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Multi-focus image fusion based on non-negative matrix factorization and difference images

Yongxin Zhang [a,b], Li Chen [a,*], Jian Jia [c], Zhihua Zhao [a]

[a] School of Information Science and Technology, Northwest University, Xi'an 710127, China
[b] Luoyang Normal University, Luoyang 471022, China
[c] Department of Mathematics, Northwest University, Xi'an 710127, China

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ABSTRACT

Multi-focus image fusion means to fuse multiple source images with different focus settings into one image, so that the resulting image appears sharper. One of the keys to image fusion is how to represent the source images effectively and completely. To address this problem, in this study a novel multi-focus image fusion scheme based on non-negative matrix factorization (NMF) and difference images is proposed. The temporary fused image is constructed by fusing the registered source images with NMF. The focused regions of the source images are detected by the salient features of the difference images between the temporary fused image and source images. The final fused image is produced by combining the focused regions. The experimental results demonstrate that the proposed method is capable of efficiently representing the source images and significantly improving the fusion quality compared to the other existing fusion methods, in terms of visual and quantitative evaluations.

1. Introduction

As an important branch of image fusion, multi-focus image fusion can be defined as the process of combing substantial information from multiple images of the same scene to create a single composite image, which can provide more comprehensive descriptions of the scene [1]. In general, fusion methods can be categorized into two groups: spatial domain fusion and transform domain fusion [2]. The spatial domain fusion methods are easy to implement and have low computational complexity, while the spatial domain methods may produce blocking artifacts and compromise the quality of the final fused image. Different from the spatial domain fusion, the transform domain fusion methods may achieve improved contrast, as well as better signal-to-noise ratio and better fusion quality [1], but the transform domain fusion methods are more time/space-consuming to implement.

Non-negative matrix factorization (NMF) is a novel technique which decomposes multivariate data into a smaller number of basis vectors and encodings under non-negative constraints, and was developed by Lee and Sung [3]. NMF is often used to nonlinearly locate purely additive, parts-based, linear, and sparse representations of the non-negative multivariate data. It can reveal the latent structure, feature and pattern of the input data [4]. Zhang et al. [5] first applied NMF in image fusion by using sharpness constraints and achieved strong fused result. At present, many multi-focus image fusion methods based on NMF have been developed [6–11], but most suffer from various issues. Xu et al. [6] have proposed a fusion method

* Corresponding author. Tel.: +86 18637930027.
E-mail addresses: chenli@nwu.edu.cn, tabo126@126.com (Y. Zhang), chenli@nwu.edu.cn (L. Chen), jiajian@nwu.edu.cn (J. Jia), chenli@nwu.edu.cn (Z. Zhao).

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using NMF coefficients to detect the focused image block. The method works better in preserving the salient information, but suffers from contrast reduction and algorithm complexity. Zhang et al. [7] have proposed a fast fusion method based on weighted non-negative matrix factorization (WNMF) and region segmentation in the spatial domain. Visible and infrared images are endowed with different weight. The method works well for multi-focus images, visible images and infrared images, but suffers from the influence of parameter settings and the complexity of the region segmentation algorithm. Ye et al. [8] have developed a fusion method based on local non-negative matrix factorization (LNMF). This method improves the objective function of the standard NMF to enhance localization constraint and works well for synthetic aperture radar (SAR) and visible images, but does not work well in the global feature extraction and detail feature representation. Liu et al. [9] have proposed a fusion scheme based on dynamic WNMF. This scheme enhances the ability of feature extraction and improves the visual quality of the fused image, but consumes more time. Wang et al. [10] have developed a fusion method based on accelerated NMF in the non-subsampled contourlet transform (NSCT) domain. The method preserves more edge detail information of the source images and improves the quality of the fused image, but is not appropriate for large scale data sets. Most of the existing fusion methods based on NMF use matrix factorization to extract the salient features of the source images. However, NMF is confronted with two main problems, namely unsatisfactory accuracy and poor generality. The processed objects of NMF are intrinsically vectors and involve necessary vectorization for every matrix in the processed matrix-set, which often causes the corresponding NMF to be a typical type of small-sample learning, and compromises the ability of NMF in generalization and feature representation [11].

