Fixed pattern noise correction and implementation for infrared focal plane array based staring system using scene statistics

Ajay Kumar, S. Sarkar and R.P.Agarwal

Abstract**—**The spatial and temporal non-uniformities in infrared focal plane array (IRFPA), which is called as fixed pattern noise (FPN), results in a slowly varying pattern on the thermal image thereby, degrading the resolving capabilities of thermal imaging system considerably. In this paper a scene based fixed pattern noise correction method using the scene statistical parameter is presented. The proposed method corrects both the additive and multiplicative types of fixed patter noise thus eliminating the need of halting the operation of thermal camera for calibration. FPGA based approach is presented for implementing the proposed algorithms. Comparison of the proposed method with Scribner algorithm and Harris constant statistics methods show it to be the most superior of the three.

Keywords**—**FPGA, fixed pattern noise, Infrared focal plane array, Thermal imaging

I. INTRODUCTION

Most of the present thermal imaging systems use infrared focal plane array (IRFPA), which consists of a mosaic of photo detectors placed at the focal plane of imaging systems [1,2,3]. The IRFPA technology has advanced immensely in recent years, resulting in the development of focal plane array (FPA) with smaller pitch and improved noise equivalent temperature difference (NETD), thus, improving the performance of the system considerably. However, it also results in several problems and most serious of them is sensor non-uniformities. Non-uniformities are mainly attributed to the difference in the photo-response of each detector in the FPA. Other degrading factors such as IRFPA temperature, finite lens aperture causing blur, finite photo responsivity of the detector; under sampling add to the non-uniformities. These spatial and temporal non-uniformities result in a slowly varying pattern on the image. This is called as fixed pattern noise and degrades the temperature resolving capabilities of thermal imaging system considerably [4, 5].

There are mainly two types of non-uniformity correction (NUC) techniques, namely scene-based [6, 7, 8, 9] and calibration-based techniques [10, 11]. To perform the fixed pattern noise correction, the scene-based techniques generally use an image sequence and rely on the scene parameters like motion or change in the actual scene. The most common calibration based technique is two-point calibration method, in which FPA is calibrated at two distinct and known temperatures using a uniformly calibrated target such as black body. The gain and the bias of the FPA are calibrated across the array so that FPA produces a uniform and radiometrically accurate output at these two reference temperatures. This method requires halting of the operation of the system and results large residual non-uniformities away from the reference calibration temperature.

In this paper, we propose a fixed pattern noise correction method based on scene statistics. The proposed method relies on the assumption that scene parameters such as mean and variance of the pixels do not vary from one frame to another. The method corrects both the additive and multiplicative types of fixed pattern noise. The proposed algorithm can be easily implemented and a FPGA based implementation methodology is presented. Furthermore, an exponential filter is used for faster convergence of the proposed method and an adaptive threshold method is used for removing artifacts. The results obtained using this method is compared with the results obtained using Scribner algorithm [12] and Harris constant statistics method [6].

This paper is organized as follows. Algorithm is presented in the section 2. In section 3, results of the algorithms are presented. Section 4 gives convergence analysis and hardware implementation methodology of the proposed algorithm is given in section 5. The conclusions are given in Section 6.

II. ALGORITHM

The infrared focal plane array sensor response is usually modeled as a first order linear relationship between the input irradiance and the detector output. For the detector element in the FPA the readout signal corresponding to the pixel of the FPA in frame is given as

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uniformities noise were introduced in the infrared sequence. First image sequence data was generated by introducing offset non-uniformities having mean and standard deviation 0 and 15 respectively and gain non-uniformities having mean and standard deviation 1 and 0.01 respectively. The second image sequence with offset non-uniformities having mean and standard deviation 0 and 5 respectively and gain non-uniformities having mean and standard deviation 1 and 0.2 respectively. Third image sequence with offset non-uniformities having mean and standard deviation 0 and 15 respectively and gain non uniformities having mean and standard deviation 1 and 0.5 respectively was generated. A temporal noise with standard deviation of 0.01 was also added in all sequences. The scene statistics algorithm with different value of M was tested on these infrared image sequences. The proposed method is compared with already published Scribner and Harris methods. The results of implementation are given in Figs. 1, 2, and 3 for different level of non-uniformities. The root mean square errors (RMSEs) for these three image sequences were calculated and Fig. 4 shows the result of variation of RMSE with number of frames.

