A SORTED NEIGHBORHOOD APPROACH FOR DETECTING DUPLICATED REGIONS IN IMAGE FORGERIES BASED ON DWT AND SVD

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ABSTRACT

The presence of duplicated regions in the image can be considered as a tell-tale sign for image forgery, which belongs to the research field of digital image forensics. In this paper, a blind forensics approach based on DWT (Discrete Wavelet Transform) and SVD (Singular Value Decomposition) is proposed to detect the specific artifact. Firstly, DWT is applied to the image, and SVD is used on fixed-size blocks of low-frequency component in wavelet sub-band to yield a reduced dimension representation. Then the SV vectors are then lexicographically sorted and duplicated image blocks will be close in the sorted list, and therefore will be compared during the detection steps. The experimental results demonstrate that the proposed approach can not only decrease computational complexity, but also localize the duplicated regions accurately even when the image was highly compressed or edge processed.

1. INTRODUCTION

As digital cameras continue to replace their analog counterparts, the importance of authenticating digital images, identifying their sources and detecting forgeries will only increase. There has been some effort in the digital signature and watermarking communities to localize image manipulation and recover original content[1]. However, signature file is separated from the image, while embedding watermark causes the reduced image quality. Another issue is that there is no completely secure authentication algorithm that can survive all attacks. Therefore in the absence of widespread adoption of digital signature and watermark, it is necessary to develop techniques that can help make statements about the condition of images.

Digital image forensics (also called passive-blind image forensics), is a form of image analysis for finding out the condition of an image without relying on pre-registration or pre-embedded information[2]. Because of the great challenge of the problem and lack of any apriori knowledge, the research should start with analyzing several simple forgery types, such as the copy-paste forgery in this paper. When detecting the forgery of an image, a fused algorithm can be used to obtain a decisive answer.

A common forgery when tampering with an image is to copy and paste portions of the image to conceal an important object or produce a non-existing situation in the scene. The copied parts may come from the same image, or from multiple images.

One of the key characteristics of copy-paste forgery is the presence of duplicated regions in the tampered image, even though the image has suffered post-processing operations such as edge blurring. The characteristic can be used as an evidence for detecting the forgery mentioned above. A direct approach for detecting duplicated image regions is exhaustive search, which can be implemented easily. However it is computationally complex. Therefore many researchers use blocking approaches to increase the speed of operation process. Fridrich[3] proposes an effective way to detect copy-move forgery blocks in a single image. The image blocks are represented by quantized DCT (Discrete Cosine Transform) coefficients, and a lexicographic sort is adopted to detect the duplicated image blocks. A similar detection method is proposed in [4], in which the image blocks are reduced in dimension by using PCA (principal component analysis). But in their algorithms, blocks are directly extracted from the original image, resulting in a large number of blocks, thus affecting the efficiency of detection algorithm.

To further reduce the amount of computation, this paper proposes a sorted neighborhood approach for detecting duplicated image regions based on DWT and SVD. The image is first reduced in dimension by DWT, and the SVD is applied to the fixed-sized overlapping blocks of low-frequency wavelet portion. The singular value vectors are lexicographic sorted and duplicated image blocks will be close in the sorted list, and therefore will be compared during the detection steps. The experiments demonstrate that the proposed approach can not only further improve efficiency, but also localize the duplicated regions accurately even when the image is highly compressed and edge feathered.

The rest of paper is organized as follows. Representation of image features is presented in Section 2.

Section 3 describes the detection approach based on DWT and SVD. Section 4 presents and discusses the experimental results, and section 5 contains conclusions.

2. REPRESENTATION OF IMAGE FEATURES

In work [3, 4], an image is divided into overlapping blocks by sliding a fixed-size window one pixel once along the image, and these blocks are represented by quantized DCT coefficients and PCA respectively. Because the energy of transformed coefficients will be focused on the first several large values, which contain most information of each block, thus rest minor values can be neglected. The drawback of these algorithms, however, is that the number of blocks is large because blocks are extracted from the original image directly, especially the larger image. Therefore we describe a DWT&SVD approach that can further reduce image scale and feature dimension while retaining its efficiency.

