Signal Processing 143 (2018) 20–27

Contents lists available at ScienceDirect

Signal Processing

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

Short communication

Near-infrared fusion via a series of transfers for noise removal

Chang-Hwan Son

Department of Software Convergence Engineering, Kunsan National University, 558 Daehak-ro, Gunsan-si 54150, Republic of Korea

A R T I C L E   I N F O

Article history:
Received 18 April 2017
Revised 8 August 2017
Accepted 26 August 2017

Keywords:
Near-infrared imaging
Multimodal fusion
Color transfer
Noise removal
Alternating minimization
Guided filtering

A B S T R A C T

Near-infrared imaging has been considered as a solution for providing high quality photographs in dim lighting conditions. This imaging system captures two types of multimodal images, namely, near-infrared gray image (NGI) and visible color image (VCI). NGI is noise free and grayscale, whereas the VCI has colors and contains noise. Moreover, there are significant edge and brightness discrepancies between NGI and VCI. In order to deal with this problem, a new transfer-based fusion method is proposed for noise removal. Different from conventional fusion approaches, the proposed method conducts a series of transfers, namely, contrast, detail, and color transfers. First, the proposed contrast and detail transfers aim at solving the serious discrepancy problem to create a new noise-free and detail-preserving NGI. Second, the proposed color transfer models the unknown colors from the denoised VCI through a linear transform, and then transfers the natural-looking colors into the newly generated NGI. The experimental results show that the proposed transfer-based fusion method is highly successful in solving the discrepancy problem. The edges and textures are clearly described and the noise is completely removed from the fused images. Most of all, the proposed method is superior to the conventional fusion methods, guided filtering, and state-of-the-art fusion methods based on scale map and layer decomposition.

1. Introduction

Recently, near-infrared imaging [1] has been introduced for providing noise-free near-infrared gray Image (NGI) and noise-contained visible color image (VCI), which are captured consecutively for the same scene during a shoot in dim lighting conditions. This near-infrared imaging system can be realized by using near-infrared pass/block filters [1] or near-infrared flash [2]. Since the captured NGI is noise free, the near-infrared imaging has been considered as a solution for high-quality image acquisition in low lighting conditions.

1.1. *Related works*

Conventional near-infrared fusion models based on the gradient difference regularization (GDR) [3–5], multiresolution (MR) [6–8], and weighted least squares (WLS) [2] have failed in removing the noise and describing the details. The first reason is that the conventional fusion models are not suitable for overcoming the serious discrepancies in the edges and brightness between the NGI and VCI. The captured NGI and VCI have different characteristics regarding color and noise. In particular, the NGI is noise free and grayscale, whereas the VCI has colors and contains noise. This different modality can be checked in the upper row of Fig. 1, wherein the edge and brightness discrepancies between the VCI and NGI exist around the red line of the bowl and petal, respectively (please see the red boxes). The second reason is that the conventional methods follow the traditional fusion strategy that attempts to combine the NGI with the VCI based on regularization and multiresolution fusion models (e.g., GDR, MR, and WLS) in the transform domain or spatial domain. In other words, conventional fusion methods can be considered as the weighted averaging of two input images, even though the NGI is used as a guidance image with the fusion models. As a result, the clean background and sharp edges of the NGI are inevitably fused with the noise of the VCI during the multimodal image fusion. The newly introduced guided filtering (GF) [9] differs from traditional fusion strategy; however, color distortion appears on the resulting images due to the brightness discrepancy. This demonstrates that the GF is closer to edge-preserving smoothing filters (e.g., bilateral filter), which are not designed to overcome the discrepancy problem, and the GF-based image fusion [10] for high dynamic rendering (HDR) is not suitable for the near-infrared fusion. More recently, the state-of-the-art methods based on scale map (SM) [11] and layer decomposition (LD) [12] are introduced for handling the serious discrepancy problem. However, the SM method tends to remove textures and over-enhanced original colors. Even though the LD method is much stronger for the detail description than the conventional fusion and GF methods, there is still room for improvement in noise

---

E-mail addresses: changhwan76.son@gmail.com, cson@kunsan.ac.kr, jjdhompy@hotmail.com

