HUE Modification Detection and Estimation using Photo Response Non-Uniformity

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Abstract

This paper presents a hue modification detection method to identify the true meaning of a digital image. To detect an image forgery, we proposed a robust forensics scheme for detecting hue modification. First, separate the photo response non-uniformity (PRNU) by a color filter array forms a pattern independent of others, the position of each PRNU pixel will do not overlap. We designed a forensic scheme for estimating the hue modification by using PRNU from each color channel of an image. We also proposed an efficient estimation scheme and an algorithm for detection and partial manipulation. This paper improves the saturation modification of the image and achieves the purity of the image.

Keywords: Digital image forensics, Photo response non-uniformity(PRNU), Sensor Pattern Noise, Hue, Color Filter Array(CFA)

I. INTRODUCTION

Digital images can be easily modified not only by highly trained professionals, but also by most average digital camera users. One of the common strategies image pirates use with digital images is hue modification. Hue is the actual color of the image. Digital images can be easily falsified by non-professional users. Since the advent of high-quality image editing tools such as Adobe Photoshop, Paintshop, etc. With an image-editing tool, a person can severely distort the actual meanings of images by modifying the hue of the images. To cope with image forgeries, a number of forensic schemes were proposed. Most schemes are based on detection local inconsistencies such as resampling artifact [1], color filter array interpolation [2], JPEG compression [3] or lighting condition [4]. The pixel photo response non-uniformity (PRNU) is widely used for detecting digital image forgeries [5]-[9]. There are also some methods for detecting identical regions are based on detecting the local inconsistencies of the image such as caused by copy move forgery [2]. Only two of these methods are able to detect hue forgery, because this does not change any other aspect of an image such as edges, shapes, gradations and PRNU.

Choi et al. [2] first proposed an algorithm for estimating the hue modification using a method of neighbouring correlation [15] induced by color filter array (CFA) in a digital camera. They proposed a simple measure of changes in the CFA patterns based on counting the number of pixels whose neighbors were satisfied with an interpolation condition. However, this algorithm loses its accuracy after using common image processing techniques such as resizing or JPEG compression that completely breaks down the demosaicing trace of an original image. Moreover, Choi’s algorithm only works with the image data processed using a CFA Bayer pattern [16].

This paper succeeds the previous idea [14] which describes a naive forensics scheme for estimating the degree of hue modification based on PRNU. The advanced methods of this paper are as follows. First, we propose an efficient estimation scheme that avoids some unnecessary intervals based on our hue modification modeling. Second, we proposed a partial manipulation technique in which a particular threshold value are adopted to determine the forged regions. Finally, we display the distribution of the test results.

II. METHODOLOGY

We described a separated PRNU technique created by CFA that forms a pattern independent of the others. Based on the previous method [14], we proposed an enhanced algorithm for detection and estimation of hue modification using separated PRNU. We also proposed an algorithm for partial manipulation. Two threshold values are adopted for estimation and partial manipulation of hue modification. The output of the image sensor was separated into three color components by a color filter array [17]. The PRNU is the unique fingerprint of a camera. This method is robust and is and reliable in image integrity verification as well as tampered region detection for introduced camera models. The raw images were taken directly using the camera models listed in Table I. All raw images are interpolated by dcraw, the most widely used raw image decoder using adaptive homogeneity directed (AHD) interpolation algorithms [21]-[22]. The PRNU pattern is a kind of Sensor Pattern Noise. It is a constant pattern that identifies the non-uniformity noises in an imaging device/camera. Many modern digital cameras can save images in a raw format and then allow the user to demosaic them. We proposed an enhanced scheme for efficiently estimating the hue modification.
A. Hue Modification on PRNU:

RGB pixel value of an image is represented as a vector with three-dimensional Cartesian coordinates. A hue modification process can be defined as a rotation of RGB pixel vector. Its magnitude is a unit vector ⃗u = (ur, ug, ub), where ur = ug = ub = 1/√3. The matrix R(θ) for a rotation by an angle of θ about an axis in the direction of ⃗u is given by,

\[
R(\theta) = \begin{bmatrix}
\alpha + \beta & \beta - \gamma & \beta + \gamma \\
\beta + \gamma & \alpha + \beta & \beta - \gamma \\
\beta - \gamma & \beta + \gamma & \alpha + \beta
\end{bmatrix}
\]

(1)

Where \( \alpha = \cos\theta, \beta = \frac{1}{3}(1 - \cos\theta) \) and \( \gamma = \frac{1}{\sqrt{3}} \sin\theta \). Multiplying this matrix to the original pixel vector \( \vec{v} = (r, g, b)^T \).

