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Improving source camera identification performance using DCT based image frequency components dependent sensor pattern noise extraction method

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A B S T R A C T

Sensor imperfections in the form of photo response non-uniformity (PRNU) are widely used to perform various image forensic tasks such as source camera identification, image integrity verification, and device linking. The PRNU contains important information about the sensor in terms of frequency contents, this information makes it suitable for various image forensic applications. The main drawback of existing methods of PRNU extraction is that the extracted PRNU contains fine details of the image i.e., the high-frequency details (edges and texture). For solving this problem we have applied a pre-processing step on widely accepted PRNU extraction methods. Our pre-processing step is based on the fact that ‘PRNU is a very weak noise signal and hence it can be efficiently extracted from the image by applying PRNU extraction method in low frequency (LF) and high frequency (HF) components of the image separately’. Initially, we have applied this pre-processing concept to the widely accepted PRNU extraction methods and found that it is able to improve the performance of most of the PRNU extraction methods. The best improvement takes place for Mihcak filter. Hence in the remaining part of the work, this generalized concept is more precisely applied to the Mihcak filter only. By utilizing the proposed pre-processing idea with the Mihcak filer, the new filter is termed as the pMihcak filter. PRNU extracted using pMihcak filter contains the least amount of HF details of the image. Also, the pMihcak filter is able to extract PRNU from low-frequency components of the image which otherwise not possible for existing PRNU extractors.

Introduction

Due to the advancement of digital technologies we have seen a rapid growth in the usage of digital imaging devices. Now digital images have become an important part of our daily life. As a result, every digital multimedia device contains a digital camera too for capturing images of good quality. The digital images are also used as trustworthy evidence in the courtroom. However with the help of recent technologies (Bluetooth, the Internet) and powerful image editing tools images can be easily distributed, edited and transferred. This has raised two fundamental questions for digital images.

1. Which device has captured the image ?
2. (How) has the image been altered after capturing ?

The above two fundamental questions are answered by the field of digital image forensic (Fridrich, 2009). In the last few years, several attempts have been made by the various group of researchers to extract features from images that help in identifying source device of images (Fridrich, 2009; Qu et al., 2013). One may know about these features by understanding the digital camera processing pipeline. Fig. 1 shows a typical digital camera processing pipeline.

Based on Fig. 1 the following components have been used as a digital device fingerprint; lens aberration noise (Choi et al., 2006; Van et al., 2007), color filter array (CFA) interpolation artifacts (Popescu and Farid, 2005; Swaminathan et al., 2007), sensor dust (Dirik et al., 2008), photo response non-uniformity (PRNU) noise (Lukas et al., 2005; Qu et al., 2013). Among all these components the PRNU based techniques have drawn much attention of various researchers. The PRNU is used to perform various image forensic tasks such as source camera identification (SCI), image integrity verification, device linking etc. In this work, we address the problem of SCI based on efficient PRNU extraction. The PRNU is a weak

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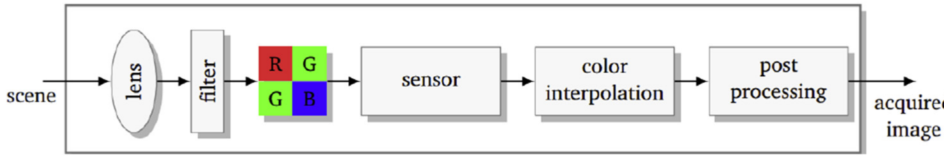

Fig. 1. A typical digital camera processing pipeline.

noise signal which is present in every image and this is a result of pixels generated by an imaging sensor by collecting the light energy. The reason that causes PRNU are imperfections in the manufacturing of the pixels' physical dimensions and the non-homogeneity that is naturally present in the silicon in sensors (Janesick, 2001). The PRNU is used as camera fingerprint and it is used to perform various forensic tasks.

