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Strip non-uniformity correction in uncooled long-wave infrared focal plane array based on noise source characterization

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ABSTRACT

In uncooled long-wave infrared (LWIR) imaging systems, nonlinear behaviors of infrared detectors and lack of column cross-calibration generate obvious strip non-uniformity in the captured infrared images. Human observers are particularly sensitive to the resulting high-frequency Fixed Pattern Noise (FPN). In this paper, we propose to learn characteristics of such strip-type FPN through a set of thermal calibration experiments. Our thermal calibration experiments discover that a polynomial curve model can be used to approximate the relationship between infrared data and strip noise of sensor detectors within a column. The derived noise behavioral model allows us to distinguish high-contrast components caused by image texture and strip noise. An effective single-image based processing algorithm is proposed to remove strip-type non-uniformity in infrared images without causing undesired blurring effects. The performance of the proposed technique is thoroughly investigated, and is compared to the state-of-the-art strip denoising algorithm using realistic infrared images.

1. Introduction

Spatial non-uniformity in infrared Focal Plane Array (FPA) is a common, although undesirable, characteristic arising from small differences in the responsivity of individual detectors. Non-uniformity typically manifests itself as FPN in the raw image data (i.e. prior to any post-capture correction). In uncooled LWIR systems, this problem becomes even more challenging since the characteristics of non-uniformity are affected by temperature fluctuations of FPA, optic lens, and other mechanical components [1,2]. The resulting FPN will significantly degrade the spatial resolution and radiometric accuracy of captured infrared images.

Infrared images are typically corrupted by obvious strip-type FPN. This kind of complex non-uniformity often makes the infrared images unrecognizable, and it is difficult to be removed using the traditional calibration-based [3,4] or scene-based [5–8] Non-uniformity Correction (NUC) techniques. Moreover, it is difficult to distinguish texture from stripe noise based on analysis of image content. For example, it is impossible to tell whether a vertical image edge is caused by a scene object or erroneous strip non-uniformity. Therefore, a general image denoising solution [9,10] will over-smooth infrared images and lose many valuable details. It becomes difficult to distinguish targets of insignificant temperature variations in the smoothed output. This is particularly a problem for the low-textured infrared images [11].

In this paper, we experimentally investigate the strip-type FPN in infrared images and further present an effective NUC method to remove it. For this purpose, we come up with a simple experimental setup for learning the characteristics of strip non-uniformity. Our thermal calibration experiments discover that a polynomial relationship exists between infrared data and strip noise of sensor detectors within a column. Based on the derived noise behavioral model, strip noise can be accurately separated from actual image texture. An effective single-frame based NUC solution is proposed to remove strip-type FPN without blurring image structures. Experiment results show that the accuracy of our proposed method is comparable to the state-of-the-art strip non-uniformity correction algorithm based on Midway Histogram Equalization (MHE) [12,13] while its average execution time is more than 6 times shorter.

2. Related works

One of the most basic and effective NUC solutions is based on radiometric calibration of the camera [3]. Temperature references (e.g. shutter or blackbody) are applied regularly to update spatial NUC factors. However this practice will demand the inclusion of extra electronic components which increases both the complexity and power consumption of the device. Moreover, this practice will

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interrupt camera's image capturing for a few seconds, therefore is not suitable for seamless and real-time infrared applications.

To overcome the limitations of above calibration-based techniques, many shutterless methods have been proposed for temperature-dependent NUC through image sequence processing [5,14,7,6]. These scene-based NUC methods are relied on either image statistical analysis [5,14,7] or temporal motion tracking [6]. Harris and Chiang [5] developed scene-based NUC algorithms based on the assumption that the temporal means and variances are identical for all pixels. Hardie et al. [6] developed NUC algorithms based on the fact that a pixel detector observing the same scene point over different times should output the same responses. Offset and gain NUC parameters are estimated so that the corrected responses become similar. The problem of scene-based NUC algorithms is that they require scene content does not change significantly from frame to frame. This is a strong assumption and does not hold valid for many scenarios. Furthermore, the scene-based NUC algorithms need to process an image sequence to estimate robust NUC factors which is not suitable for frame-based implementation. Finally, if the image sequence does not contain enough scene motions, the previous images may appear as the "ghosting" artifacts in the current image frame.

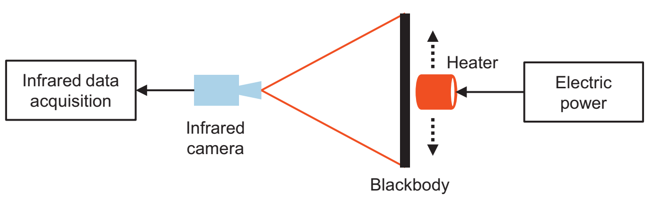

Fig. 1. The schematic diagram of the experimental setup for learning characteristics of strip non-uniformity.

