Improving the Computational Cost for Copied Region Detection in Forensic Images

Tu Huynh-Kha, Thuong Le-Tien, Synh Ha, Khoa Huynh-Van

Abstract—This research work develops a new method to detect the forgery in image by combining the Wavelet transform and modified Zernike Moments (MZMs) in which the features are defined from more pixels than in traditional Zernike Moments. The tested image is firstly converted to grayscale and applied one level Discrete Wavelet Transform (DWT) to reduce the size of image by a half in both sides. The approximation sub-band (LL), which is used for processing, is then divided into overlapping blocks and modified Zernike moments are calculated in each block as feature vectors. More pixels are considered, more sufficient features are extracted. Lexicographical sorting and correlation coefficients computation on feature vectors are next steps to find the similar blocks. The purpose of applying DWT to reduce the dimension of the image before using Zernike moments with updated coefficients is to improve the computational time and increase exactness in detection. Copied or duplicated parts will be detected as traces of copy-move forgery manipulation based on a threshold of correlation coefficients and confirmed exactly from the constraint of Euclidean distance. Comparisons results between proposed method and related ones prove the feasibility and efficiency of the proposed algorithm.

Index Terms—Forgery detection (FD); Copy-Move; Discrete Wavelet Transform (DWT); Zernike Moment (ZM), modified Zernike Moment (MZM), feature vectors; lexicographical sorting; blocks matching

1. Introduction

Nowadays, digital image technology has been developed endlessly in many fields from applications to technology. Everything on our life is mostly encoded into images and considered an efficient information transmission channel. In fact, images attract your attention from the first sight and also make a person believe in something seen. However, we are not sure that all images are original and so, the research on image forgery is essential. In case of counterfeit, images are followed by various effects including active which is orient to good things and passive purposes which can be false evidences in investigation, insurance, Image forgery detection has been emerging as a remarkable research in applications of computer vision, digital image processing, biomedical technology, criminal investigation, image forensics, etc When powerful software tools for image processing have been developed and used widely, the forgery in image is more popular and the detection of counterfeit is more sophisticated. In fact, there are many faked images are so delicate that we cannot confirm whether an image is manipulated by naked eyes (see Fig.1).

There are two groups of techniques for tracing

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Manuscript received January 7, 2016; revised March 27 and June 15, 2016; accepted July 25, 2016.

Digital Object Identifier 10.31130/jst.2016.28

Fig. 1: Original, Copy-Move and Spliced Images by Photoshop.
(a),(c),(e),(g) Original images; (b) Copy-move image from (a); (d) Copy-Move image from (c); (f) Spliced image from (e) and (g); (h). Another spliced image from (e) and (g).
the counterfeits in images including active and passive/blind techniques. The first requires embedded security codes such as watermarking or digital signatures to be inserted in the original images while there is no any information is given in the second. This also means the input in passive methods is only the tested images and the information of original images is blind. In passive/blind techniques, the processing also depends on forged details coming from image itself called copy-move or from the others called splicing. Because images are forged by different manipulations, the detection techniques are various and certainly, they still have their limitations. Therefore, more and more researches on blind techniques for detecting the counterfeit in the images are proposed.

This article develops a blind algorithm to detect the forgery in copy-move images using DWT and feature comparison of overlapping blocks to find the similar regions which is trace of copy manipulation and tampering as well. Although there are some feature extraction methods considered previously in image forgery detection such as: Local Binary Pattern, PCA, SIFT, traditional Zernike moment, statistical analysis of pixels, singular value decomposition, intensity of pixels, Radon transformation,...[1], applying modified Zernike moments (MZMs) with updated parameters to reduce the geometric error is the new feature extraction in copy-move image detection. Combination of DWT and MZMs into the algorithm is the novelty of the paper. The literature review of forgery detection in copy-move images will be presented in section II before developing an algorithm in section III. The simulation results will be shown in the next section and the conclusion is in the last one.

2. Literature Review

In tampered images by copy-move manipulations, an image part is copied and pasted into a different place to hide information or create a copied object in the same image. Therefore, the principle of detection the forgery in copy-move images is finding the similarity of small image regions through features comparison.