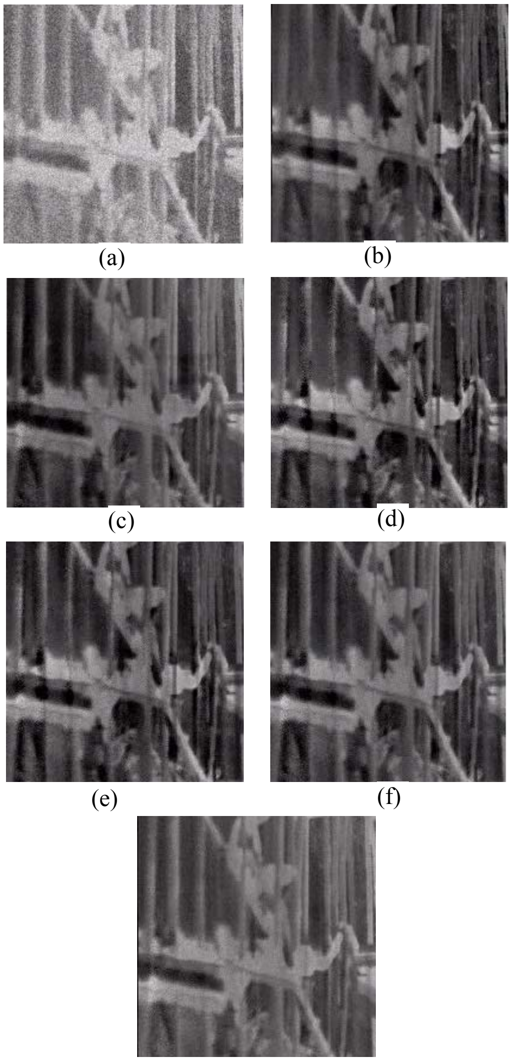

(a) (b) (c) (d) (e) (f) (g)

Fig 1 (a) Input 200th frame with $m_a = 1, m_b = 0, \sigma_a = 0.01, \sigma_b = 15$ (b) Scribner Algorithm (c) Harris Algorithm (d) Proposed Algorithm with M=10 (e) M=20 (f) M=50 (g) M=100

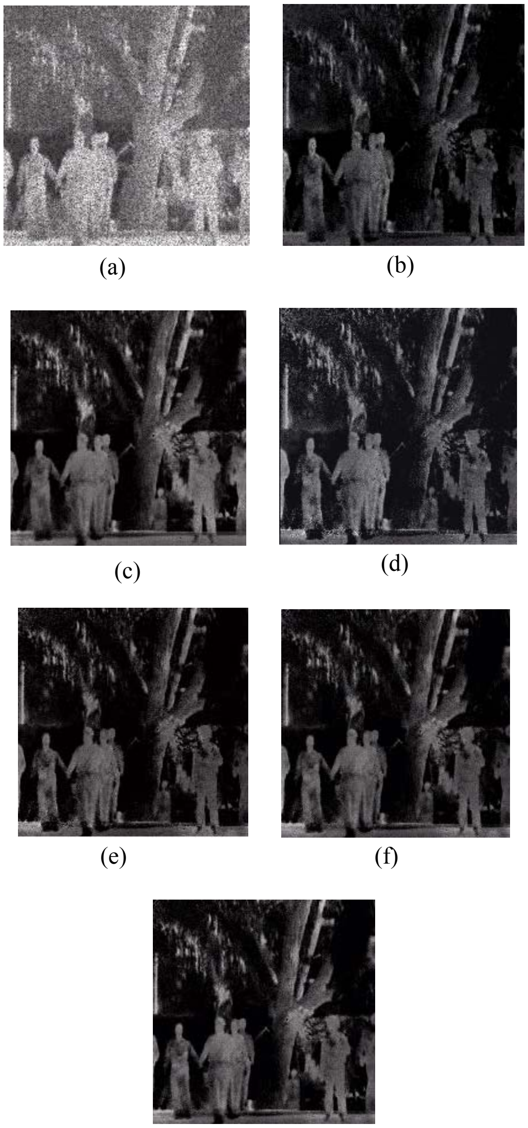
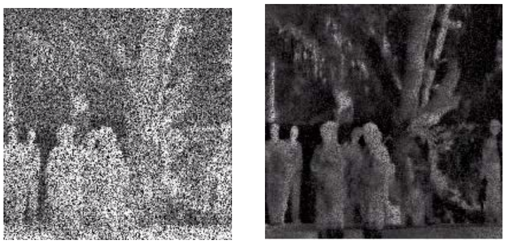
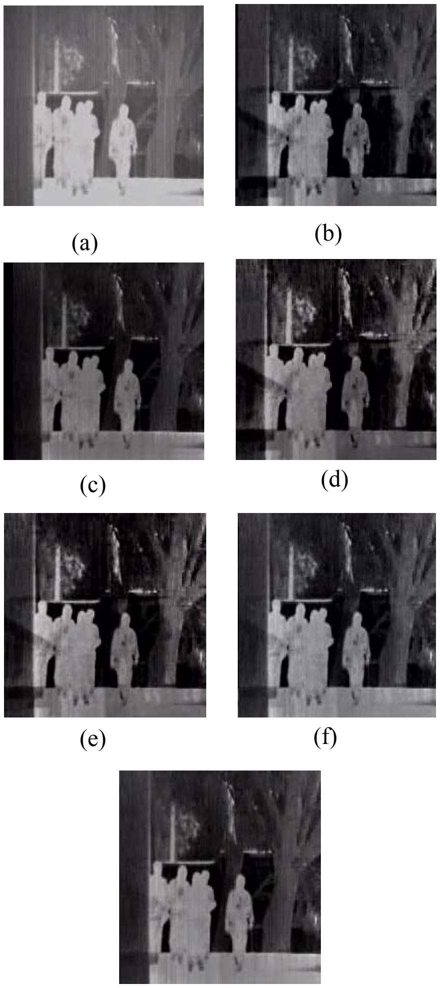