DWT, which is a multilevel decomposition technique, is localized in space and in frequency. The localization feature both in space and frequency, in turn, results in a number of useful applications such as data compression, detecting features in images, and removing noise and so on[5] . In our approach, the image is firstly decomposed through DWT into a series of wavelet coefficients corresponding to the image's spatio-frequency sub-bands: let us call I_j^{θ} the sub-band at resolution level *j* and with orientation $\theta \in \{LL, LH, HL, HH\}$. As is well known, most of the image energy is concentrated at the low-frequency sub-band I_j^{LL}, whose size is only $1/4^j$ of the original image size. Then sliding window operation is only applied to I_j^{LL} sub-band, and SVD is used to extract the features of all blocks.

SVD Definition: any real $m \times n$ (In general, let m>=n) matrix *A* can be decomposed uniquely as

$$A = U \Lambda V^T \tag{1}$$

Where U is an $m \times m$ orthogonal matrix, V is an $n \times n$ orthogonal matrix, and Λ is an $m \times n$ matrix whose off-diagonal entries are all zeros and whose diagonal elements satisfy

$$\sigma_1 \geq \sigma_2 \geq \ldots \geq \sigma_n \geq 0 \tag{2}$$

It can be shown that $r = rank(A)$ equals the number of nonzero singular values. $\sigma_i, i = 1, \ldots r$ represent the SVs in descending order[6].

There are two purposes for using SVD: (1) SV vector is the unique, steady representation of a block. It is optimal for given image in the sense that the energy packed in a given number of transformation coefficients is maximized; (2) it further reduces feature dimension from $m \times n$ to *r*.

3. THE SORTED NEIGHBORHOOD APPROACH BASED ON DWT AND SVD

After describing wavelet low-frequency component with block SVs, the sorted neighborhood detection is performed. It relies on the assumption that duplicated vectors will be close in the sorted list and have the same offset, therefore will be compared during the detection steps[7]. The neighborhood feature, along with coordinates offset makes the detection of duplicated regions available. The details of the duplicated image regions detection process are described as follows.

(1) Let $I_{r \times c}$ be the gray image of the size $r \times c$;

(2) For the whole image $I_{r \times c}$, DWT is calculated, and the low-frequency component $A_{m \times n}$ is obtained, where $m = \lfloor r/2^j \rfloor$, $n = \lfloor c/2^j \rfloor$, *j* is resolution level, and $\lfloor \; \rfloor$ is the integer round operation;

(3) Suppose *w* be a window of the size $a \times b$ (here we assume that the size of the blocks is smaller than the duplicated region to be detected). The sliding window operation of moving a pixel once is performed on the low- frequency coefficients $A_{m \times n}$, and there are $N_w = (m - a + 1)(n - b + 1)$ such blocks;

(4) Each block is sent sequentially to the SVD and represented as a 1**r* reduced dimension vector, where $r = \min(a, b)$. Therefore a $N_w \times r$ matrix is obtained;

(5) Sort the rows of $N_w \times r$ matrix in lexicographic order to yield the sorted matrix *S*. Let $\vec{s}_i$ ($i = 1, \ldots, N_w$) denote a row of *S*, and let (x_i, y_i) denote the top-left corner coordinates in the *A* of the block that corresponding to $\vec{s}_i$;

(6) Scanning *S*, for the neighbored rows $\vec{s}_i$ and $\vec{s}_j$, calculate the offsets $(\Delta x, \Delta y)$ of corresponding coordinates;

(7) For every pair of rows $\vec{s}_i$ and $\vec{s}_j$ which satisfies $\Delta x > |a| \; or \; \Delta y > |b|$, compute its offset frequency $C(\Delta x, \Delta y) = C(\Delta x, \Delta y) + 1$ (C is initialized to zero);

(8) Set a threshold *T*, if there exists $C(\Delta x, \Delta y) > T$, which denotes the image has duplicated regions, and then goes to next step for localization, otherwise end the algorithm;

(9) For all $C(\Delta x, \Delta y) > T$, the matching blocks that contributed to that specific offset $C(\Delta x, \Delta y)$ are marked with the same color. If the marked blocks are adjacent,

they might consist the copy-paste regions; if the blocks are isolated, they can be removed by mathematical morphology operations[8].