Different from the fusion methods mentioned above, in this paper a new method based on NMF and difference images is proposed. NMF is used to construct the temporary fused image and extract the underlying salient information from the source images, such as latent structure, features and pattern. In order to improve the accuracy of the focused region detection, differences in the gradient features of the temporary fused image and source images are used to detect the focused regions in the source images. The problem of fusing multi-focus images is addressed by selecting the most salient local features from the difference images to form a composite feature space. The objective of the current paper is to improve the efficiency and performance of the fusion method, with three main contributions to this field of study: (1) temporary fused image construction for effective image fusion by using NMF; (2) focused region detection of source images by comparing the salient features computed from the difference images; (3) blocking artifacts elimination through a sliding window technique. The major advantages of the proposed method include a simplified implementation procedure and wide applicability to different fusion tasks. Moreover, the proposed method can efficiently extract the focused regions details from the source images, and improve the visual quality of the fused image.

The remainder of the paper is organized as follows. In Section 2, the basic concept of NMF and the image fusion model based on NMF are briefly described, followed by the fusion method with NMF for image fusion in Section 3. In Section 4, extensive simulations are performed to evaluate the performance of the proposed method. In addition, several experimental results are presented and discussed. Finally, concluding remarks are drawn in Section 5.

2. Related work

2.1. Non-negative matrix factorization

NMF incorporates the non-negativity constraint and thus obtains the parts-based representation, as well as enhances the interpretability of the issue correspondingly [12], which is a low-rank approximation technique for unsupervised multivariate data analysis, and produces non-negative matrix to process an image [13]. NMF factorizes an $n \times m$ original matrix V into two factor matrices. One is an $n \times r$ non-negative basis matrix W and the other is an $r \times m$ non-negative weight matrix H. The two factor matrices can approximate the original matrix V according to some cost functions. Model [3] is described as follows:

$$V_{iu} \approx (WH)_{iu} = \sum_{a=1}^{r} W_{ia} H_{au} \tag{1}$$

where n, m, r are positive integers and $r < \min(n, m)$. In general r is chosen, so that $(n+m)r < nm$. In order to accurately estimate the factor matrices W and H, an objective function is defined as follows:

$$F = \sum_{i=1}^{n} \sum_{u=1}^{m} [(V_{iu} - (WH)_{iu})]^2 \tag{2}$$

For reaching a local maximum of the objective function, an iterative approach is given by the following Algorithm [3]. The convergence of the algorithm has been proven by Lee and Seung [3,4].

$$\begin{cases} W_{ia} \leftarrow W_{ia} \sum_j V_{ij}/(WH)_{ij} H_{aj} \\ W_{ia} \leftarrow W_{ia}/\sum_j W_{ja} \\ H_{aj} \leftarrow H_{aj} \sum_i W_{ia} \left(V_{ij}/(WH)_{ij} \right) \end{cases} \tag{3}$$

In recent years, several variants of NMF, such as LNMF [14], sparse non-negative matrix factorization (SNMF) [15], and non-negative matrix factorization with sparseness constraints (NMFsc) [16], have been proposed to improve NMF from various perspectives. These extensions are mainly performed on modified models, modified constraints, and modified cost functions.

2.2. Image fusion model based on NMF

One important variable in the reduction of dimensions in each NMF method is commonly known as the variable r (number of the basis vector). How large a data matrix will be reduced is determined by r. The larger value of r the less the dimension is reduced, and the smaller value of r the more the dimension is reduced [13]. Guillamet et al. [17] found that different multi-bases can be obtained by using the NMF method with different configurations of the parameter r,