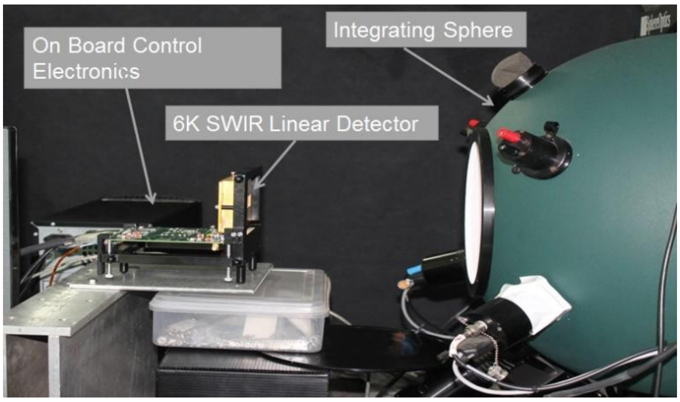

Figure 2. Experimentation Setup to acquire uniform illumination

As seen in fig. 2, 6k SWIR detector is setup at exactly center point from sphere's aperture. Distance between detector and sphere's aperture is adjusted such that, at fixed integration time, detector's whole dynamic range convers from high illumination to low illumination from integrating sphere. On board control electronics includes, i) Field Programmable Gate Array (FPGA) as a main processing core which drives and controls the detector by providing necessary driving signals and control commands, ii) Programmable System on Chip (PSoC) as a controller to set and control various analog and digital voltage level for detector and FPGA and also used to send commands and data from LabVIEW to FPGA from SPI interface. Pixel data readout by FPGA and routed it to National Instrument's PCI6552 card installed in PC which has 32GPIO.

Detector response is inversely proportional to incoming light intensity. So, if detector is exposed to bright part of scene, output pixel count will be low and if detector is exposed to dark part of scene, output pixel count will be high. Detector covers maximum 11,600 digital count of dynamic range in dark condition and minimum 400 digital counts of dynamic range in brightest condition.

To correct NU by using illumination based TPC technique, total 32 set of frames are acquired at high illumination by adjusting light illumination at 18% of dynamic range and low illumination by adjusting light illumination at 70% of dynamic range as shown in Fig. 3.

Total 32 frames are acquired at 50% dynamic range to perform NUC. Raw data contains 7.139% NU. Three bad pixel are appears between 4500 to 5200 pixel range. Raw data as a 3D plot is shown in Fig. 4.

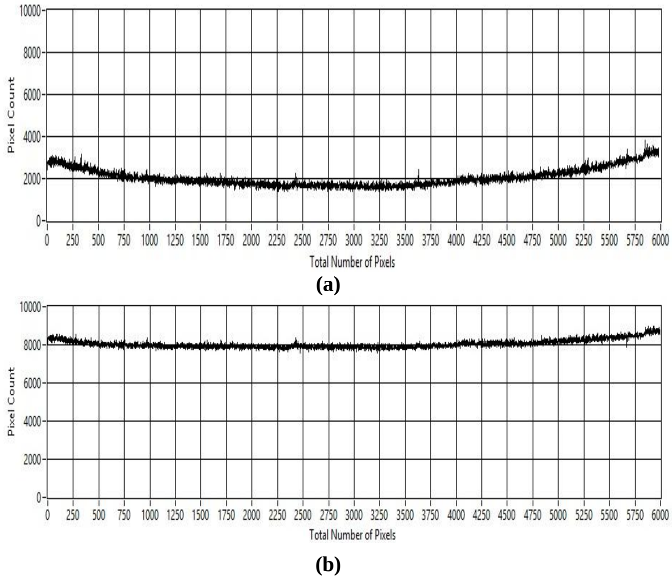

Figure 3. Framed acquired at Uniform, (a) High Illumination, (b) Low Illumination

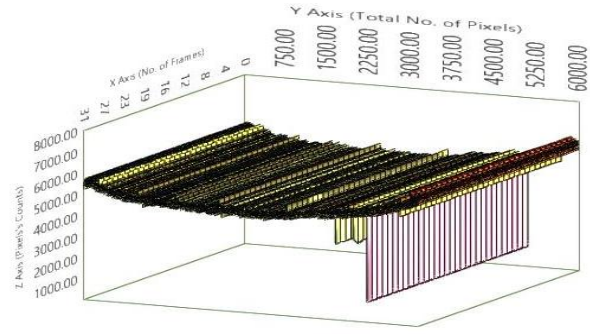

Figure 4. Raw Data with presence of NU and Bad Pixels

To correct presence of NU in raw data, calibrated gain and parameter is applied on each pixel. Fig. 5 shows corrected data after applying NUC algorithm in 3D plot.

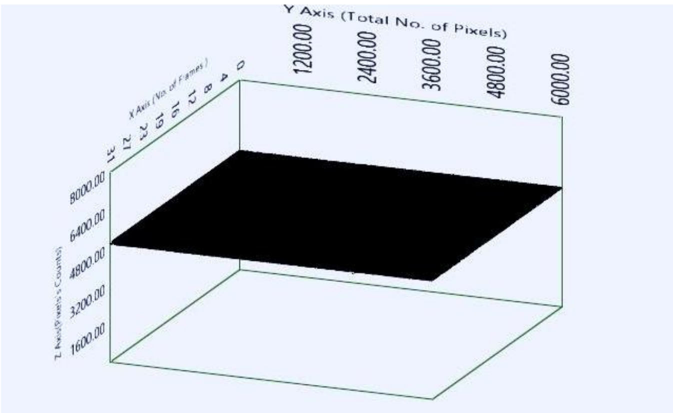

Figure 5. Corrected data after applying NUC algorithm

Photo response NU (PRNU) for uncorrected scene data is measured which is 7.1398% and after applying NUC algorithm, it is 1.792%. PNRU measurement for proposed algorithm illustrate that TPC algorithm reduces almost 5.347% of non-uniformity present in acquired data from SWIR detector.

VII. CONCLUSION

The proposed algorithm has been tested on temporally averaged 32 frames of acquired IR data. The PRNU measurement was carried out for both uncorrected data and corrected data which concludes that up to 5.3478% of pixel's NU is reduced by applying TPC NUC algorithm. This algorithm removes both multiplicative and additive spatial noises. LabVIEW tool is used to design whole algorithm and data representation plots.

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