Signal Processing 115 (2015) 120–129

Contents lists available at ScienceDirect

Signal Processing

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

Efficient identification of arbitrary color filter array images based on the frequency domain approach

Yong-Huai Huang [a,2], Kuo-Liang Chung [b,*,1], Tseng-Jung Lin [b]

[a] Department of Electronic Engineering, Jinwen University of Science and Technology, No. 99, AnChung Rd., Xindian Dist., New Taipei City 23154, Taiwan, R.O.C.

[b] Department of Computer Science and Information Engineering, National Taiwan University of Science and Technology, No. 43, Section 4, Keelung Road, Taipei 10672, Taiwan, R.O.C.

ARTICLE INFO

Article history:
Received 13 August 2014
Received in revised form
10 March 2015
Accepted 29 March 2015
Available online 4 April 2015

Keywords:
Color filter array
Fourier transform
Frequency spectrum
Mosaic images

ABSTRACT

For reducing the cost, most digital cameras are equipped with a CCD or CMOS sensor and a RGB color filter array (CFA) for each pixel to capture one primary color component, and hence produce a mosaic image. Suppose the input mosaic image without the CFA structure information, this paper presents a novel efficient method, consisting of a training-based scheme and an identification scheme, for identifying its CFA structure using the frequency domain approach. Initially, based on a set of training mosaic images with different CFA structures, a training-based scheme is proposed to build up the representative spectrum for every CFA structure. As the model maps, the constructed representative spectra can be reused in subsequent identification processes. The proposed identification scheme first constructs the representative spectrum of the header-less input mosaic image as the query map. Then, a matching scheme is proposed to identify the corresponding CFA structure of the query map from the model maps. Experimental results demonstrate that the proposed identification method has low computational cost and high identification accuracy merits for mosaic images without prior header information, when compared with the state-of-the-art spatial domain-based method by Chiu et al.

1. Introduction

Nowadays, digital cameras have become increasingly popular in the consumer electronics market. To reduce hardware costs, most digital cameras use a single charge-coupled device (CCD) or a complementary metal-oxide-semiconductor (CMOS) sensor with a color filter array (CFA) to capture one primary color component for each pixel [1]. Such images are called mosaic images. Fig. 1 shows 11 typical CFA structures. The first 10 CFA structures [2] in Fig. 1 are red–green–blue (RGB) CFAs in which the Bayer CFA [3] is the most well-known structure; the last CFA structure, i.e. the Hirakawa CFA [4], is a non-RGB CFA in which six colors are considered and each one is a linear combination of red, green, and blue components.

Most of the digital cameras can produce full RGB color image in JPEG file format [5] from the captured mosaic image through a series of image processing operations, such as demosaicing, noise removal, white balance control, resizing, and image compression. The produced JPEG files are convenient for media storage. However, some of the above digital camera's operations may result in image quality degradation, the resultant images are unsuitable for professional users, e.g. photographers, artists, and graphic designers. Besides the JPEG file format, many digital cameras also offer the raw image

* Corresponding author.
E-mail addresses: yonghuai@ms28.hinet.net (Y.-H. Huang), klchung01@gmail.com (K.-L. Chung).

[1] Supported by the Ministry of Science and Technology of R.O.C. under contract NSC102-2221-E-011-055-MY3.

[2] Supported by the Ministry of Science and Technology of R.O.C. under the contracts NSC102-2221E-228-006 and MOST 103-2221-E-228-004.