Weiqi Luo [2] proposed an algorithm to extract image features by using seven characteristic features computed from the statistical analysis of pixels in an image block. The first three features are the average of red, green, and blue components respectively and the other four features are computed based on the division of that block into two parts in 4 directions: horizontal, vertical, and two diagonal directions. In 2008, an algorithm named Singular Value Decomposition (SVD) [3] was applied to extract the algebraic and geometric features from small overlapping image blocks and to produce singular value feature vectors. In the Dartmouth Computer Science Technical Report of 2004, Alin C Popescu and Hany Farid proved that Principle Component Analysis (PCA) is efficient to extract the image features [4]. The procedure to produce each feature vector is called principle component analysis in which values are obtained by using the theorems of covariance matrix, eigenvectors and linear basis for each image block with the initial conditions of zero-mean. However, the feature extraction methods solved problems copy-move without geometric transformation in the forged region.

Another group of features extraction methods considering geometric transformation in copied blocks before pasting to any place are also proposed. A 9-dimensional vector is also introduced in [5] to solve the problem with a fixed angle rotation on the copied regions. Elements of this vector are calculated based on the intensities from four equal-sized sub-blocks on each block. The first element is the average intensity, the next four elements are ratios of average intensities and the last four elements are differences of average intensities. Hieu Cuong Nguyen and Stefan Katzenbeisser [6] proposed Radon transformation to extract the features and use phase correlation to detect the pairs of matching vectors. The proposed method is well performed for the forged images which the rotation angle of the copied region is less than 4°, has Gaussian noise addition with a SNR greater than 35dB and smaller block size 8x8 pixels.

Since 2013, a new method to extract the image features by describing the spatial structure of the gray image texture called Local Binary Pattern (LBP) was introduced by Leida Li [7]. The method is applied for gray scale images in which the features are extracted from the low frequencies. As the previous methods, the feature matching is defined based on the threshold. Moreover, the post-processing including a special designed filter and morphological operations is also considered in the process of detection. The method is robust to JPEG compression, noise contamination, blurring, rotation and flipping. However, it is difficult to detect the rotated regions with general angles. Investigation of invariant block features and appropriate selection of the dimension of features are suggested to improve the random rotation.

The achievement of detecting a manipulated image in which the copied area is rotated with arbitrary angles was introduced by Hailing Huang in 2008. This method extracts keypoints using Scale Invariant Feature Transform (SIFT) algorithm [8] in which Descriptor vectors are compared to search matched keypoints based on Euclidian distance and a threshold called Distance ratio threshold. The higher threshold value is, the more false matching is obtained. A suitable threshold and searching strategy for keypoints matching are applied. This gives good performance on post processing consisting of JPEG compression, rotation, noise, scaling, compound image processing and will be improved to apply to low SNR and small size tampered region.

Seung-Jin Ryu suggested Zernike moments as a method to extract the features from the overlapped sub-blocks in the suspicious image [9]. These feature vectors are then sorted lexicographically and the similarity of two adjacent blocks is calculated using Euclidian distance and a threshold to find the candidates for
the forgery. The Precision (exactness), Recall (completeness), and F1-measure (both Precision and Recall) are then applied to the suspicious regions to confirm the forgery. In the case of blocks with the similar Zernike moments, to ensure the exactness of detection, calculating the distance between of the actual blocks of image will be considered.

In case of features extracted after applying transformation such as Discrete Wavelets Transform (DWT) or Discrete Cosine Transform (DCT), features vectors can be vectors of quantized DCT coefficients [10], sharpness/blurriness [11] from DWT. Singular Value Decomposition (SVD) is also a method to extract features of overlapping blocks of low-frequency in wavelet sub-band [12] before sorting to find the duplicated vectors. This approach decreases the computational complexity and localizes the duplicated regions with high compressed and edge processed.

Using Undecimated Dyadic Wavelet Transform (UDWT) and Zernike moments is proposed as a new method to detect the forgery in copy-move images by Jiyun Yang [13] in 2013. In this paper, the applying UDWT is firstly used to collect the low frequencies (LL) components. Traditional ZMs is then computed to produce feature vectors of overlapping blocks on LL and find the copied regions from these vectors. Lexicographical sorting, correlation coefficients with a threshold value are used to find the similar vectors and limit the exact forged blocks from the groups of similar vectors obtained in lexicographical sorting step, respectively.