(a) (b) (c) (d) (e) (f) (g)

Fig 2 (a) Input 1000th frame with $m_a = 1, m_b = 0, \sigma_a = 0.2, \sigma_b = 5$ (b) Scribner Algorithm (c) Harris Algorithm (d) Proposed Algorithm with M=10 (e) M=20 (f) M=50 (g) M=100


(a) (b)

(g)

Fig.6 (a) Input Image 700th frame (b) Scribner Algorithm (c) Harris Algorithm (d) Proposed Algorithm with M=10 (e) M=20 (f) M=50 (g) M=100



(a) (b)

(c) (d)

(e) (f)

(g)

Fig.7 (a) Input Image 1400th frame (b) Scribner Algorithm (c) Harris Algorithm (d) Proposed Algorithm with M=10 (e) M=20 (f) M=50 (g) M=100

IV. CONVERGENCE of ALGORITHM

As the proposed algorithm uses the scene statistics for calibration, the numbers of frames required for convergence and calibration can be determined using a probabilistic convergence analysis. The basic approach considers random variables Y_1 , Y_2, …… Y_n and their estimates $\hat{Y}_1$, $\hat{Y}_2$ …. . $\hat{Y}_n$ When n is large and y is a random variable such that it's estimate $\hat{Y}$, is given by $\hat{Y} = \hat{Y}_1 + \hat{Y}_2 + \ldots + \hat{Y}_n$ then, according to central limit theorem, the random variable y can be approximate by a normal distribution. On this basis it can be shown that if 95% of the estimations is required to have an error within ± ε, then number of frames required to have an error within ± ε can obtained using the central limit theorem from the following relationship [14].

$$\varepsilon = 1.96.\frac{\sigma_n}{\sqrt{n}} \tag{14}$$

Assuming variance to be unity, number of frames required to restrict error to different limits are calculated. Table 1, presents a picture of the dependence of the required number of frames on the error. It shows that a fairly large number of frames are required to contain the error to a reasonable limit. For example, as large as 1537 frames are needed for 5% error.

Error (ε)	Number of frames needed (n)
0.25%	1440000
1.0%	66564
5.0%	1537
10.0%	269
33.67%	9

Table 1. Error Vs number of frames

V. HRADWARE IMPLEMENTATION

5.1 *System Configuration*

In order to verify the real time functionality and performance of the proposed algorithm, FPGA based hardware is designed using Xilinx XC2VP50 FPGA [15] as the processing element. 320 x 240 elements InSb infrared focal plane array (IRFPA) [16] is used to design the infrared imaging system, which is interfaced with Xilinx XC2V2000 FPGA based video processing board (VPB). Figure 8 illustrates the configuration for hardware implementation. The analog video signal from IRFPA is pre-processed in the VPB and converted into a digital data using a 14-bit analog to digital converter (ADC). The 14 bit video data is then subjected to 2 point fixed pattern noise (FPN) correction. Several functions such as digital scan conversion, global gain & offset, dynamic range compression, polarity control, contrast enhancement and noise removal are then implemented on the corrected data. Finally a 10 bit data is generated that is given to THS8133 video digital to analog converter (DAC) where it is mixed with blanking and synchronization signals to generate a CCIR standard analog video for display. The FPGA is interfaced with four 1M x16 SRAMs and two 512K x16 flash memories. Two flash memories are required for storing gain and offset coefficients

