Information Fusion 35 (2017) 102–116

Contents lists available at ScienceDirect

Information Fusion

journal homepage: www.elsevier.com/locate/inffus

A novel multi-focus image fusion approach based on image decomposition

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ARTICLE INFO

Article history:
Received 17 May 2015
Revised 3 June 2016
Accepted 18 September 2016
Available online 20 September 2016

Keywords:
Multi-focus image fusion
Image decomposition
Cartoon content
Texture content

ABSTRACT

Multi-focus image fusion is an effective technique to integrate the relevant information from a set of images with the same scene, into a comprehensive image. The fused image would be more informative than any of the source images. In this paper, a novel fusion scheme based on image cartoon-texture decomposition is proposed. Multi-focus source images are decomposed into cartoon content and texture content by an improved iterative re-weighted decomposition algorithm. It can achieve rapid convergence and naturally approximates the morphological structure components. The proper fusion rules are constructed to fuse the cartoon content and the texture content, respectively. Finally, the fused cartoon and texture components are combined to obtain the all-in-focus image. This fusion processing can preserve morphological structure information from source images and performs few artifacts or additional noise. Our experimental results have clearly shown that the proposed algorithm outperforms many state-of-the-art methods, in terms of visual and quantitative evaluations.

1. Introduction

Multi-focus image fusion could be defined as the process of fusing substantial information from multiple images of the same scene to generate a single composite image. The fused image would be more suitable for human visual perception. Currently, multi-focus image fusion technology has been widely used in computer vision, clinical medicine, remote sensing, military surveillance and digital imaging, and so on [1–7]. In recent years, a flurry of fusion algorithms have been introduced from many and diverse points of view, which can be categorized into three groups: pixel-level fusion, feature-level fusion and decision-level fusion [1,2,5]. In comparison to the latter two schemes, the main superiority of pixel-level fusion domain is that the original information is directly involved. Although the pixel-level fusion methods comprise the open-ended problems: high computational complexity, poor fidelity and blocking artifacts, this promising area is receiving ever-increasing attention and is still intensely ongoing. This work has concentrated mainly on the study of the pixel-level fusion domain.

The growing appeal of this research area can be observed from the large number of scientific papers [9–15], which could be categorized into two main groups: multi-resolution scheme and multi-spectral scheme. Multi-resolution domain fusion usually transforms the inputs into multi-resolution representation, and then selects the decomposed information to reconstruct the fused image. These methods enable the efficient combination of the relevant information that are spectrally independent or spatially overlapped. Thus, multi-resolution-based fusion algorithms have attracted great research attentions based on different multi-resolution decomposition, such as discrete wavelet transform (DWT) [8], gradient pyramid [9], contrast pyramid [10]. However, these methods are complicated, high time-consuming to implement and sensitive to the sensor noise. Unlike the former one, multi-spectral domain fusion directly operates on the pixels or regions of the source images. Its main principle is selecting the more clarified pixels or regions to construct the fused image. Averaging, intensity-hue-saturation [11], principal component analysis [12], independent component analysis [13] based fusion algorithms fall under this category. To the best of our knowledge, the major drawbacks of multi-spectral domain fusion methods is that it introduces spatial distortions and blocking artifacts in the resultant fused images. Recently, a corpus of fusion algorithms in the pixel-level fusion domain have been

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http://dx.doi.org/10.1016/j.inffus.2016.09.007
1566-2535/

