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Boundary finding based multi-focus image fusion through multi-scale morphological focus-measure

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ABSTRACT

Multi-focus image fusion aims to extract the focused regions from multiple partially focused images of the same scene and then combine them together to produce a completely focused image. Detecting the focused regions from multiple images is key for multi-focus image fusion. In this paper, we propose a novel boundary finding based multi-focus image fusion algorithm, in which the task of detecting the focused regions is treated as finding the boundaries between the focused and defocused regions from the source images. According to the found boundaries, the source images could be naturally separated into regions with the same focus conditions, i.e., each region is fully focused or defocused. Then, the focused regions can be found out by selecting the regions with greater focus-measures from each pair of regions. To improve the precision of boundary detection and focused region detection, we also present a multi-scale morphological focus-measure, effectiveness of which has been verified by using some quantitative evaluations. Different from the general multi-focus image fusion algorithms, our algorithm fuses the boundary regions and non-boundary regions of the source images respectively, which helps produce a fusion image with good visual quality. Moreover, the experimental results validate that the proposed algorithm outperforms some state-of-the-art image fusion algorithms in both qualitative and quantitative evaluations.

1. Introduction

Due to the limited depth of field, the optical lens can only capture images focused on the partial scene [1,2]. However, the partially focused images are usually not sufficient for the complete and accurate understanding of the scene, which would limit the performance of many related tasks, such as object detection and recognition [3–5]. Fortunately, multi-focus image fusion techniques have emerged to deal with the above problem by integrating the salient sharp features from multiple images of the same scene. In recent years, many kinds of algorithms have been proposed for multi-focus image fusion and these algorithms can be roughly classified into two categories: transform domain based algorithms and spatial domain based algorithms [3].

Transform domain based algorithms usually convert the source images into another feature domain, in which the source images could be effectively fused. At the beginning, the multi-scale geometric analysis based image fusion algorithms are prevailing, such as pyramid based and wavelet based algorithms. These algorithms usually decompose the source images into multi-scale pyramids, in which features of the images could be effectively extracted and fused. Then with the fast development of sparse representation, several algorithms [6,7] based on sparse representation are presented to fuse the source images and show good performance. The sparse representation based algorithms firstly train an over-complete dictionary using large scale of natural images, and then each source image could be represented with sparse coefficients of the trained dictionary. Afterwards, the fusion image could be reconstructed from the source images by combining the dictionary with maximum sparse coefficients. Moreover, the transform domain based image fusion algorithms show their advantages in the capability of fusing many types of images, such as multi-focus images, infrared and visual images, and CT and MRI images. However, the fusion images of these algorithms often undergo some global effects (e.g. halo or blurring effects) [3,8], when the contents at the same spatial position of multiple images are different.

Recently, the researchers have paid much attention on the spatial domain based multi-focus image fusion algorithms, which mainly include pixel-based, block-based and region-based algorithms [9]. The simplest pixel-based image fusion algorithm directly averages the pixel values of all source images. The direct av-

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erage method is simple and fast, but its fusion images often yield blurring effect and lose some original image information. In recent years, several state-of-the-art pixel-based image fusion algorithms have been proposed, such as guided filtering based algorithm [10], dense SIFT based algorithm [11] and multi-scale weighted gradient based algorithm [12]. These algorithms firstly generate the fusion decision map by detecting the focused pixels from each source image, and then refine the fusion decision map through some powerful tools, such as guided filtering [13] and SIFT-based image registration [14,15]. Although these newly presented algorithms could improve the visual qualities of the fusion images, most of these algorithms might lose some original image information due to the inaccurate fusion decision maps.

The block-based image fusion algorithms [4,16,17] decompose the source images into blocks with equal size. Then, the focused blocks are detected as those blocks with greater focus-measures from each block-pair. However, the performance of these algorithms is restricted to the block size. Meanwhile, the focus-measure cannot always rightly identify the fully focused block from each block-pair, which may lead to blocking artifacts of the fusion images. Huang et al. [8] evaluated performance of the block-based fusion algorithms, and their results indicated that the block-based algorithms could produce good fusion images by choosing a suitable block-size and an effective focus-measure.

To avoid the block-size selection problem, several kinds of algorithms have been proposed. Aslantas et al. [18] chose the block size by using an optimization method, but its iterative procedures for optimization were time-consuming. Besides, several region-based image fusion algorithms [19] are presented to split the source images into regions rather than blocks. The region-based algorithms firstly segment the source images by using image segmentation techniques such as normalized cuts [20], and then image fusion is performed by measuring clarities of the corresponding regions and combining the sharply focused regions. However, the segmentation procedure usually reduces the efficiency of the region-based algorithms, and the segmentation accuracy greatly affects the final qualities of the fusion images.