http://dx.doi.org/10.1016/j.sigpro.2017.08.019

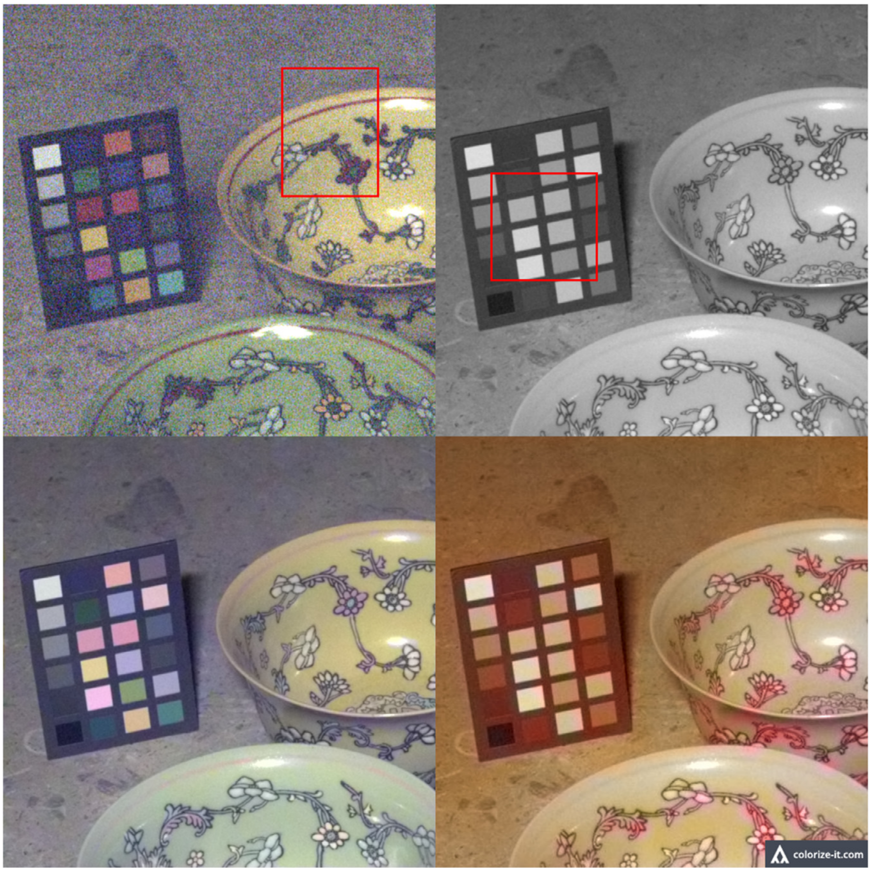

Fig. 1. Captured noise-contained VCI and NGI (upper row), and the resulting images generated by using the naive fusion method (left image at the bottom row) and the colorization (right image at the bottom row) [13].

removal. Moreover, the LD method is too slow due to the time-consuming sparse coding.

1.2. Proposed approach

Different from the conventional methods mentioned above, a new fusion method based on a series of transfers is proposed for noise removal. The central idea of this paper is to add colors to the captured noise-free NGI. The simplest method is to use the naive fusion method that combines the captured noise-free NGI with the denoised version of the chrominance planes of the captured VCI. However, there are serious discrepancies in the brightness and image structures between the captured VCI and NGI, which means that the naive fusion method results in color and edge distortions on the fused images. Another approach is to use the state-of-the-art colorization method via deep learning [13]. Nevertheless, there are serious color distortions on the colorized NGI, which means that the image-pair approaches based on the WLS, GDR, and MR are better than the single-image-based colorization [13]. The bottom row of Fig. 1 shows the color distortion on the resulting images with the naive fusion and colorization methods.

The goal of this paper is to propose a new transfer-based fusion method that adds the colors of the denoised VCI to the NGI. In other words, it is shown throughout this paper how the colors of the denoised VCI can be transferred into the noise-free NGI by solving the discrepancy problem between the captured VCI and NGI. Therefore, this paper proposes contrast and color transfer models. The proposed contrast transfer model finds the mapping relation between the NGI and the denoised VCI, and then generates a new NGI to be colorized, which is different from a captured NGI. The proposed color transfer model is derived from the mapping relation, and then it modifies the colors of the denoised VCI that will be transferred into the newly generated NGI. The main difference between the proposed method and the conventional methods is that the conventional approaches based on GDR, WLS, MR, SM, GF, and LD attempt to remove the noise on the VCI, whereas the proposed approach transfers the colors of the VCI into the NGI for noise removal.

2. Fusion strategy

Figs. 2 and 3 show how the proposed method is quite different from the conventional fusion methods for noise removal. The conventional fusion methods convert the multimodal images into the transform domain (e.g., Wavelet/FFT domains) to utilize the edge strength and entropy ratios between the noise and clean images at different scales [6–8,14], or to provide a fast computation of the guided filtering based on the GDR [3–5]. In addition, spatially varying norms can be used according to the gradient distributions (e.g., flat/texture/edge distributions) [15]. In the spatial domain, the regularization parameter can be adjusted adaptively with the WLS model according to the edges of the guidance image [2].

It was recently shown that sparse representation [16] and low-rank matrix approximation [17–19] are very effective in modeling the regularizer for noise removal. Following this trend, sparse regularization [12] with the learned dictionary was used for VCI and NGI image fusion. Similarly, low-rank matrix approximation [17–19] can be considered for VCI and NGI image fusion. More specifically, l0-norm [12] may be replaced by the nuclear norm [17–19]. For complex noise removal, the nuclear norm can be modeled with the frequency coefficients [18,19].