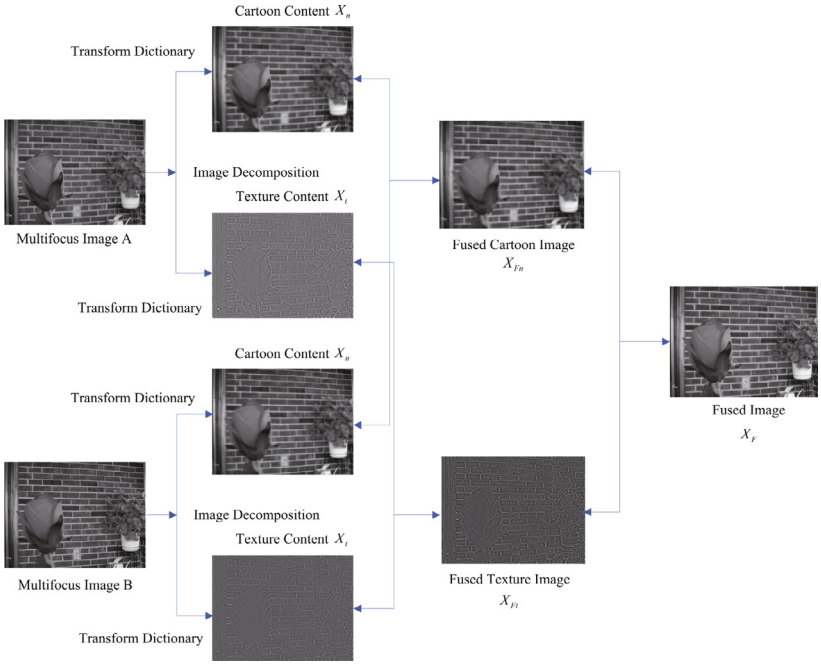

Fig. 1. The basic multi-focus image fusion scheme based on image cartoon-texture decomposition.

reported to solve the crucial problems, but this topic is largely still open.

Note that the crucial issue is to effectively represent the foundational atoms of the inputs in the pixel-level fusion framework. More recently, a class of image decomposition-based fusion techniques [16–18] have attracted increasingly more attention. The key motivation behind lies in the observation that natural images could be efficiently decomposed into morphological structure components: texture contents and cartoon contents. The texture contents hold textures, oscillating patterns, fine details and noise, while the cartoon contents contain the geometric structures, isophotes and smooth-piece of source images. To preserve the textural information, a new color-gray image fusion algorithm based on Morphological Component Analysis (MCA) is proposed to seek out the most important information [16]. In order to effectively exploit the property of morphological diversity of images and the advantages of MCA, a novel multi-component fusion method is presented to generate better fused images [17]. Specific to the problem of high computational complexity, a novel pixel-level fusion algorithm based on multi-level local extrema (MLE) is constructed to reflect the regional pattern and edge information of source images [18]. The generic fusion framework based on image cartoon-texture decomposition is shown in Fig. 1 [16–18]. Generally, the incoherent components of source images could be efficiently separated and represented by image decomposition algorithms, which include MCA, Total-Variation (TV), TV-l_1, TV-l_2 and other extended methods [17,19–22]. According to the properties of morphological structure components, proper fusion rules are constructed to extract complementary contents. Ultimately, the fused cartoon and texture components are combined to generate the final all-in-focus image.

Although the above described models are feasible, there are three main open-ended problems in multi-focus image fusion framework based on image cartoon-texture decomposition: (1) how to construct the proper decomposition algorithm to achieve fast convergence is a crucial problem; (2) how to naturally approximate the morphological components remains an open and difficult issue; (3) how to extract complementary information to generate the all-in-focus image is also an open-ended research project.

In this work, we aim to solve these general problems to get high-quality separated contents, achieve rapid convergence and obtain the all-in-focus image. In practice, an improved multi-focus image fusion approach is proposed specific to the mentioned problems. On the one hand, the texture and piecewise smooth (cartoon) parts are obtained by an improved iterative re-weighted image decomposition algorithm. From a practical point of view, it could remove the problem of information distortion and achieves rapid convergence with an effective underlying representation of different spatial morphologies. On the other hand, according to the properties of cartoon and texture contents, proper fusion rules are constructed to fuse the cartoon component and the texture component, respectively. These can combine the complementary information into the final fused image. Finally, the two fused components are integrated to generate the final all-in-focus image. This work would generate an extended depth-of-focus image, which is more suitable for human visual perception. It could also overcome the problems of poor fidelity and blocking artifacts in the conventional fusion methods. The main contributions can be summarized as follows:

(1) In the pixel-level fusion domain, it is crucial to achieve high fused image quality by effectively representing the building atoms of multi-focus images. In this work, an iterative re-weighted image decomposition algorithm is proposed to precisely separate and approximate the morphological structure components. Furthermore, it can get global optimal solution and diminishes part of noise.
(2) From a practical point of view, high computational complexity imposes restrictions on putting fusion algorithms into practice. The proposed image texture-cartoon decomposition method can greatly reduce computation complexity building on the convergence and robustness.
(3) According to the properties of the separated contents, proper fusion rules are presented to fuse cartoon component and texture component, respectively. The all-in-focus image is obtained by combining the fused cartoon and texture contents, which is more suitable for human visual perception. This fusion processing can preserve the complementary in-