It will give a hue modified pixel vector \( \vec{v}' = (r', g', b')^T \), which is obtained by multiplying original pixel vector and RGB pixel vector. Fig.1 shows the sample image for partial manipulation detection experiment and estimation. Fig 1 shows the input image and its hue modification.

![Fig 1: (a) Input image (b) Hue modified image](image)

To find the hue modification effect on the separated PRNU, we can analyze this modification of hue rotations in the RGB color space. Three pixel vectors of the color are given by, \( \vec{v}_r = [\vec{p}_r, \vec{p}_g, \vec{p}_b]^T \), \( \vec{v}_g = [\vec{p}_r, \vec{p}_g, \vec{p}_b]^T \) and \( \vec{v}_b = [\vec{p}_r, \vec{p}_g, \vec{p}_b]^T \). It is defined within the RGB colorspace, which represent pixels from the red, green and blue positions of the CFA. To represent the PRNU components, remove the interpolated value of \( \vec{p}_c \), which has a propagation error by demosaicing [19] and obtained normalized PRNU noise pixels as follows:

\[
\vec{\eta}_r = \begin{pmatrix}
\alpha + \beta \\
\beta + \gamma \\
\beta - \gamma
\end{pmatrix}, \quad \vec{\eta}_g = \begin{pmatrix}
\beta - \gamma \\
\alpha + \beta \\
\beta + \gamma
\end{pmatrix}, \quad \vec{\eta}_b = \begin{pmatrix}
\beta + \gamma \\
\alpha + \beta \\
\beta - \gamma
\end{pmatrix}
\]

(2)

\( \theta \) is defined as the degree of hue modification. Using these pixel vectors, generated a 1×3 synthetic noise within the image is \( \vec{l}_c = [\vec{\eta}_r, \vec{\eta}_g, \vec{\eta}_b] \) and a hue modified image is given by \( \vec{l}'c(\theta) = [\vec{\eta}_r(\theta), \vec{\eta}_g(\theta), \vec{\eta}_b(\theta)] \). A demosaicing algorithm is a digital image process used to reconstruct a full color image from the incomplete color samples from a image sensor overlaid with a color filter array (CFA). Non-professional users. Since the advent of high-quality image editing tools such as Adobe Photoshop, Paintshop, etc. With an image-editing tool, a person can severely distort the actual meanings of images by modifying the hue of the images. To cope with image forgeries, a number of forensic schemes were proposed. Most schemes are based on detecting local inconsistencies such as resampling artifact [1], color filter array interpolation [2], JPEG compression [3] or lighting condition [4]. The pixel photo response non-uniformity (PRNU) is widely used for detecting digital image forgeries [5]-[9]. There are also some methods for detecting identical regions are based on detecting the local inconsistencies of the image such as caused by copy move forgery [2]. Only two of these methods are able to detect hue forgery, because this does not change any other aspect of an image such as edges, shapes, gradations and PRNU. Fig 2 shows the demosaiced image with a hue modified pixel vector. Then calculate the correlation \( \rho'_c(\theta) \) as follows:

![Table 1: Digital Camera Models](image)
\[ \rho_c'(\theta) = \text{corr}(I_c(\theta), I'_c(\theta)) \]  

The correlation plot of the hue modified image and the de-mosaiced image with a hue modified pixel vector is interest points, symmetric, with maximum point on the hue. Fig 3 shows the correlation plot between the hue modified image and the Demosaiced image.

**B. Design a Hue Modification Algorithm:**

1) Number equations consecutively with equation numbers in parentheses flush with the right margin, as in (1). First use the equation editor to create the equation.