In addition, $C(\Delta x, \Delta y)$ is generated to record the frequency of all kinds of offset $(\Delta x, \Delta y)$. Because the similar block pairs should be non-overlapping, $C(\Delta x, \Delta y)$ is incremented only for those pairs which satisfy $\Delta x > |a| \; or \; \Delta y > |b|$.

A meaningful duplicated region in image forgery will likely be a connected small image blocks rather than a collection of many isolated blocks. Therefore, if the duplicated region exists, $C(\Delta x, \Delta y)$ that attributed to that specific offset must be a relatively large value, and will exceed the threshold *T*.

4. EXPERIMENTAL RESULTS AND DISCUSSIONS

To demonstrate the power of proposed image detection approach, we will first introduce the experimental setup, and give the detection results obtained under various manipulations of duplicated regions, both for gray-level images and color images in Section 4.1 and 4.2 respectively. In Section 4.3, our proposed approach will be compared with prior related work in literature.

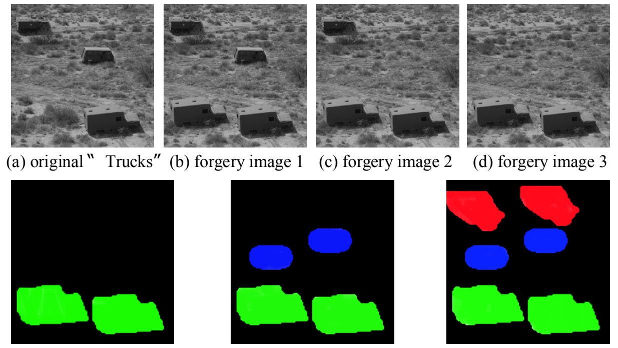
In our implementation, the Haar wavelet transform is used. The window size is 4*4 pixels. *T* = 64 is chosen as the threshold value of offset frequency.

4.1. Detecting Duplicated Regions in Gray-level Images

The proposed approach is tested with a variety of gray-level images, but here we only give the results of using the 256*256 “Trucks” gray-level image in BMP format for example. The original and three tampered images are shown in Figure 1(a)-(d). Figure 1(b) is forgery image 1 that is tampered with by copying the truck in bottom right corner of Figure 1 (a), followed by pasting onto a back, non-overlapping position; Figure 1(c) is forgery image 2 where the car in the middle of Figure 1(b) is removed and filled with turf in the vicinity. Moreover an edge feathering operation is used; Figure 1(d) is a further tampering to Figure 1(c), in which the armored car in the upper left corner is replaced by similar background patches. The detection results for three tampered images are shown in Figure 1(e)-(g), respectively.

For tampered “trucks” images, we also test JPEG compressed images with high quality factors. The detection results are still good up to quality factor of 70. Through dilation and erosion operations[8], the localization results of JPEG tampered images are similar to those of BMP format.

Experiments demonstrate that the proposed approach does work well in most cases, even when the forgery images have been JPEG compressed or edge processed to a certain extent.

