Print-cam Resilient Watermarking based on Fourier Transform

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Abstract: Synchronization problems are still challenging issues in image watermarking field. In this paper, we present a robust image watermarking for projective deformations produced by print-cam system. The approach associates watermark insertion in invariant domain based on Fourier transform with correction pre-process for projective distortions, blur and color degradations. The robustness of the proposed method is tested and compared with different existing approaches. The comparison test is presented with simulated projective distortions and with real print-cam system using two different smartphones (iPhone6 and Samsung S5). The results show better performance of the proposed method in term of robustness, compared with other tested methods.

1 INTRODUCTION

Image watermarking is the process of embedding digital information called watermark into an image that can later be detected or extracted. With the rise of using smartphones, print-cam image watermarking comes as a convenient procedure to detect watermarks from printed and captured images. In general, image watermarking should satisfy three main requirements (Cox et al., 2008), imperceptibility or the invisibility of the watermark in the image, capacity or the quantity of the information that can be inserted and robustness that indicates how well the watermarking technique resists attacks. Here, attacks and distortions are any type of manipulations that make the detection process fails to find the watermark in the image. Although print-cam scheme has the advantage of place-free and time-free conditions, it suffers from many attacks compared with other existing schemes like print-scan watermarking system (Riad et al., 2015).

Print-cam system produces several attacks including; image blur from the used materials (printer and smartphone), color degradation, lighting variation including light reflection and geometric distortions from the freehandedly use of the smartphone (Pramila et al., 2007). Geometric distortions in this case are precisely called perspective or projective distortions that are combinations of rotation, translation, scaling and tilting of the optical axis (Hartley and Zisserman, 2003). Robustness against geometric distortions is crucial in every design of image watermarking method. “Invariant domains”, “template based methods” and “feature based methods” are the main strategies dealing with geometric problem in watermarking field. They have been widely used to face print-scan attacks but they afford only a partial response to the problematic of projective distortions that combines Rotation Scale Translation (RST) attacks and the tilting of the optical axis. Projective deformations are still a challenging problem.

In this paper we adapt print-cam image watermarking method to be robust against projective distortions, using Fourier transform as watermarking based domain, with a set of pre-process corrections including projective, blur and color corrections. The proposed method combines frequency domain with spatial frame based approach to provide better robustness against projective distortions. The proposed method is tested with simulated projective distortions for 500 ID images. In addition, it is tested with real print-cam system using two smartphones iPhone 6 and Samsung S5. The results are compared with existing watermarking method based on spatial, wavelet and Fourier-Mellin domains.

The paper is organized as follow: section 2 describes the print-cam attacks, section 3 reviews the state of the art regarding geometric solutions in

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watermarking field, section 4 is devoted to our proposal method. The experimental results are presented in section 5. Finally, section 6 is for the conclusion of the study.

2 PRINT-CAM ATTACKS

Print-cam image watermarking is a watermarking system where the watermarked image is printed out then captured with a mobile phone's camera to detect and/or extract the watermark. In this case image watermarking system has four main processes; process of inserting the mark into the image, this operation can be applied on different domains (spatial, Fourier, Wavelet) depends on the used method for the insertion. Then printing process where the watermarked image is transformed from the digital form to analog form using the printer as one of the system materials. Capturing process, where smartphone's camera is considered as another material of the system to transform the watermarked image from the analog to the digital form, where the user take a picture of the printed image freehandedly. Finally, detection process to search for the inserted watermark on the image to verify its authentication. This operation should be done on the same domain used on the embedding process.

Attacks or problems are every deformations and/or actions that occur to the watermarked image and harm the mark, in a way to make the detection/extraction operation fails to find the mark in the image. The following explains different attacks and problems in form of three main categories; problems related to the materials of the print-cam system, problems related to the user, and problems related to the environment.

2.1 Attacks Related to the Printer and Camera's Smartphone

The materials of the system are the printer and the camera, as we mention before the printer is used to convert the digital form of the image into analog form, and the camera is responsible to convert the image from analog to digital form. These transformations produce many changes on the original watermarked image.