The first step reduces computation time by removing unnecessary search intervals. This method is based on a small number of samples. The range of the sample is divided by the regular interval \( \Delta i \). First, select the samples, \( n_s = \lceil \frac{360}{\Delta i} \rceil \) samples at regular interval \( \Delta i \) in the range of hue value \([0, 360] \) and create a set of selected hue values \( \Theta = \{\theta_1, \theta_2, \ldots, \theta_{ns}\} \). The hue value of the suspicious image \( I_{sus} \) is modified with the values in \( \Theta \) and then obtained a hue modified image set is given by

\[ I_{sus} = \{I_{sus}(\theta_1), I_{sus}(\theta_2), \ldots, I_{sus}(\theta_{ns})\}. \]

Then we apply a denoising filter \( F \) into \( I^0_{sus} \), then the equation becomes \( I^0_{sus} = \{n_c(\theta_1), n_c(\theta_2), \ldots, n_c(\theta_{ns})\} \) of noise residuals in the image. We calculated the cross correlation between noise residuals \( I_{sus} \) and \( I^0_{sus} \), and then choose \( \theta' \) with the largest value as an intermediate candidate of modified hue degree.

\[ \theta' = \arg\max_{\theta} \sum \text{corr}(n_c(\theta), P_c) \text{ where } \theta \in \Theta. \] (4)

2) In this step set \([\text{Min}_d, \text{Max}_d]\) for the candidate range, \( \text{Min}_d \leftarrow \theta' - \Delta i/2 \) and \( \text{Max}_d \leftarrow \theta' + \Delta i/2 \). If there is a global maximum \( \hat{\theta} \) in the range \([\text{Min}_d, \text{Max}_d]\), we can find \( \hat{\theta} \) using an algorithm based on a hill climbing search since the slopes around the maximum point converge towards it.

The design of Algorithm 1 comes from the concept of a binary search tree with hill climbing optimization technique. It is a mathematical optimization technique which belongs to the family of local search. It is an iterative algorithm that starts with an arbitrary solution to a problem, then it changes a single element in the solution.

<table>
<thead>
<tr>
<th>Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>\text{Min}_d \leftarrow \theta' - \Delta i/2</td>
</tr>
<tr>
<td>\text{Max}_d \leftarrow \theta' + \Delta i/2</td>
</tr>
<tr>
<td>\text{itv} \leftarrow \Delta i</td>
</tr>
<tr>
<td>\mathcal{E} \leftarrow \text{smallest unit of hue modification}</td>
</tr>
<tr>
<td>\text{while } (\text{itv} &gt; \mathcal{E})</td>
</tr>
<tr>
<td>\quad \text{LeftEstimation} \leftarrow P_c \text{ corr}(n_c(\text{Min}_d + \frac{\text{itv}}{4}), P_c)</td>
</tr>
<tr>
<td>\quad \text{RightEstimation} \leftarrow P_c \text{ corr}(n_c(\text{Max}_d - \frac{\text{itv}}{4}), P_c)</td>
</tr>
<tr>
<td>\quad \text{If } \text{LeftEstimation} &gt; \text{RightEstimation then}</td>
</tr>
<tr>
<td>\quad \quad \text{Max}_d \leftarrow \text{Max}_d - \text{itv}/2</td>
</tr>
<tr>
<td>\quad \quad \text{else}</td>
</tr>
<tr>
<td>\quad \quad \quad \text{Min}_d \leftarrow \text{Min}_d + \text{itv}/2</td>
</tr>
<tr>
<td>\quad \quad \text{end if}</td>
</tr>
<tr>
<td>\quad \text{itv} \leftarrow \text{itv}/2</td>
</tr>
<tr>
<td>\text{end while}</td>
</tr>
<tr>
<td>\text{Return } \hat{\theta} \leftarrow \text{mod}\left(360 - \frac{\text{Max}_d + \text{Min}_d}{2}, 360\right)</td>
</tr>
</tbody>
</table>

If the change produces a better solution and incremental change is made to the new solution, repeated until no further improvements can be made. First to calculate the correlation values in the intermediate angles to the left and right sides of
candidates. Second, a narrow search range toward the direction of greater value and reduced the interval by half. These iterations were repeated until intervals smaller. The estimated degree $\hat{\theta}$ was calculated based on the final candidate range $[\text{Min}_d, \text{Max}_d]$.