A number of papers have been published on techniques for removing 1D stripe noise [15,16]. These methods typically apply a threshold that distinguishes image edges and stripe noise to avoid edge blurring. However, this strategy will falsely remove weak image edges and keep strong stripe noise. The approach described in [16] groups pixels from the same readout channel (e.g. within a column) and apply a linear correction model to normalize these pixels so that adjacent channels produce output with the same mean and standard deviation. In [17], the authors proposed a single frame scene-based NUC algorithm using gradient-based regularization. The solution aims to seek the optimal image with a vertical gradient as close to the original image as possible and make the energy of the horizontal gradient as small as possible. This method will also blur images with vertical features. Recently, Tendero et al. proposed an effective stripe removal method based on column-wise Midway Histogram Equalization (MHE) [12]. This method does not require separating image edges and stripe noise, therefore can effectively eliminate stripe noise without blurring edges.

3. Thermal calibration and noise modeling

The schematic diagram of the experimental setup is given in Fig. 1. We make use of a ceramic infrared lamp (heater) to heat up a black metal plate (blackbody) unevenly. Then, we capture 640×480 resolution infrared images of the blackbody using a commercial uncooled LWIR thermal imaging camera with 17 μm pixel size. We manually set off its on-chip strip noise cancellation algorithm and some sample images are shown in Fig. 2. It is observed that the captured infrared images contain a smoothly varying intensity field caused by the unevenly heated blackbody,

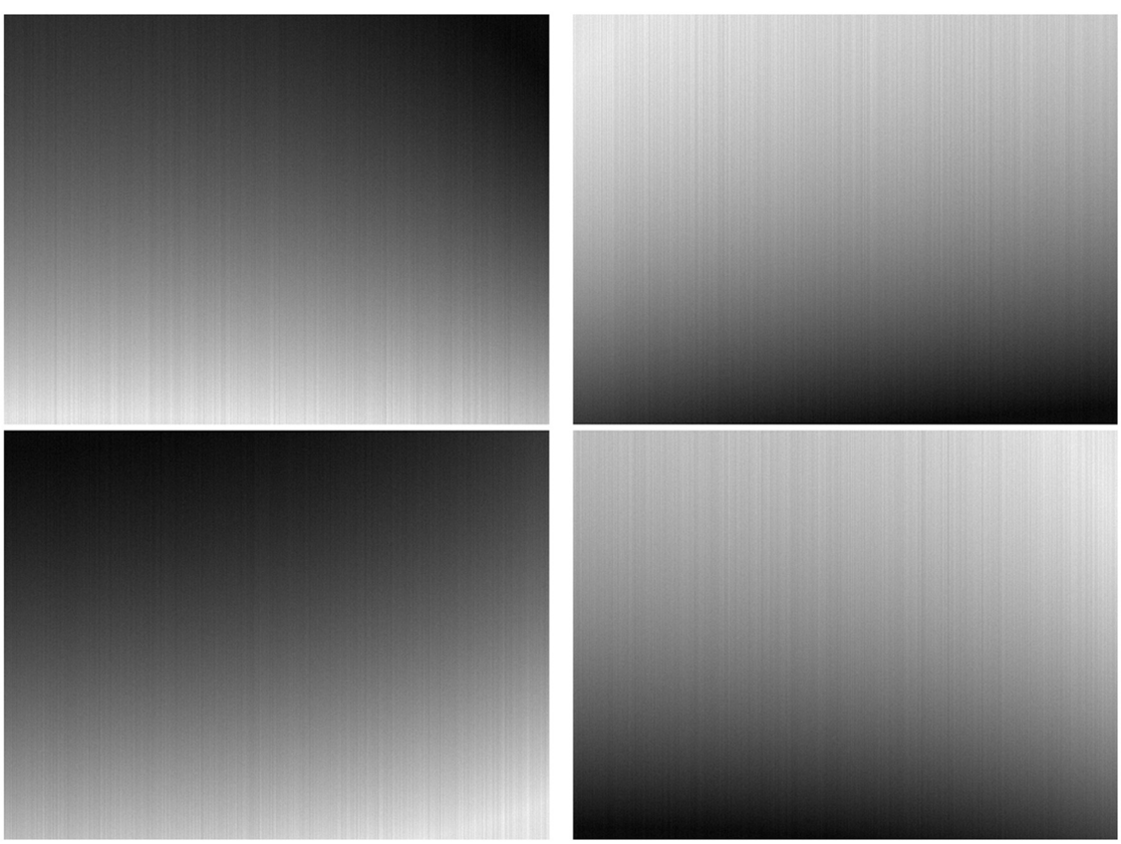

Fig. 2. Sample infrared images of an unevenly heated blackbody. Note that the images contain a smooth varying intensity field, some obvious vertical strip noise, and no major texture or edges. The shape of the intensity field is adjusted by changing the position of heater behind the blackbody.