For printers, in market, there are various types as Laser printer, Ink-jet printer, Dye-sub printer and others; each one has its complex operations, which introduce different kinds of attacks and distortions. Also the same printer may give different results at different times due to the printer properties or ink qualities (Pramila et al., 2007). However, the common attacks related to almost all the printers are noise and blurring of the pixels, which it can be visual by human eyes or not depending on the quality of the printer. In addition, Paper quality, the printing quality is related directly to the properties of the used printing paper. The same for cameras, as printers, there are many types but all work with one basic concept, which is mapping 3D world into a 2D image, coordinates. The camera system in general characterized by two types of parameters, and any change of them have a significant impact on the produced image. The parameters are extrinsic parameters and intrinsic parameters (Hartley and Zisserman, 2003), where the first ones are related to the position of the camera along with the object, and the second ones are internal and fixed to a particular camera/digitization setup, which allow a mapping between cameras coordinates and pixel coordinates in the image frame. Therefore, the problems related to this part of camera system are lens distortions, which is caused by the optical design of the lenses. In general there are three known types of optical distortion – barrel, pincushion and mustache/ moustache (also known as wavy and complex) (Wang et al., 2013). Likewise camera resolution is one of the camera quality that determines how many pixels camera can produce, The less megapixels the camera offers, the less information is being recorded in the image is. Usually the smartphone camera has low resolution than for example DSLR camera (Seo, 2016). Moreover in this category of print-cam attacks any problem concerns the mechanical part of the materials will damage the image and so the watermark.

2.2 Attacks Related to the User

In print-cam process, the user interferes only while taking a picture of the printed image. So the problems related to the external parameter of the camera are done mostly by the user, we can call those attacks as: Perspective distortions which is caused by the camera relative to the subject, it is a combination of four main geometric distortions; rotation, translation, scale, and tilt of the optical axis, therefore it is known as 3D geometric distortions. For Motion blur, mostly the shaking of the user's hand while taking the picture causes it. It is difficult to detect the watermark in this kind of images.

2.3 Attacks Related to the Environment

Other kind of attacks are related the environment or the place where the capturing process is done, like light or changes of luminance that can destroy the watermark. Also multiple light sources, direction of the light, shadows, flashlight, flatness and color of the light, all have an impact to detection failure of the watermark (Pramila et al., 2007). As well as Light reflection with the presence of glass kind material, between the printed image and the camera. Moreover, other Noises due to the air interface will degrade the quality of the image.

All the previous attacks can be classified under controlled and uncontrolled attacks. In such way that the controlled attacks, as attacks related to materials, can be predicted and fixed. However, uncontrolled attacks, like 3D geometric distortions and light, are hard to predict and fix. In the following, we focus on the 3D geometric distortions.

3 STATE OF THE ART

There are three main followed strategies to deal with geometric problem in watermarking filed:

Invariant domains; they are spaces with specific geometric invariance that can be used for watermark insertion. For example, the magnitude of Fourier transform is invariant to translation. In case of rotation, the Fourier magnitude is rotated with the same angle and for scaling it is scaled with the inverse scaling factor. (Poljicak et al., 2011) and (Riad, et al., 2016) proposed a Fourier based watermarking method using circular insertion in the frequency domain. The method is invariant to translation and rotation, however it is not invariant to scaling if the size of the original image in unknown. With (Xiao et al., 2012), RST invariant watermarking domain was proposed based on Fourier-Mellin transform. In practical, the proposed domain has approximate invariance to RST distortions. Moreover, other invariant watermarking method were proposed based on geometric moment invariants, such as; complex moments and Zernike moments (Zhu et al., 2010) and (Singh and Ranade, 2014). Nevertheless, they suffer from poor reconstruction quality.