Lukas *et al.* (Lukas et al., 2005, 2006) initiated the PRNU based SCI work. The original authors used a set of flat-field images and then extract noise residue from each image. The estimated noise residues are then averaged to obtain a camera reference PRNU noise. Later Chen *et al.* (Chen et al., 2007, 2008), used the Maximum Likelihood Estimator (MLE) for estimating the camera reference PRNU. Chen *et al.* (Chen et al., 2007) also proposed two PRNU post-processing methods the first is zero mean and second is wiener filtering to suppress various non-unique artifacts that are shared by the cameras. This post-processing basically reduces the false rejection rate (Chen et al., 2007). In (Li, 2010) Li *et al.* proposed five enhancement models. Li's (Li, 2010) idea was based on the fact that 'stronger signal component in the PRNU is less trustworthy and hence it should be suppressed so that no scene details are present in the estimated PRNU'. Later it was found that Li's (Li, 2010) enhancement model suppresses useful PRNU components too (Kang et al., 2012). Next PRNU enhancement method was proposed by Kang *et al.* (Kang et al., 2012). This method uses phase only component of the PRNU. Here the basic assumption of Kang *et al.* (Kang et al., 2012) was that the PRNU estimated by (Lukas et al., 2006) does not have features of white Gaussian noise. Hence Kang et al. (2012) proposed a method, that stores phase only component of PRNU. This operation is performed in Fourier domain. An approach that suppresses random noise contamination in the PRNU noise was proposed in (Tomioka et al., 2013). Theoretically, this approach (Tomioka et al., 2013) generates a reduced sized and high-quality PRNU that may lead to more trustworthy SCI.

An approach for merging the noise residuals to form the PRNU using weighted average method was proposed in (Lawgaly et al., 2014). This approach suppresses non-unique artifacts of PRNU by using the weighted averaging method proposed in (Chen et al., 2008). Since PRNU extraction is achieved using the de-noising filter; hence the choice of de-noising filter significantly contributes to the accuracy of PRNU estimation. The effect of the choice of de-noising filter is discussed for SCI and forgery detection in (Chierchia et al., 2010; Cortiana et al., 2011). Lin *et al.* (Lin and Li, 2016b) show that the PRNU can be estimated accurately by removing the filtering distortion. In (Cooper, 2013), Cooper *et al.* pointed out that though PRNU extracted using widely accepted wavelet-based Mihcak filter (Mihak et al., 1999) contains high-frequency details of the image. This reduces the true positive rate (TPR) of SCI. A PRNU extraction method based on 8-neighbor context adaptive interpolator (CAI) was developed by Kang *et al.* (Kang et al., 2014).

Noise introduced due to the color interpolation algorithm in the camera processing pipeline may lead to extract PRNU that contains color interpolation noise. This problem was the first time addressed in (Li and Li, 2012) where authors proposed a color decoupling algorithm. Hu *et al.* (Hu et al., 2010) proposed a method that separately extracts the PRNU from all three (red, green and blue) color channels of the image. After that, the PRNU is obtained by selecting the pixel with the largest magnitude. Despite different methods discussed so far, few other de-noising filters such as perona malik diffusion (PMD) (Van Houten and Geradts, 2012) filter and guided image filter (Zeng and Kang, 2016) are also used for PRNU extraction.

As discussed earlier the PRNU extracted by existing PRNU extraction methods contain high-frequency details (edges and texture) of the image. This is due to the reason that PRNU is present in low frequency and high-frequency components of the image, and as the PRNU is a noise like signal hence its effect is more on high-frequency component and comparatively less on the low-frequency component. As a result, it can not be extracted from the high and low-frequency component of the image **optimally**. For solving this problem we have applied a pre-processing step on the widely accepted PRNU extraction methods. Our pre-processing step is based on the fact that PRNU is a very weak noise signal and hence it can be efficiently extracted from the image by applying PRNU extraction method in high and low-frequency components of the image separately. In this work, we have applied this pre-processing step on most of the widely accepted PRNU extraction methods. We have found that the proposed concept is able to improve the efficiency of most of the PRNU extraction methods, and the best results are obtained for the Mihcak filter. Hence this generalized pre-processing step is more specifically applied to Mihcak filter only. We named new filter as the pMihcak filter. PRNU extracted using pMihcak filter contains the least amount of high-frequency details of the image.

The remaining part of this paper is organized as follows. Section Preliminaries explains some preliminaries concepts that are required for proper understanding of the proposed work. Section The proposed method contains detailed description of our method. Our numerical evaluation framework and experimental results are discussed is section Numerical evaluation framework and Experimental Results respectively. Conclusions are drawn in section Conclusion.

Preliminaries

This section covers few basic concepts that are required for proper understanding of the proposed work.

(PRNU-focused) camera model

In the proposed work we are using pixel output model as suggested in (Healey and Kondepudy, 1994). Based on this the final image generated by a digital camera is given by:

$$I = I_0 + K \cdot I_0 + N_t, \tag{1}$$

where N_t denotes the combination of independent random noise components. The model is adopted in most of the existing PRNU-based techniques. And, many techniques model $K \cdot I_0 + N_t$ combined as white Gaussian process. In the literature, some authors