Bai et al. [2] resolved the block-size problem by proposing a new quadtree based image fusion algorithm, in which they introduced an effective quadtree decomposition strategy and a weighted focus-measure. In the quadtree-based algorithm, the source images were decomposed into a quadtree structure with optimally-sized blocks. Through combining the blocks with maximum focus-measures from each block-pair, the fusion image could be produced with much better visual quality than the traditional block-based algorithms. However in this algorithm, some small blurred and smooth regions may be inappropriately segmented into the sharp blocks, which would affect the visual effect.

To further improve the qualities of the fusion images, we propose a novel boundary finding based multi-focus image fusion algorithm. At the beginning, the proposed algorithm takes the merit of focus-situation detection method [2] to roughly locate the boundary regions between the focused and defocused regions. Then, the boundary regions are reconstructed to generate the better boundaries. Via the reconstructed boundaries, the source images could be segmented into regions with the same focus conditions, which means each segmented region is fully focused or fully out of focus. Thirdly, the proposed algorithm detects the focused regions by selecting the regions with greater focus-measures from each pair of regions, and then these focused regions could be naturally merged to generate the fusion decision map. Finally, the fusion image could be well produced according to the fusion decision map and fusion rules. In order to accurately measure the sharpness of the corresponding regions, we also construct an effective focus-measure, named as the multi-scale morphological focus-measure, by integrating the gradients at different scales.

The proposed algorithm has been tested on the commonly used image sets, and compared with several state-of-the-art image fusion algorithms by utilizing both qualitative and quantitative evaluations. The experimental results show that the proposed algorithm outperforms the compared algorithms in both qualitative and quantitative ways. The contributions of this paper can be concluded as follows: (1) proposing a novel multi-focus image fusion algorithm through boundary finding; (2) presenting a new and effective focus-measure for measuring image clarities. Besides, this paper is the extended version of an international conference paper [21]. Compared to the preliminary conference paper, we have done substantial extensions by adding: (1) detailed descriptions and illustrations about the proposed algorithm; (2) five new compared algorithms and two new comparison examples; (3) evaluation for the proposed multi-scale morphological focus-measure.

2. Proposed algorithm

Multi-focus image fusion essentially aims to extract the focused regions from each source image and combine them together to generate an everywhere focused image. Generally, the spatial domain based algorithms firstly divide the source images into regions, and then focus-measures of the regions in each pair are computed and compared. Then the fusion image could be produced by combining the regions with greater focus-measures from each region-pair. Thus, the division scheme of the source images and focus-measure are two crucial components of the spatial domain based algorithms. And the researchers have also started from these two aspects to tackle the multi-focus image fusion problem [2,9,11,17,22].

Through observation, the boundaries between the focused and defocused regions could naturally segment the partially focused images into regions with the same focus conditions, which means that each segmented region is fully focused or fully out of focus. Then, the segmented sharp regions could be selected and combined to produce an all-in-focus image. Thus, the task 'image division' in multi-focus image fusion can be transformed into finding the special boundaries within the focused and defocused regions. In this paper, we propose a novel boundary finding based multi-focus image fusion algorithm through the multi-scale morphological focus-measure. Firstly, the multi-scale morphological gradients of the source images are calculated. Secondly, the boundary regions between focused and defocused regions could be roughly located according to the gradient information of the source images. Thirdly, the found boundary regions are reconstructed to achieve the fine boundaries, which could separate the source images into regions with the same focus conditions. Then, the fusion decision map could be obtained by combining the image indices of the regions with greater focus-measures. In this paper, the focus-measure is constructed by integrating the multi-scale morphological gradients, therefore we name this focus-measure as the multi-scale morphological focus-measure. Finally, the fusion image could be well produced according to the fusion decision map and fusion rules. For a clear view of the processing procedures, a flow chart of the proposed algorithm is illustrated in Fig. 1. To the best of our knowledge, the proposed algorithm is the first multi-focus image fusion algorithm through boundary finding. To clearly detail the proposed algorithm, the rest of paper is organized as follows. In Section 3, construction and evaluation of the multi-scale morphological focus-measure is introduced. Section 4 describes the boundary finding method. Image fusion is conducted in Section 5. The experimental results and discussions are given in Section 6. Finally, conclusions are made in Section 7.