Template based methods; templates with known structure helps to reflect the geometric distortion applied on the image. In (Kutter, 1999), watermarking method is proposed invariant to RST using template in Fourier domain. In this case, template embedding should be careful in form of embedding position and strength. In (Pramila and Keskinarkaus, 2008), a frame based watermarking method was proposed to correct the projective distortions before the detection phase using four corners detection of the frame on the ID image. In (Thongkor and Amornraksa, 2014), watermarking method for Thai ID cards is proposed, where the projective distortions are rectified using feature points from both the watermarked image and the original image. Yet, their method is a non-blind method. The robustness of template based watermarking methods against geometric attacks relies on the successful detection of the template.

Feature based methods; feature or interest points are used to create regions for watermark insertion and detection. This technique uses geometrical stable feature points to localize the watermark in the image. In (Bas et al., 2002), feature points are extracted using Harris detector to create triangular regions for watermark insertion. However, this approach is not invariant to the scaling. With (Ye et al., 2014), scale invariant feature transform (SIFT) is used to produce circular regions for watermark insertion. This type of watermarking method requires that the group of feature points used for insertion process should be found the same in the detection process, which is non-trivial especially in the case of capturing image with smartphones.

4 PROPOSED METHOD

The watermark is first embedded in the input image. After the print-cam process, three different correction steps process the captured image: a frame-based perspective correction, a Wiener filter to decrease image blurring and adjustment to eliminate color degradations. Finally, the decision is taken, during the detection process, whether the pre-processed image is watermarked or not according to a given threshold value.

4.1 Watermarking Technique

In this section, the proposed watermark insertion and detection techniques are detailed.

4.1.1 Watermark Insertion

Watermark embedding is performed in the DFT magnitude of the colored image luminance (chrominance components are not modified). A symmetric watermark is inserted along a circle of radius r in the DFT magnitude. The watermark W of

N elements is inserted in the mid coefficients as follows:

$$M_W = M_f + \alpha \times W, \quad (1)$$

where M_W the magnitude of the watermarked DFT coefficient is, M_f is the original one after filtering the embeddable coefficients using a Gaussian filter, and α is the strength parameter. The choice of α is related to the invisibility of the watermark. The adaptive strength α is determined to obtain the desired value of PSNR, in general equal to 40dB (Riad et al. 2016). The final watermarked image is reconstructed by applying the inverse DFT to obtain the luminance of the watermarked image from which color image is recovered using the unmodified chrominance components.

4.1.2 Watermark Detection

The blind decoder needs only the captured image and the watermark W. First, the DFT is applied to the luminance of the captured image. Then, the coefficients are extracted from the magnitude along the radius r. The maximum of the normalized cross-correlation C_{max} is computed between the extracted coefficients F and the sequence W of the watermark, as shown in equation (2):

$$C_{max} = \max_{0 \le j \le N-1} \frac{\sum_{i=0}^{N-1}(W(i) - \bar{W})(F(i+j) - \bar{F})}{\sqrt{\sum_{i=0}^{N-1}(W(i) - \bar{W})^2 \sum_{i=0}^{N-1}(F(i+j) - \bar{F})^2}}. \quad (2)$$

Where N is the sequence length, $\bar{W}$ and $\bar{F}$ are the means of the watermark and extracted Fourier coefficients respectively. The watermark is said to be present if the maximum value of the normalized cross-correlation exceeds a threshold t.

4.1.3 Threshold Estimation

To estimate the threshold, detection theory problems are often formulated as a classical hypothesis testing problem; with the null hypothesis ($H0$) for images without watermark, and the alternative hypothesis ($H1$) for images containing the watermark (Nguyen et al., 2009). The threshold decision or the criterion response must be taken based on observations of a set of watermarked and non-watermarked images. It is chosen according to some application-dependent criteria, either to minimize the false rejection (when the watermarked image detected as non-watermarked) and false alarm (when the non-watermarked image detected as watermarked) or to find a trade-off between them. For many applications, the threshold is defined by placing a constraint on the false alarm (also called Neyman-Pearson criterion) (Yan et al., 2001). The probability of false alarm is defined as:

$$P_{fa} = P(x > t \backslash H_0 = \int_t^{+\infty} pdf(H_0), \quad (3)$$

where P_{fa} is the probability false alarm. For Fourier watermarking domain, we used theoretical model for the calculation of pdf mentioned in (Riad et al., 2016). Depending on cross correlation coefficient C of a watermark with size L, and non-watermarked image, the pdf in this model can be modelled as:

$$P_{fa} = P(C > t \backslash H_0) = \frac{\int_0^{cos^{-1}(t)} sin^{L-2}(u)du}{2\int_0^{\pi/2} sin^{L-2}(u)\, du}. \quad (4)$$

For the testing part of this study, we fix the value of the false alarm, so that each tested domain will have its own specific threshold value for the sake of the objectivity of the experiment.

4.2 Correction Pre-process

4.2.1 Geometric Correction

The operation of transforming coordinate points from a 3D world to the 2D image plane is called projective transformation. The projective transformation of 2D ID cards coordinates into 2D image coordinates can be presented in the form of a matrix relation (equation (5)):

$$\begin{pmatrix} x \\ y \\ 1 \end{pmatrix} = H \begin{pmatrix} X \\ Y \\ 1 \end{pmatrix}, \quad (5)$$

where $(X, Y)^T$ are real coordinates, $(x, y)^T$ are image coordinates and H is the 3×3 Projective matrix (Hartley and Zisserman, 2003).

For the projective correction, we have to estimate the matrix H. It have 8 degree of freedom, hence, 4 known corresponding pair points are needed to solve the system equation (6):

$$\begin{cases} x = \dfrac{h_{11}X + h_{12}Y + h_{13}}{h_{31}X + h_{32}Y + 1}, \\ y = \dfrac{h_{21}X + h_{22}Y + h_{23}}{h_{31}X + h_{32}Y + 1}. \end{cases} \quad (6)$$

With frame synchronization method based on Hough transform in (Gourrame et al., 2016), the 4 corners of distorted image are detected and the image is geometrically corrected by applying the inverse of the estimated projective matrix as the following steps show:

Step 1: Detect the four corners: we use Hough line to detect the frame of ID image, and then we get the four points from the intersections of those lines.

Step 2: Estimate the projective matrix: with corresponding four points, we solve the system equation in (4).

Step 3: Apply the invert transformation in the whole image, to remap the rectified image.

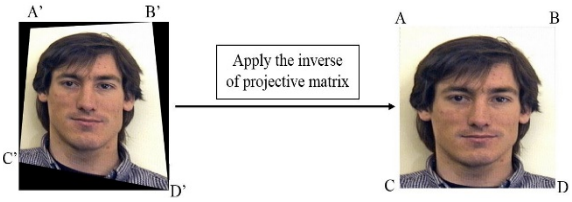


Figure 1: Projective correction process.

4.2.2 Blur Correction

Image blurring process is commonly modelled as the convolution of a clear image with a blur kernel (Point Spread Function PSF) plus noise. Non-blind image deblurring is dependent on prior knowledge of the system and of its parameters. Wiener filter minimizes the mean square error between the degraded and the estimated images, it is expressed in the frequency domain by the following equation:

$$\hat{I} = I \frac{H^*}{H * H^* + \frac{1}{SNR}}, \quad (7)$$

where H is the Fourier transform of the impulse response of the system. H^* Is the complex conjugate of H, I and $\hat{I}$ are the Fourier transforms of the degraded and estimated images, respectively. The SNR represents the signal to noise ratio. In this work, we used a Wiener filter (Riad et al., 2015) since the print-cam watermarking system is known. The PSF of the system and its noise variance must first be estimated [20]. Noise variance was estimated from four printed and captured images of uniform gray level, respectively 50, 100, 150, 200. Image variance was computed for each tested gray level. The mean of the image variance is the final noise variance.

