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Multi-focus image fusion based on edges and focused region extraction

Juanxiu Tian[a,b], Guocai Liu[a,*], Jingguang Liu[a,b]

[a] College of Electrical and Information Engineering, Hunan University, Changsha 410082, China
[b] College of Computer and Communication, Hunan Institute of Engineering, Xiangtan, 411104, China

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ABSTRACT

The aim of multi-focus image fusion is fusing multiple partially focused images into a sharper image. One of the keys to image fusion is how to detect the focused regions. This paper presents an image fusion method based on two different types of edges and focused region extraction. The first type of edges, called salient focused edges, only exist in the focused regions. They are detected from high-pass filtered images by a threshold method, and then used to distinguish focused regions from source images based on a quad-tree structure. The second type of edges synthesized by 'Canny' edges are used to refine the boundaries of focused regions. Finally, the extracted focused regions are combined into a clear fused image. Experiments show that the proposed algorithm can extract focused regions with proper boundaries. Therefore, the fused images can avoid distortion artifacts and well preserve the sharpness on the focused objects. The proposed method outperforms some state-of-the-art algorithms in terms of visual quality and quantitative indices.

1. Introduction

In the process of photography, focusing objects of interest is an important technique for obtaining clear images. Due to finite depth-of-field, the focused objects are sharp, and the objects outside the range of depth-of-field in the same scene are blurred. So the image is partially clear. Multi-focus fusion technology is to extract the focus features or regions from multiple images of the same scene and synthesize a sharp image. The key is extracting focus regions and combining them into a fully clear image.

In the past decades, many image fusion methods have been proposed. In general, they can be roughly categorized into four classes: multi-scale transforms (MST) based methods, sparse representation based methods, methods performed in spatial domains and methods combining different transforms [1]. MST are widely used in image fusion. Typically, the high frequency components of MST are utilized to indicate sharpness. Although many multi-scale methods produce nice images, they lead to pixel distortion due to nonlinear operations in the multi-scale domain [2].

Recently, the sparse representation theory is applied to image fusion [3]. The sparse coefficients can efficiently represent the saliency information of the original images. Yang and Li apply it to image fusion firstly [4]. Several multi-focus image fusion methods have also used the concept successfully [5–8]. Readers can consult the recent review [1] for more details.

The spatial domain algorithms are based on a local operation. They can avoid global problems and preserve more original information from the source images than the transform domain algorithms [9]. Spatial domain methods fuse intensity values of pixels from the input images directly. A good idea is to select the sharper pixels over all input images to compose the fused image.

* Corresponding author.
E-mail addresses: juanxiutian@126.com (J. Tian), lgc630819@hnu.edu.cn (G. Liu).

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Evaluation metrics, such as variance [10], energy of Laplacian [11] and spatial frequency [12], are developed to determine the sharpness of each pixel. However, for most of the pixel-based methods, presence of noises can cause inaccurate measurement of sharpness and degrade fusion performance since sharpness is evaluated locally based on each pixel [13]. In the past few years, some novel spatial domain methods based on gradient information have been proposed [2,14,15]. The latest research has adopted convolutional neural networks to automatically learn a direct mapping between source images and focus map using high-quality image patches [16].

To overcome the effects of noises, block-based or region-based methods have been proposed [9,17,18]. There are two main important factors which affect the performance of the block-based methods. One is how to select the size of block and the other is how to measure sharpness of block. Quad-tree structure, which provides an optimal subdivision of blocks intuitively, is introduced into multi-focus fusion [9,19,20]. In general, the algorithm proposed by Bai et.al provides good performance [9]. However, some small blurred and smooth regions may be inappropriately segmented into the sharp blocks, which would affect the visual effect. The subsequent study presents a multi-focus image fusion method based on boundary finding (BF), which can currently obtain state-of-the-art result in multi-focus image fusion [21]. Yet, the multi-focus boundary extracted by BF may shift away from the exact multi-focus boundaries when the boundary regions of the source images are very complex or there are exist large smooth regions in the source images.

To further improve the accuracy of the focused region boundaries, a multi-focus fusion method based on two types of edges is proposed. The first type of edges exist only in the focused regions and called salient focused edges (SEs). SEs are utilized to distinguish the focused regions from multi-focus images. The second type of edges are detected with 'Canny' method, and they are utilized to refine the boundaries of the focused regions. Our idea is inspired by the fact that the edges of the image are clear and sharp if an object is in focus. So, their values in the high-pass filtered image are high. Therefore, SEs can be detected from high-pass filtered image by a threshold method.

Several advantages of the proposed method can be concluded as followings:

(1) The detected SEs can be used to discriminate between focused regions and blurred regions.
(2) No parameters need to be adjusted during the edge detection.
(3) The SE-driven subdivision method can extract the focused blocks effectively.
(4) The proposed method can extract the focused regions properly with boundary refinement.

This paper is organized as follows. The framework and details of the proposed method are introduced in Section 2. In Section 3, extensive experiments are conducted to test our algorithm. The performance assessments are provided by comparing it with some state-of-the-art algorithms in terms of visual quality and several quantitative fusion evaluation indices. Section 4 is the discussion and conclusion.

2. Methodology

According to the imaging theory, a point on in-focus object-plane is projected to a pixel on the image sensor, hence its image is clear and sharp [22]. The intensity of any edge point of the focused objects changes quickly. The magnitude value in high frequency sub-band of the object image is high. On the contrary, any point out of focus is spread out to a disk on the image sensor, hence its image is blurred. So the intensity of any edge point out of focus changes smoothly, and the resulting magnitude in high frequency sub-band is low.

Therefore, the SEs can be detected in the high frequency sub-band of the object image. The proposed method uses SEs to discriminate focused regions from source images, and extracts the focused regions in a quad-tree structure. The outline of the proposed method is shown in Fig. 1. It can be described as following.

(1) Salient focused edge detection. Suppose that there are two multi-focus images, denoted by image A and B. Compute their high-pass filtered images, then detect SEs of image A and B and fuse them into a label image by a threshold method.
(2) Focused block detection based on the label image in a quad-tree structure.
(3) Focused region recognition by removing holes and burrs via spatial consistency verification (SCV).
(4) Estimating whether boundary refinement of the focused regions is needed. If refinement is needed, it uses the edges of focused regions to guide the refining process. Otherwise, it skips to step (5). The refinement is to shrink the boundary of the relative small focused region repeatedly until it meets the edges.
(5) Image fusion by combining the focused regions of source images based on the focused region map.

2.1. Salient focused edge detection

(1) Denote the registered source image as $\boldsymbol{I}_X$, $X \in \{A, B\}$, use "pyrexc" filter $\boldsymbol{h}_p$ to compute the high-pass filtered images $\boldsymbol{H}_A$ and $\boldsymbol{H}_B$ respectively using Eq. (2) [23,24].