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Detail enhancement for high-dynamic-range infrared images based on guided image filter

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HIGHLIGHTS

- New detail enhancement algorithm has been raised in this paper.
- Greatly simplified the computation process to the existing methods.
- Better noise suppression when enhancing the detail of IR images.
- Effective in enhancing the detail information of IR images.

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ABSTRACT

Detail enhancement and noise reduction play crucial roles in high dynamic range infrared image processing. The main focuses are to compress the high dynamic range images with an effective way to display on lower dynamic range monitors, enhance the perceptibility of small details, and reduce the noises without causing artifacts. In this paper, we propose a new method for detail enhancement and noise reduction of high dynamic range infrared images. We first apply a guided image filter to smooth the input image and separate the image into the base component and the detail component. This process also gives us an adaptive weighting coefficient associated with the details generated by the filter kernel. After the filtering process, we compress the base component into the display range by our modified histogram projection and enhance the detail component using the gain mask of the filter weighting coefficient. At last, we recombine the two parts and quantize the result to 8-bit domain. Our method is significantly better than those based on histogram equalization (HE), and it also has better visual effect than bilateral filter-based methods. Furthermore, our proposed method is much faster, non-approximate and suffers much less gradient flipping artifacts compared to the bilateral filter-based methods because the guided image filter uses the local linear model. We demonstrate that our method is both effective and efficient in a great variety of applications. Experimental verification and detailed analysis are shown in this paper.

1. Introduction

Nowadays, high-quality thermal cameras can detect temperature difference within 0.01 K. They can also accommodate the temperature range about 50 K. For these reasons, modern infrared cameras are able to produce images with a wide dynamic range of 14-bit (or more), which exceeds the 8-bit sensitivity of a typical display device. Nevertheless, a human visual system only has the capability of distinguishing 128 gray levels of an image [1]. Hence, we need a procedure to compress the dynamic range of the raw images into a lower range. Thus, it is suitable for the display system and enhances the significant details of images during the compressing and then improve the image visual quality.

Dynamic-range compression (DRC) has been widely investigated and a number of visualization techniques have been proposed in literature. Such techniques are applied specifically in the visible spectral domain and take no account of the characteristics of infrared images. Thus, specific technology must be studied especially for high dynamic range infrared images, which will be useful for adjusting the raw data into a proper range for display and maintaining or even improving objects' visibility and overall contrast.

Traditional gamma correction is a widely used for contrast enhancement owing to its simplicity and the convenience of displaying infrared images in real-time system. It improves image

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contrast through a specified gamma correction curve [2]. Other widely used methods are automatic gain control (AGC) and histogram equalization (HE)-based method [10,15–17]. The AGC method is quite simple. It removes extreme values and linearly compresses the raw data to a display range [18]. Unlike the AGC, HE employs non-linear and non-monotonic transfer functions to map the pixel intensity values between the input and output images. A large number of algorithms derived from HE are aimed to overcome the drawbacks of HE [3,4] such as increasing noises, losing details and washing out effect in some homogeneous areas. Technically, they can be categorized into two types: the global HE (GHE) and the local HE (LHE) [14]. The plateau histogram equalization (PHE) [21,22] and brightness preserving bi-HE (BPBHE) belong to the traditional GHE. They can suppress the enhancement of homogeneous regions by involving some tuning parameters. Compared to the GHE methods, the LHE techniques also act as the same role in display wide dynamic range infrared images. LHE applies histogram equalization in the local region of an image. This makes the image quality superior to GHE but has high computational expense and complexity. Adaptive histogram equalization (AHE) [3] can improve the local contrast and bring out more details of the image by computing the histogram through a local window centered at a given pixel to determine the mapping for this pixel. But it produces significant noises during processing. The improved AHE: contrast limited AHE (CLAHE) [4] has more flexibility in choosing the local histogram mapping function, and it can reduce undesired noise amplification. A novel contrast enhancement method called partially overlapped sub-block HE (POSHE) [5] has the capability to highlight the local details, and it dramatically reduces the computational time. All in all, these aforementioned HE-based methods could compress the dynamic range of the raw images more effectively than AGC. Given that they just process the images based on histogram information, obviously they cannot do a satisfactory job for detail enhancement.