4.2.3 Color Correction

Color distortion is a result of many factors occurring during the print-cam process. The correction is established first by estimating the color distortion function then applying the inverse of this function to the distorted image in a given color domain (RGB, HSV,…). Polynomial 4th order correction method is used by solving the following equation in the RGB domain:

$$\begin{cases} R' = a_0 + a_1 R + a_2 R^2 + a_3 R^3 + a_4 R^4, \\ G' = b_0 + b_1 G + b_2 G^2 + b_3 G^3 + b_4 G^4, \\ B' = c_0 + c_1 B + c_2 B^2 + c_3 B^3 + c_4 B^4. \end{cases} \quad (8)$$

The R, G and B denote the original Red, Green and Blue color pixel value and R', G' and B' denote the distorted output color pixel value. To estimate the function a color palette in (Riad et al., 2016) with specific color collections is used.

5 EXPERIMENTAL RESULTS

In this section, the Fourier watermarking method is compared to two other existing methods in print-cam state of art. The first is discrete Wavelet transform (DWT) based method inspired from (Pramila et al., 2008), and the second is spatial based method in (Thongkor and Amornraksa, 2014).

We present two tests: a first simulated test where we apply only simulated perspective deformations on ID images as mentioned in (Gourrame et al., 2016). Only the frame-based perspective correction is applied. In the second test, we apply real print-cam attacks on ID watermarked images printed on a paper and digitized using smartphones freehandedly (iPhone 6 and Samsung S5) (Gourrame et al., 2018). Perspective correction is associated to the blur and color corrections. Additional results are also shown.

5.1 Simulated Test

For the first test, we used 500 ID digital images from the PICS database (Hancock, 2008). Perspective attacks were simulated and the frame-based perspective correction was applied. All watermarking methods were implemented under the same protocols and conditions. The steps of the test are shown in the following figure:

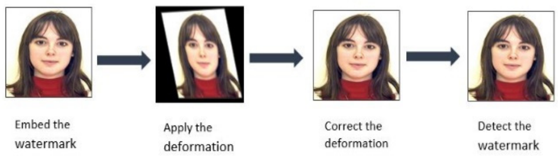
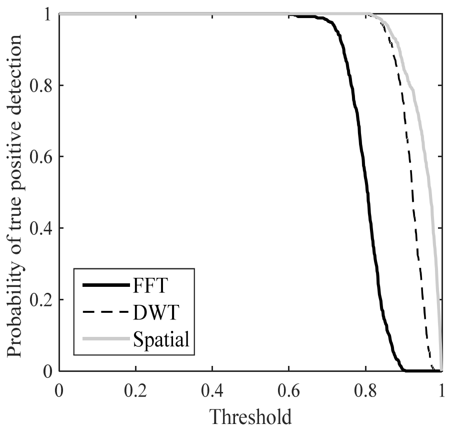
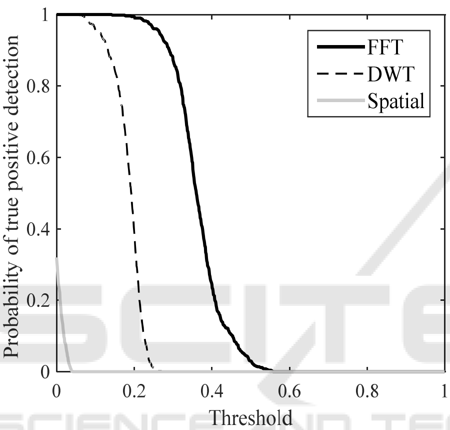


Figure 2: Simulated testing process.

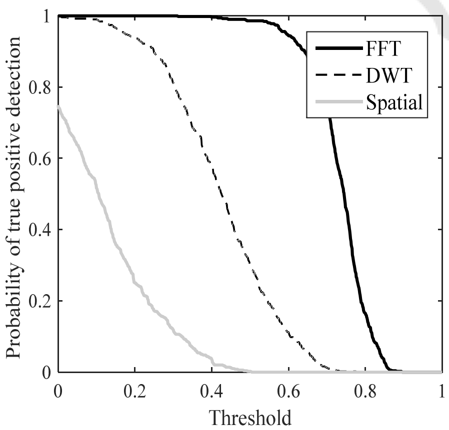
For perspective distortions, the simulation of 3D rotation of the image (3 rotations around the *x*, *y*, and *z*-axes) is used simultaneously with the simulation of camera position (viewpoint position) that defines the polar angles θ and φ (polar angle in the *x-y* plane, polar angle above or below the *x-y* plane). These angles are measured in degrees.