3. Proposed Algorithm

In copy-move images, the forged regions are detected by looking for the similar corresponding blocks based on their feature vectors. Instead of using UDWT and traditional ZMs in both LL sub-band and HH sub-band to find the copy-move manipulation [13], this paper proposes Modified Zernike Moments (MZMs), which are produced by mapping a number of pixels to the unit circle more than in the tradition Zernike moments, to extract the blocks features from LL sub-band to detect the forgery in copy-move images. The replacing UDWT by a one-level DWT reduces the computational complexity by a quarter (see Fig.2) and the applying MZMs gives higher exactness in feature extraction than the traditional ZMs. The more number of pixels is mapped, the more sufficient features are extracted. Then the similar regions can be searched in the LL sub-band only with high precision, not considered more in the HH subband as in [13], which reduces the processing time. Therefore, combination of one-level DWT and MZMs is proposed to detect the copied regions in copy-move images efficiently. The related theories and the algorithm are presented in the following items.

3.1. Discrete Wavelet Transform DWT [14]

With a 2D image \( f(x, y) \), two dimension DWT will produce one separable scaling function \( \varphi(x, y) \) and three separable directionally sensitive wavelets \( \psi^H_{(x,y)}, \psi^V_{(x,y)}, \psi^D_{(x,y)} \) corresponding to variations along the horizontal edges, vertical edges and diagonals, respectively. These functions are defined in (1), (2), (3) and (4).

\[
\varphi(x, y) = \varphi(x)\varphi(y) \quad (1)
\]
\[
\psi^H_{(x,y)} = \psi(x)\varphi(y) \quad (2)
\]
\[
\psi^V_{(x,y)} = \varphi(x)\psi(y) \quad (3)
\]
\[
\psi^D_{(x,y)} = \psi(x)\psi(y) \quad (4)
\]

where \( \varphi(x), \varphi(y) \) are one dimension scaling functions and \( \psi(x), \psi(y) \) are one dimension wavelet functions.

In DWT, the scaling function defines the difference in scales between two nearest neighboring approximations while the wavelets functions defines the differences in information between adjacent approximations.

The scaled and translated basic functions are defined by (5) and (6)

\[
\varphi_{j,m,n}(x, y) = 2^{j/2}\varphi(2^j x - m, 2^j y - n) \quad (5)
\]
\[
\psi^i_{j,m,n}(x, y) = 2^{j/2}\psi^i(2^j x - m, 2^j y - n) \quad (6)
\]

for all \( j, k \in \mathbb{Z}, m, n = 0, 1, 2, ..., 2^j - 1 \). In (6), \( i \) is \( \{H, V, D\} \) that identifies the directional wavelets from (2), (3) and (4). Then discrete wavelet transform of image \( f(x,y) \) of size \( M \times N \) is done by defining the approximation and directional coefficients as in (7) and (8).

\[
W_{\varphi}(j_0, m, n) = \frac{1}{\sqrt{MN}} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x, y)\varphi_{j_0,m,n}(x, y) \quad (7)
\]
\[
W_{\psi}^i(j_0, m, n) = \frac{1}{\sqrt{MN}} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x, y)\psi^i_{j_0,m,n}(x, y) \quad (8)
\]

where \( j_0 \) is an arbitrary scale, \( W_{\varphi}(j_0, m, n) \) are approximation coefficients of image \( f(x,y) \) at scale \( j_0 \) and \( W_{\psi}^i(j, m, n) \) are coefficients used to add the horizontal, vertical and diagonal details for scale \( j \geq j_0 \).

DWT is used in this article for the multiscale purpose so processing steps are concentrated in the approximation which takes the scale function from DWT and reduces the size of image by a half in both rows and columns after each decomposition level. A 2D one-level decomposition of a 2D image and the corresponding analysis filter bank, which is applied in the proposed algorithm in this paper, are shown in Fig.2 and Fig.3.

3.2. Reduce the computational complexity using DWT

Copy-move manipulation is often done in objects and so, looking for the similar information in the approximation subband from one level DWT instead of doing in the tested image improves computational time due to the size of image is reduced by a quarter. To find the forgery in an \( M \times N \) image, similar regions which are considered the copied ones should be detected. Actually, copied parts are collection of small overlapping blocks having the size of \( m \times n, (m < M, n < N) \).
If the detection is directly done in the tested image, \((M - m + 1) \times (N - n + 1)\) blocks are compared while the number of blocks to be compared in approximation by one-level DWT is \([\frac{1}{2}(M - m) + 1] \times [\frac{1}{2}(N - n) + 1]\) (see Fig.4).