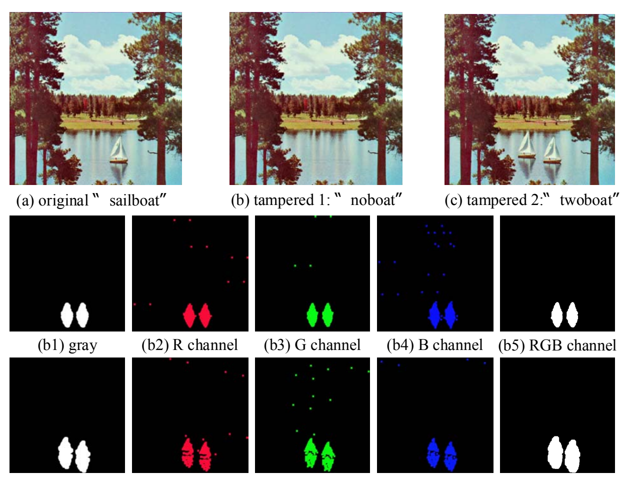


(a) original "Trucks" (b) forgery image 1 (c) forgery image 2 (d) forgery image 3
(e) the detection result of (b) (f) the detection result of (c) (g) the detection result of (d)

Figure 1 The detection results of gray-level images

4.2. Detecting Duplicated Regions in Color Images

In this section, we shall give some experimental results of tampered color images. There are at least two ways in which this approach can be extended to color images. The first one is to convert a color image to the gray-level image using the formula $I = 0.299R + 0.587G + 0.114B$, and then the detection algorithm proceeds as in the gray-level image case. The second approach is to independently process each color channel (RGB) to yield three duplication results, and the final detection is obtained by performing “and” operation, followed by dilation and erosion operations.



(a) original "sailboat" (b) tampered 1: "noboat" (c) tampered 2: "twoboat"
(b1) gray (b2) R channel (b3) G channel (b4) B channel (b5) RGB channel
(c1) gray (c2) R channel (c3) G channel (c4) B channel (c5) RGB channel

Figure 2 The detection results of color images

Shown in Figure2 (a)-(c) are original and tampered “sailboat” color images. The manipulations consist of copying and pasting a neighboring region in the image to conceal a sailboat, or to reproduce a sailboat. Figure 2(b1), (c1) are the detection results by applying the first approach to “noboat” and “twoboat” images. Figure2 (b2)-(b5), (c2)-(c5) are the results showing how to detect duplicated regions of “noboat” and “twoboat” by using the second approach, including R channel detection maps, G channel detection maps, B channel detection maps and the final detection maps, respectively.

4.3. Comparison with Existing Approaches

In this section, we shall compare our approach with other existing ones. The image used for the comparison is of size 512*512 with 256 gray-level, and the block is of size 8*8 pixels.

Table 1 Comparison results of the three approaches for a 512*512 gray-level image with 8*8 window block

Algorithm	Image Representation	Block(8*8) Number	Feature Dimension
Fridrich	DCT& quantization	255,025	64
Popescu	PCA	255,025	32
Proposed	DWT&SVD	62,001	8

As is well known, the sort matrix scale is the major factor affecting the computation complexity. The total amount of its rows denotes block number, and the total amount of columns denote feature dimension. Table 1 lists the comparison results. The block number in our approach is approximate a quarter of those obtained by other two approaches. Furthermore, the feature in our algorithm is 8-dimension, while features in Fridrich[3] and Popescu[4] algorithms are 64-dimension and 32-dimension respectively. From table 1, it is obvious that the sort matrix in our approach is smaller in size than those in other two approaches under the same experimental condition. By comparison, it is found the proposed approach based on DWT&SVD can better improve detection efficiency.

5. CONCLUSION

Digital image forensics is still a research area at its infancy. A specific copy-paste type of image forgery is researched in this paper, and an efficient approach is presented to detect duplicated regions in an image. The image is first reduced in dimension by DWT, and the SVD is applied to the fixed-sized overlapping blocks of low-frequency in wavelet sub-band. Duplicated regions are then localized by lexicographically sorting and neighborhood detecting for all blocks. Experiments indicate our approach is able to authenticate and localize the copy-paste efficiently.

Our future work will proceed to detect other types of image artefacts, such as spliced images, photorealistic computer graphics and so on, so that passive-blind image forensics can be used in various forgery circumstances.

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