$$\hat{\theta} \leftarrow \text{mod}(360 - \frac{\text{Min}_d + \text{Max}_d}{2}, 360)$$  \hspace{1cm} (5)

Fig 4 shows the tabulation details of hue modification with expected hue degree($\theta'$) and estimated hue degree($\hat{\theta}$). The estimated degree $\hat{\theta}$ indicates that the degree of the modified hue. If $\hat{\theta}$ is zero, then the suspicious image $I_{sus}$ did not undergo any hue manipulation. In contrast, if $\hat{\theta}$ is not zero, then hue of the Isus was modified.

![Fig. 4: Hue modification and angular estimation](image)

**C. Partial Manipulation Detection and Estimation:**

To detect the hue modified areas, we defined a $w \times w$ pixel sliding window that moved across the reference pattern $P$ and suspicious image $I_{sus}$. Using this window, we obtain the block $I(i, j)$ to be investigated and its corresponding reference pattern $P(i, j)$ via the following equations

$$P(i, j) = P[n][m], \quad (6)$$

$$I_{sus}(i, j) = I_{sus}[n][m], \quad (7)$$

where $i - \frac{w}{2} \leq n, m \leq i + \frac{w}{2}$, and $[n][m]$ denotes the image pixel from the $n$-th row and the $m$-th column. Using the proposed estimator $F(P, I)$, we obtained an estimation map $M_{\theta}$ of $I_{sus}$. Fig 5 shows the estimation and detection map. In the estimation map, the forged regions are mapped to the estimated hue value.

$$M_{\theta}(i, j) = F(P[i, j], I_{sus}(i, j)).$$  \hspace{1cm} (8)

![Fig. 5: Estimation map](image)

If the inspected image has been partially tampered, the estimation degree of the tampered region will not have a value of zero. Calculate the correlation map by using $M\theta(i, j)$ using a particular threshold factor $\text{thr}$. The threshold values defined by the hue pixel values (0:360). The estimation result $M\theta(i, j)$ will not be accurate. Then determine whether the pixel $(i, j)$ was modified using:

$$Z(i, j) = \begin{cases} 1, & |\theta_0 - M\theta(i, j)| \geq \text{thr} \\ 0, & \text{otherwise} \end{cases}$$ \hspace{1cm} (9)

Where $Z(i, j)$ indicates whether the hue of each pixel is modified or not. The operator $|\cdot|$ denotes an absolute value in the range ( 0, 360], and $\theta_0$ indicates the un modified degree value, '0'. Fig.7 shows the estimation and detection map. In the estimation map, the forged regions are mapped to the estimated hue value.

![Fig. 7: Estimation and detection map](image)
D. Saturation Modification:

Color saturation refers to the intensity of color in image. The hue refers to the color of the image itself, while saturation describes the intensity (purity) of that hue. Saturation is the colorfulness of a color relative to its own brightness. The color saturation method is applied to the image to improve purity of the image. This method can improve image quality and have good visual effect. Fig 6 shows the saturated modification of the image.

Then the histogram equalization method is applied to the image. It enhances the contrast of images by transforming the values in an intensity image or the values in the color map of an indexed image. Histogram equalization technique is usually used to increases the global contrast of many images. This is obtained by grouping certain adjacent grey values. Thus the number of grey levels in the enhanced image is less than that of number of grey levels in the original image. When applying the histogram equalization method on the colors like Red, Green, and Blue components of an RGB image may yield changes in the images color balance since the relative distributions of the color channels change. Fig 7 shows the hue modified raw image.

III. CONCLUSION

In this paper, we discusses about a family of photo response non-uniformity (PRNU) based on image manipulation techniques as well as to localize the hue modification regions and to estimate the modified degree. We proposed an efficient estimation scheme for partial manipulation detection experiment and its estimation. We plan to extend the method to estimation of other types of image property modification such as white balancing.

ACKNOWLEDGMENT

I also acknowledge my gratitude to all other faculty members of the Department of Electronics and Communication.

REFERENCES