Therefore, the number of feature vectors is reduced by \((M - m + 1) \times (N - n + 1) - \left[\frac{1}{2}(M - m) + 1\right] \times \left[\frac{1}{2}(N - n) + 1\right]\)

For example of 32x32 blocks, the number of overlapping blocks in a 512x512 image is 231361 while there are 58081 overlapping blocks in approximation subband. The ratio of number of blocks in the tested image and in the approximation is 3.98.

3.3. Increase the exactness using Modified Zernike Moments (MZMs) [15]

3.3.1. Traditional Zernike

Zernike moments are often used to represent the images by their rotation invariant property. ZMs are a class of orthogonal moments and constructed to an arbitrary order in which the higher order, the more sensitive to noise. The Zernike polynomials are a set of complex, orthogonal polynomials defined over a marginal boundary being called the unit circle (or unit disc).

\[
V_{nm}(x, y) = V_{nm}(r, \theta) = R_{nm}(r) \exp(jm\theta)
\]

where \(n \in \mathbb{Z}^+; m \) is an integer defining the rotation subject to the conditions \(n - |m| = \text{even}, \ |m| \leq n; \ r \) is the length of the vector from origin to pixel coordinate \((x, y); \ \theta = \angle(r, x)\) in counter clockwise direction, \(N_{nm} = \sqrt{\frac{2(n+1)}{\pi} \delta_{nm}}\) is the normalization factor.

Mapping an image function \(f(x, y)\) into a unit circle, the Zernike Moment of order \(m\) with repetition \(m\) is:

\[
A_{nm} = \frac{n+1}{\pi} \sum_x \sum_y f(x, y) V_{nm}(x, y), x^2 + y^2 \leq 1
\]

The ZMs in rotated images and original unrotated images are different in phase shifts, but not in magnitudes. Therefore, the absolute value of \(A_{nm}\) written in \(|A_{nm}|\) is suggested to be the rotation invariant feature.

3.3.2. Modified Zernike Moments

MZMs are defined by ZMs in which the number of pixels used to calculate moments are more than in the traditional ZM, which leads more sufficient features and less geometric error. Fig.2 shows the mapping pixels to unit circle to compute ZMs by traditional and modified method.

Consider a block of pixels as in Fig.5a. To compute ZMs by traditional model in polar coordinate \((r, \theta)\) with \(|r| \leq 1\), a linear mapping process is required to obtain the corresponding image coordinates \((i, j)\) in the unit circular domain \((r, \theta) \in \mathbb{R}^2\) (see Fig.5b and 5c) from which ZMs are calculated. The mapping is obtained by

\[
\begin{align*}
    x_i &= c_1 i + c_2 \\
    y_j &= c_1 j + c_2
\end{align*}
\]

where \(c_1 = \frac{2r}{N+1}\) and \(c_2 = -r\) and value of \(r\) is equal the radius of the unit disc \((r = 1)\), followed by \(c_1 = \frac{r^2}{N+1}\) and \(c_2 = -1\) in the traditional approach.

In the modified method, a new mapping (see Fig. 5d, 5e) is applied so that the number of pixels to represent

Fig. 2: One-level decomposition of a 2D image. (a) The original image; (b) A one-level DWT; (c), (d) Positions of corresponding sub-bands.

Fig. 3: One-level analysis filter bank.

Fig. 4: 2-D DWT. (a) Original image; (b) One-scale DWT; The black block at left-top corner in (a) is \(m \times n\) block; The black block at left-top corner in (b) is \((m/2) \times (n/2)\) block.
M2Mzs is more than in the traditional one which is done by analyzing a square circle in Fig.5f where $r$ is defined as radius of the circle. Four sides of the square are $r_1 = \sqrt{\pi}$ and the diameter of the unit circle is $d = 2r = 2$. In case of the area of the square is equal to that of the circle, $r_1 = r\sqrt{\pi}$.

$$r_1 = r\sqrt{\pi} = \sqrt{\pi} \rightarrow x = 1 - \frac{2 - \sqrt{\pi}}{2} = \frac{\sqrt{\pi}}{2} \quad (13)$$

$$A_{2\Delta ABO} = \frac{1}{2} \times 2r \sin \alpha = x \pi r = \frac{\sqrt{\pi}}{2} \sin \alpha \quad (14)$$

