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An improved non-uniformity correction algorithm and its hardware Implementation on FPGA

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Abstract: The Non-uniformity of Infrared Focal Plane Arrays (IRFPA) severely degrades the infrared image quality. An effective non-uniformity correction (NUC) algorithm is necessary for an IRFPA imaging and application system. However traditional scene-based NUC algorithm suffers the image blurring and artificial ghosting. In addition, few effective hardware platforms have been proposed to implement corresponding NUC algorithms. Thus, this paper proposed an improved neural-network based NUC algorithm by the guided image filter and the projection-based motion detection algorithm. First, the guided image filter is utilized to achieve the accurate desired image to decrease the artificial ghosting. Then a projection-based moving detection algorithm is utilized to determine whether the correction coefficients should be updated or not. In this way the problem of image blurring can be overcome. At last, an FPGA-based hardware design is introduced to realize the proposed NUC algorithm. A real and a simulated infrared image sequences are utilized to verify the performance of the proposed algorithm. Experimental results indicated that the proposed NUC algorithm can effectively eliminate the fix pattern noise with less image blurring and artificial ghosting. The proposed hardware design takes less logic elements in FPGA and spends less clock cycles to process one frame of image.

Key words: Infrared focal plane array; non-uniformity correction; neural network; guided filter; motion detection; FPGA.

1. Introduction

Infrared Focal Plane Array (IRFPA) is the most important part in an infrared imaging system[1]. However, due to the immature manufacturing processes and the dark-current noise, different detectors of an IRFPA are unable to output the same value under the same infrared irradiance, which is called the non-uniformity of IRFRA. This phenomenon will impose some fixed pattern noise (FPN) on the infrared image, which severely degrades the quality of images. Therefore, developing an effective non-uniformity correction (NUC) algorithm and implementing it on the embedded hardware platform are necessary tasks to improve the image quality for an infrared imaging system.

In recent years, different NUC algorithms have been proposed, which can be mainly divided into two categories, the reference-based NUC and the scene-based NUC algorithm. Two-point correction (TPC) is a typical reference-based algorithm. This method employs uniform blackbody as reference irradiance sources to calculate the correction parameter. The advantages of these methods lie in its simplicity and low computational complexity. Thus, it is very suitable to implement this kind of algorithms on the embedded hardware platform. For instance, Zhou[2] presented an improved TPC algorithm and implemented it on a FPGA+DSP based platform. Tomasz Sosnowski[3] implemented TPC as a part of image processing on an FPGA based platform. However, repetitive recalibration must be done when correction coefficients become invalid, which would interrupt the normal operation of the imaging system and increase maintenance costs.

The scene-based NUC algorithm can acquire and calibrate coefficients continually and automatically without interrupting the normal system operation. Typical scene-based NUC algorithms mainly contain constant statistics[4-7] based, temporal high-pass filter[8-10] based, Kalman filter based[11-14], registration based[15-17] and neural network[18] based algorithms.

The neural network based non-uniformity correction (NN-NUC) algorithms are widely used because of its better adaptively and noise immunity. However, the traditional NN-NUC would result in ghosting artifact to the moving object and image blurring to static scene, which restrict its application. In Scribner's algorithm, the local spatial neighborhood average is utilized to estimate the desired output of one pixel. The mean filter will lead the blurring of edge in estimated image and result in image blurring on the static scene and ghosting artifacts on the previous position of the moving objects.

Many researchers have proposed a number of improved algorithms. Hui Yu[18] set two different learning rate on gain and bias correction coefficients respectively, which will accelerate the convergence speed. Jufen zhao[19] utilized the ***L0*** gradient minimization method to achieve the estimated irradiance, which will make a good balance between non-uniformity and the details preservation. Fan FAN[20] utilized the a 1D-Guassian filter to achieve the desired image for the line scanning Infrared image. Though, Nicolas Celedon et al.[21] presented a FPGA-based hardware platform to implement the original Scribner's algorithm. Most improved algorithms don't consider the real-time ability to apply it on the hardware platform.

In order to solve the problems mentioned above, in this paper, an improved NN-NUC algorithm is proposed. First, the mean filter in Scribner's algorithm is substituted by the guided filter (GF)[22]. The guided image filter is an edge-preserving smoothing operator, which will severely decline the ghosting artifacts during the correction process. Then, a moving detection algorithm based on projection is utilized to prevent the blurring of the stationary scene caused by invalid updating of coefficients. Finally, An FPGA-based hardware design of the proposed improved algorithm is introduced completely.

The remainder is organized as follows. In section 2, the correction model of proposed NUC algorithm is introduced. In section 3，the hardware design and the implementation based on FPGA are discussed. In section 4, the proposed algorithm is applied to real and simulated infrared image sequences and the experimental results are analyzed in detail. The hardware resource analysis and the conclusion are given in section 5 and in section 6 respectively.

2. Improved non-uniformity correction algorithm

A. Neural network based NUC

Neural network based Non-uniformity correction (NN-NUC) algorithm was first proposed by D. A. Scribner[1]. In this algorithm, it is assumed that the response of each detection-element in an IRFPA can be corrected by a linear model

$$I^{k}_{nuc}(i,j) = G^{k}(i,j) \times I^{k}_{orig}(i,j) + O^{k}(i,j) \quad (1)$$

where (i,j) is the coordinate of a detector element in a IRFPA, k means the number of frame, $I^{k}_{orig}(i,j)$ is the original output of each detectors