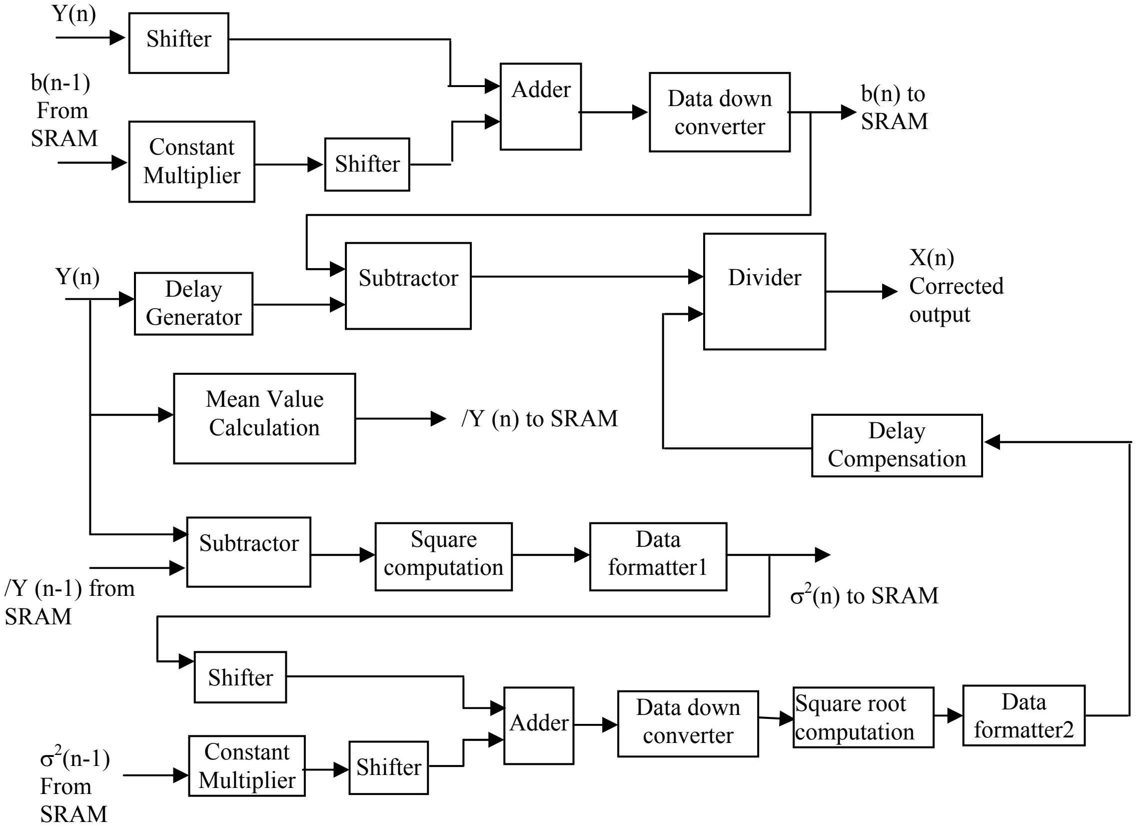


Fig 9. Data path implementation of the algorithm

5.2 *Performance analysis*

The proposed algorithm has been implemented in VHDL using Xilinx ISE foundation series software version 6.3 and simulated with modelsim simulator [15]. The design has been implemented in Xilinx XC2VP50 device. Furthermore, Scribner algorithm [12] and Harris algorithm [6] were also implemented on the same hardware and table II illustrates the comparative results of implementation.

Parameter	Scribner Algorithm	Harris Algorithm	Proposed Algorithm
Number of slices FF	146	971	971
Number of occupied slices	404	954	965
Total number of 4 input LUT	567	1181	1202
Number of GCK	1	1	1
Maximum Frequency of operation	769.82MHz	751.36MHz	746.26MHz
Estimated Power consumption	951mW	953mW	953mW

Table 2 Comparative results of implementation

It can be seen that proposed algorithm and Harris algorithm [6] utilizes almost same device resources, where as Scribner algorithm [12] utilizes lesser device resources. However, Scribner algorithm only corrects the offset non-uniformities and does not correct the gain non-uniformities, which may be very important particularly when scene dynamics are changing very fast. The estimated power consumption for the three algorithms as reported by the Xilinx power analysis software is almost same.

VI. CONCLUSION

In this paper, an approach for correcting the sensor fixed pattern noise based on scene statistics is presented. The proposed method is tried with exponential filter for faster convergence having different lengths of filter. The proposed method is compared with the methods proposed by Scribner and Harris and the RMSE of the different algorithms are calculated. The results indicate that the proposed method gives better results and removes both the additive and multiplicative fixed pattern noise. Furthermore, a hardware realization of the proposed method indicates the real time implementation of the algorithm