The angle $\alpha$ between $x$ and $r$ obtained by

$$\alpha = \cos^{-1}\left(\frac{x}{r}\right) = \cos^{-1}\left(\frac{\sqrt{\pi}}{2}\right)$$

$$\rightarrow \beta = \frac{(90 - 2\alpha)\pi}{180} \approx 0.6074753677 (rad) \quad (15)$$

The area of $2\angle COD$ (or $\beta$) is $A_{2\angle COD} = \frac{1}{2}r^2\beta = \frac{1}{2}\beta$. Finally, the total numerical area inside the circle and the square is

$$A_{total} = 4A_{\angle COD} + 4A_{\Delta AOB} = 2\beta + 4x \pi r \sin \alpha$$

$$\approx 2 \times 0.6074753677 + 2\sqrt{\pi} \sin(\cos^{-1}\left(\frac{\sqrt{\pi}}{2}\right))$$

$$\approx 2.857134103$$

Since $A_{total} \approx 2.857134103$, the total pixels of proposed method inside unit disc are $[2.857134103 \times N^2]$ (pixels). Similarly, considering the traditional model, we have the total numerical area inside the unit circle is

$$A'_{total} = \pi \quad (16)$$

Hence, the value of ratio $h_0$ (in reducing the G.E) between the proposed model ($A_{total}$) and the traditional model ($A'_{total}$) is

$$h_0 = \frac{A_{total}}{A'_{total}} = \frac{2.857134103}{\pi} \approx 0.909 \quad (17)$$

Therefore, by shrinking the traditional ROI (see Fig.5a) with a ratio $h_0 = 0.909$ to obtain the new mapping (see Fig.5d), our research will transform a traditional to modified ROI having more pixels within to the unit circle (see Fig.5e). Therefore, there are more feature extraction points compared with previous ones in different ROIs. The updated parameters include $h$, $c_1$ and $c_2$ defined by $h = x = \sqrt{\frac{\pi}{2}}$, $c_1 = \frac{\sqrt{\pi}}{N-1}$ and $c_2 = -\frac{\sqrt{\pi}}{2}$.

The equation used to compute the transformed coordinate $(x, y)\text{ in } (12)$ is modified to be $x_i = c_1(i + 0.5) + c_2$ and $y_j = c_1(j + 0.5) + c_2$ where $c_1 = \frac{\sqrt{\pi}}{N}$; $c_2 = -\frac{\sqrt{\pi}}{2}$.

The transformed pixel coordinates after shrinking are located as shown in Fig.6.

### 3.4. Algorithm

The paper develops an algorithm to detect the forged regions in terms of copy-move in an image by combining DWT and M2Mzs. A tested image is converted to grayscale before applying DWT to reduce the dimension of image. Due to the forgery is often manipulated on the information and content of the image so the approximation sub-band is considered to be the main data to find the counterfeit. Feature vectors of overlapping blocks, which are divided form approximation, will be obtained by computing M2Mzs for each block. These vectors are lexicographical sorted to find the groups of similar vectors which are consecutive in the features vector matrix. The correlation coefficients of consecutive vectors are calculated to define the similar vectors. Similar vectors will be checked again by computing their Euclidean distances to make sure that they are not less than the size of processed block which can be comprised of many overlapping blocks. This constraint is due to the fact that blocks lie close each other may be similar. Candidate vectors will be limited again from similar ones by calculating the correlation coefficients with the predefined threshold to confirm the exact copied regions. By combining the ideas mentioned above, the detail steps of algorithm are described generally as follows.

1. Input the image I of size $M \times N$

2. Check the image. If I is color, convert to grayscale. Otherwise, move to next step.

3. Apply one-level DWT to I. Consider the scaling coefficients (LL1) from approximation subband $I_a$. The size of $I_a$ is $(M/2) \times (N/2)$.

4. Divide the $I_a$ into overlapping blocks by sliding a $b \times b$ block one pixel along from the upper left to bottom right. Then the number of overlapping blocks is equal to $(M - b + 1) \times (N - b + 1)$.
5. Compute the MZM on each block to create its feature vector. Totally, there are \((M - b + 1) \times (N - b + 1)\) feature vectors from considered blocks.

6. Arrange these feature vectors in a matrix A in which each row represents a feature vector.

7. Sort matrix A in lexicographically. Similar vectors will be arranged contiguously.

8. Compute the correlation coefficients between consecutive rows \(V_i\) and \(V_{i+1}\) in A by to find pairs of similar vectors which their correlation coefficients are greater than a threshold of 0.95.