http://dx.doi.org/10.1016/j.sigpro.2015.03.023
0165-1684/

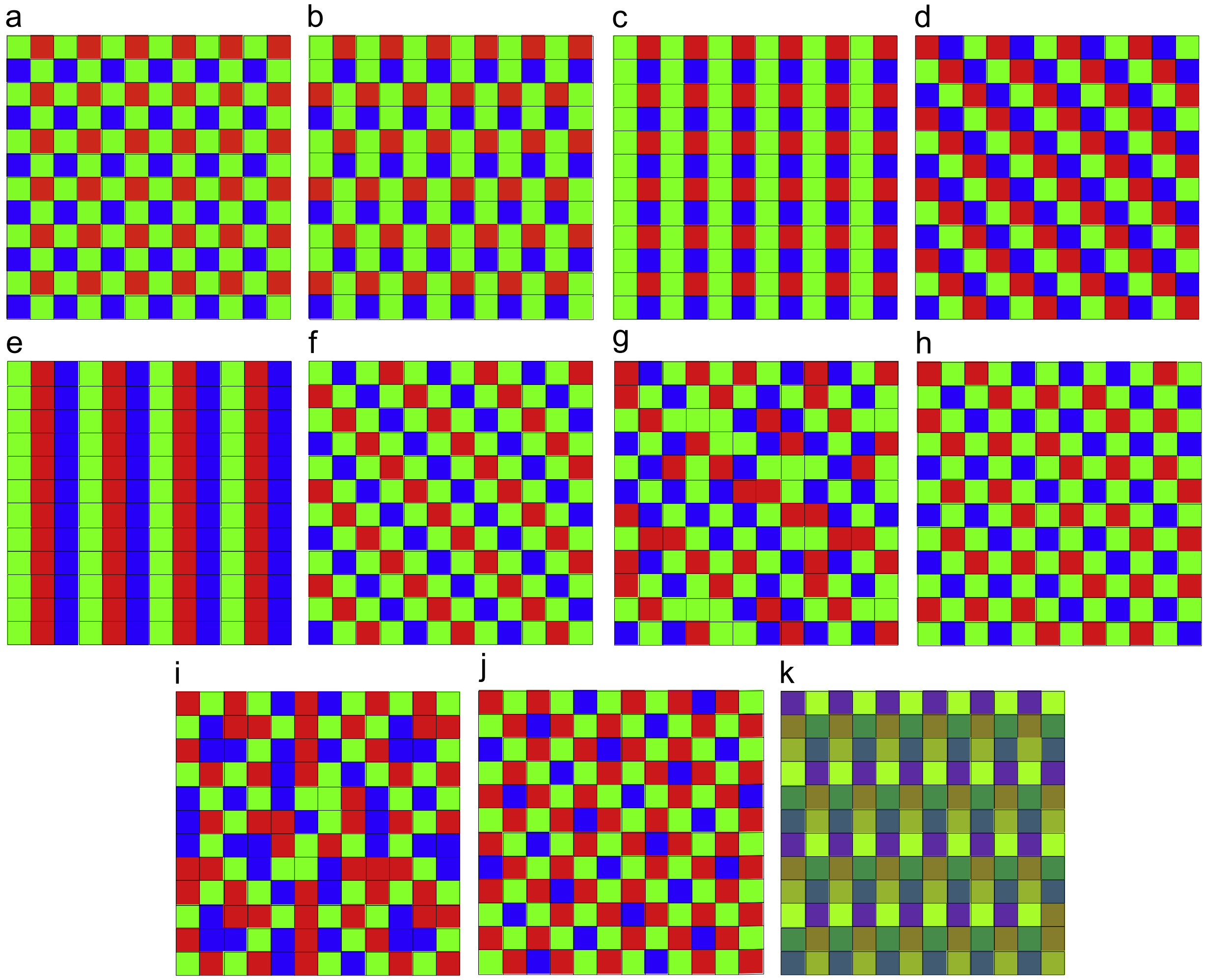

Fig. 1. Ten typical RGB CFA structures: (a) Bayer CFA, (b) Lukac and Plataniotis CFA, (c) Yamanaka CFA, (d) diagonal stripe CFA, (e) vertical stripe CFA, (f) modified Bayer CFA, (g) HVS-based CFA, (h) type I pseudo-random CFA, (i) type II pseudo-random CFA, (j) type III pseudo-random CFA, and (k) Hirakawa CFA.

format, which directly records mosaic images captured from CCD or CMOS sensor and without applying any digital camera's operations, to avoid the quality degradation. Recently, the raw image format has become popular among professional users because they can select better image algorithms instead of the ones used in digital cameras. As the popularity of the raw image format, more and more researchers focus on mosaic images and several related algorithms have been developed, such as compression [6–8], super-resolution [9,10], and demosaicing [11–14].

Given a mosaic image, its CFA structure is required to be known in advance from the header in TIFF-EP format for image manipulations. If, however, the prior header information is unknown for the input mosaic image, e.g. the header may be lost due to network packet loss in transmission or storage damage, the related image manipulations cannot work well. In such a header-less situation, Chiu et al. [15] proposed a spatial domain-based total average square difference minimization approach for identifying the CFA structure of the mosaic image. However, their method is rather time-consuming and the identification accuracy is dependent on the window size used. Therefore, it is necessary to design a new approach to substantially reduce the computational cost and enhance the identification accuracy, leading to the main motivation of this research.

For an input mosaic image whose CFA structure is not available, this paper presents a novel efficient method for identifying its CFA structure using the frequency domain approach. The proposed method consists of two schemes: (1) the four-step training-based scheme to build up the representative spectra as the model maps for the concerned CFA structures and (2) the three-step matching scheme to identify the CFA structure of the input header-less mosaic image. In the four-step training-based scheme, suppose there are n training mosaic images for the ith CFA structure, $0 \le i \le 10$. In the first step, the Fourier transform is performed on every training mosaic image to obtain the high-pass spectrum map. In the second step, the high-energy blocks in each high-pass spectrum map are located and the coefficients in every high-energy block are reserved, but those in the non-high-energy block are discarded. In the third step, a successive thresholding approach is proposed