(a)



(b)



(c)

Figure 3: Probability of true positive detection as a function of the threshold values before (a), after (b) the perspective attacks and (c) after the perspective corrections.

The 500 ID images were deformed under random values of perspective attacks similar to those occurring when taking an image freehandedly with a smartphone. The rotation values around the x, y, and z axes were respectively taken from the intervals [-5°, 5°], [-5°, 5°], and [-10°, 10°]. View point values of θ and φ were respectively between [0°, 10°] and [60°, 90°]. We corrected the geometric deformation using frame-based perspective correction.

The probability of true positive detection as a function of the detection threshold is shown in Figure 3.

Results show that the DWT and spatial based methods are better than the Fourier one in the case where no perspective or projective attack occurs. The probability of true positive detection of the Fourier method outperforms the other tested methods in the case of perspective attacks. Finally, the quality of the detection after geometrical correction for Fourier is almost identical to the quality when no attack was present. This is not the case for the other methods. This can be explained as follows: The geometric correction is not perfect and some residual rotations and translation still survived. The Fourier method is naturally adapted to rotation and translation attacks and is less sensitive than DWT or spatial methods to these residual attacks.

To confirm these preliminary results, test in real situations will be conducted in the next section.

5.2 Real Test

The three methods were tested in real conditions. 480 ID images (240 are marked and 240 are not marked) were printed on a paper support with a Konica Minolta C284 printer (Dot-Matrix type) with a resolution of 300 dpi and size 43x43 mm^2 for the printed ID image.

Then captured freehandedly with iPhone 6 and Samsung S5 with a resolution of 8 megapixels and 16 megapixels respectively (remember that the acquisition is freehandedly). The camera of the two devices are set by default parameters: no filter, no flashlight during the capturing process. The pictures have been captured under daylight illumination (Gourrame et al., 2018). The steps of this test are shown in the following figure:

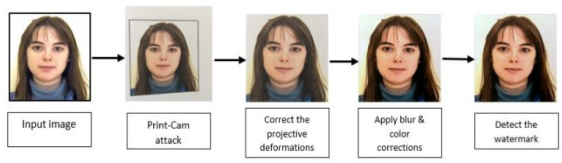


Figure 4: Process of the test.

In Figure 5, the proposed Fourier watermarking method, with the complete correction process, is compared with the other two tested methods in terms of ROC curves.

The performance of the watermarking method in the FFT domain is better than those watermarking methods in other domains. These results confirm the results obtained during the simulated test.