9. Collect similar vectors from the previous step and save them in a matrix \(L\).

10. Calculate the Euclidean distances \(D_i\) between block \(B_i\) and block \(B_{i+1}\) corresponding to vectors at position \(i\) and \(i + 1\) in \(L\) and compare their distance to a distance threshold of 180. Blocks with \(D_i\) greater than or equal 180 are candidate blocks.

11. A collection of blocks satisfying step 10 are considered forgery. Mark the corresponding regions in the image as the copied parts.

4. Simulation Results

The proposed algorithm is run in Matlab2013 by PC with processor Intel(R) Core i5-2400 CPU@3.10 GHz, RAM 4.0GB. The tested images are color and firstly converted to grayscale before applying the algorithm. The size of overlapping blocks is 16x16. The threshold value of correlation coefficients to collect candidate groups from groups of similar vectors used in the algorithm are set to 0.95. The wavelet transform used in the algorithm is selected from the Wavelet families, such as Db1, Haar, Db2, in which "Haar" gives the best results. Some simulations of the algorithm are shown in Fig.7.

The dataset used in the simulation is called [16]. This is a ground truth database for benchmarking the detection of image forgery. With 48 base images, many copy-move images are produced by copying, scaling, rotating in base images or in separate snippets from them. Gaussian noise and JPEG compression artifact can also be added. The simulation results are compared to some remarkable methods such as HU, PCA, KPCA, traditional Zernike moment and UDWT. Although the computational time of the proposed method is higher at step of extracting MZMs due to more pixels, applying one level DWT reduces the size of image down to half also improves the processing time. The proposed method is more exact and less time. These results prove the feasibility and efficiency of the proposed algorithm (see Fig.7).

Evaluation

Precision \(p\) and recall \(r\) are parameters used to evaluate the efficiency of proposed algorithm and compare to other methods as well. The paper computes these parameters at pixel level and also find value \(F_1\) based on both precision and recall by (18), (19) and (20) as follows [16]

\[
\begin{align*}
\text{Precision} & \quad p = \frac{TP}{TP + FP} \\
\text{Recall} & \quad r = \frac{TP}{TP + FN} \\
F_1 & \quad F_1 = 2 \cdot \frac{pr}{p + r}
\end{align*}
\]

whereas \(TP\) is the number of true forged pixels, \(FP\) is the number of false forged pixels and \(FN\) is the number of miss forged pixels. Precision is the probability of the exact forgery detection while recall is the probability of forged image detection.

In addition, the time of detection \(t(s)\), which is defined from the beginning step to the detection step of algorithm, is also considered.

The comparison between the proposed method and methods above are shown in Table 1, Fig.8, Fig.9, Fig.10 and Fig.11. From the comparison of precision rate in Fig.8, the proposed method gives the higher accuracy in copy-move detection although their probabilities of
forged image detections and F1 are approximate (see Fig. 8, Fig. 9). With the processing time is listed in Fig. 11, the proposed method improves not only the exactness but also the computational cost. Fig. 12 shows some other results for forgery detection for both grayscale and color images and proves the efficiency of the proposed method.
TABLE 1: Results for copy-move detection at pixel level (%) for Fig.7.

<table>
<thead>
<tr>
<th>Methods</th>
<th>Fig.7(b)</th>
<th>Fig.7(d)</th>
<th>Fig.7(f)</th>
<th>Fig.7(h)</th>
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<td>p</td>
<td>r</td>
<td>F1</td>
<td>t(x10s)</td>
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5. Conclusion

The paper proposes an effective algorithm by using one level DWT and modified Zernike moments to detect the copied regions in images. The processing in the approximation subband from one-level decomposition DWT instead of in the original image reduces computation time. In addition, the applying MZMs shrinking the ROI to a new model so that the unit circle covers the image square improve the exactness in feature extraction. The algorithm is run and compared to the previous related ones not only the exactness but also the processing time. The size of processing block is limited in 16x16 and the algorithm has not yet applied in the image with both copy-move and splicing manipulation. Therefore, developing algorithms to detect the forged region less than 16x16 or considering the images which includes both copy-move and splicing are future works.

Acknowledgment

This research is funded by Vietnam National University Ho Chi Minh City (VNU-HCM) under grant number B2015-20-02.

References

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