In order to enhancing details while compressing dynamic range, some advanced methods are proposed. The balanced CLAHE and contrast enhancement (BCCE) [6] as well as the bilateral filter and dynamic range partitioning (BF&DRP) [7] are two methods for visualizing high dynamic range infrared images proposed by Branchitta et al. In the BF&DRP method, input images are smoothed into the base component and the detail component by a bilateral filter. The detail component is acquired by subtracting the base component from the input images. Then the two components are processed independently through a set of tunable parameters. These parameters should be carefully tuned to adjust the visualization system for the specific scenario.

Recently, Zuo et al. [8] proposed a novel method of display and detail enhancement for high-dynamic-range infrared images based on the framework of BF&DRP; here we call it BF&DDE. This approach is clearly superior in detail protection and noise reduction than other methods. It separates the raw image into two components using a modified bilateral filter, and then processes each component independently. The base component is projected to the display range, and the detail component is added back after an adaptive gain control process. Because of the mechanism of the bilateral filter, the gradient flipping artifacts are produced. The BF&DDE uses an adaptive Gaussian filtering (AGF) to avoid the unwanted artifacts. We found in our experiments that the AGF can suppress the gradient flipping artifacts to a certain extent but could not completely avoid it. In some particular scene with strong edges, the gradient flipping artifacts can be very annoying. Besides, the high computation cost of the bilateral filter and the AGF makes the actual application of BF&DDE restricted. For these reasons, a new method of display and detail enhancement for high dynamic range infrared images is proposed. We use the guided image filter (GIF) instead of the bilateral filter (BF). Its advantages include as follows: first, the GIF is a fast and non-approximate linear algorithm, its computational complexity is independent of the filtering kernel size [9]. Second, we use a mask as detail identifier to enhance the detail component adaptively, and set independent tuning parameters during the filtering process. The proposed method can be more flexible to reduce the background noises. This method can achieve the great effect of detail enhancement and noise reduction, and furthermore, works better near strong edges.

2. The principle of the proposed algorithm

He et al. [9] has proposed a novel filter, the guided image filter (GIF), which is widely applicable in computer vision and graphics. As they said, the GIF not only do a great job in edge-preserving but also can be computed efficiently. Inspired by the sensational effect of the BF&DDE [8] in high dynamic range infrared images processing, we design the framework of our method and improve it. We first use a GIF to smooth the input image and treat the result as a base layer, which contains the large amplitude variations which must be compressed. The subtraction of the input image and the base layer is then determined as the detail layer. The detail layer must be expanded because it contains the small signal variations related to fine texture. We process the two layers respectively and recombine them at last. Fig. 1 illustrates the intact principle scheme.

The key assumption of the GIF is a local linear model between the guidance image G and the filtered output I_{gif}. The guidance G can be acquired from the adjacent image or the input image I_{in} itself. When I_{in} and G are identified, the expression of the GIF is formulated as follow:

$$I_{gif}(i,j) = \sum_{(i',j')\in w_{i,j}} W_G(i',j') I_{in}. \tag{1}$$

The notation $(i', j') \in w_{i,j}$ indicates that (i', j') are pixels in a filter window that centered at the pixel (i, j). $W_G(i', j')$ is the kernel weights function which can be used as the weighting coefficient to enhance the details. We regard the filter output I_{gif} as the base component I_B. Then, the detail component I_D is merely obtained as:

$$I_D(i,j) = I_{in}(i,j) - I_B(i,j). \tag{2}$$

We process the two components separately. The base layer is mapped into the proper range using modified histogram projection with a threshold and a displacement factor, then we get the result I_{BP}. Meanwhile the detail layer is enhanced using the adaptive gain control method and we get the result I_{DP}. Finally, the two layers are recombined and regulated linearly to the proper range for display:

$$I_{out} = I_{BP} + I_{DP}, \tag{3}$$

The detail layer only has a small range, we can just compress the base layer to a lower range in case that when the detail layer is added back, the results would not overflow. Here the process is quite flexible and diverse.

3. Guided image filtering techniques

3.1. Filtering process

The GIF [9] is a linear translation-variant filter and Eq. (1) is its general expression. In Eq. (1), the kernel weights can be explicitly expressed by:

$$W_G(i',j') = \frac{1}{|w|^2} \sum_{\substack{(i'',j'')\in w_{i,j},\\ (i'',j'')\in w_{i',j'}}} \left(1 + \frac{(I_{in}(i'',j'') - \mu_{i',j'})(I_{in}(i',j') - \mu_{i',j'})}{\sigma_{i',j'} + \varepsilon}\right), \tag{4}$$