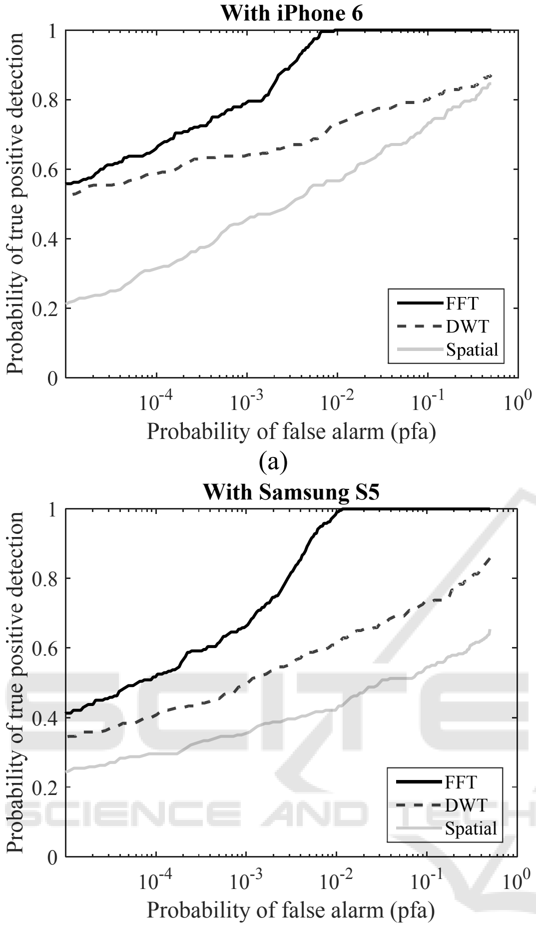


Figure 5: Comparison of ROC curves between the three methods with corrections for (a) iPhone 6 and (b) Samsung S5.

As a result, the following Figure 6 represents the total errors according to different pfa values of the three tested methods.

According to Figure.6, the minimum error rates are found for the Fourier method. It corresponds to a pfa value of 10^{-2}. The following table shows the minimal errors for the three methods and for the two smartphones.

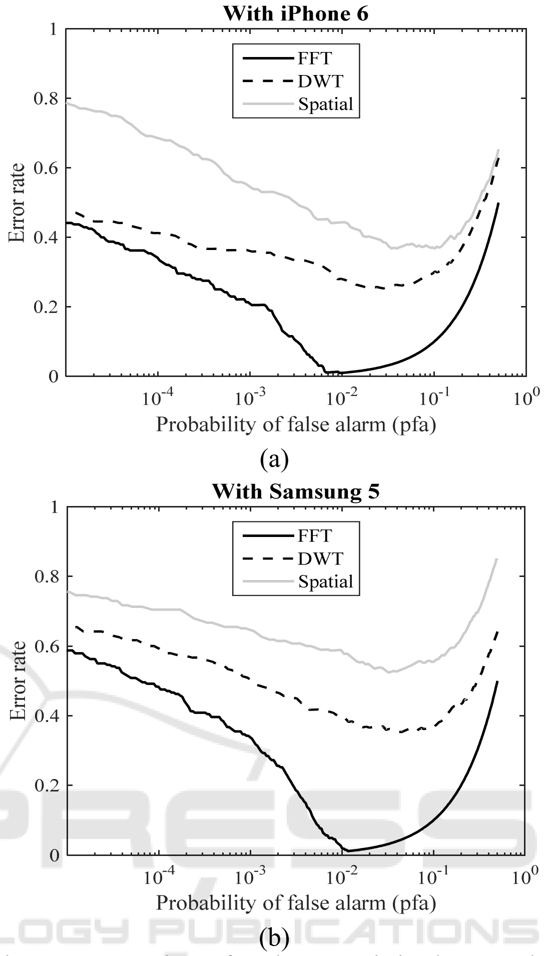


Figure 6. Comparison of total error variation between the three methods with (a) iPhone 6 and (b) Samsung S5.

Table 1. Minimal error rate for the three methods and the two smartphones

Methods	Minimal error rate	
	iPhone6	Samsung S5
FFT	1.02%	1.07%
DWT	25.52%	35.31%
Spatial	36.77%	52.35%

The results show the outstanding performances of the proposed method with a minimal error rate of 1.02% and 1.07% for respectively iPhone 6 and Samsung S5. These numbers are to be compared with the other results (25.52% in the best case). Lastly, few differences were found between the two smartphones (iPhone6 and Samsung S5), although the former led to fewer errors when considering the Fourier method.

6 CONCLUSIONS

This paper presents a resilient image-watermarking scheme based on Fourier transform for print-cam attacks that can be implemented on a smartphone. The method contains a pre-process stage to correct the projective deformations of images taken freehandedly as well as blur and color correction. The idea behind these corrections is to use prior knowledge of the devices involved in the process. The results show better performance of the proposed method, in term of detection rate, compared with other competitive methods. Which demonstrate the robustness against print-cam attacks.

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