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The Influence of Image Enhancement Filters on a Watermark Detection Rate

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Abstract:

In this paper is evaluated the effect of image enhancement filters on the watermark detection rate. State-of-the-art watermarking methods are still very sensitive to complex degradation attack such as print-scan process, so the detection rate of a watermark method decreases considerably after such an attack on a watermarked image. Therefore, to improve the detection rate, the degradation of the image is reduced by using image enhancement filters. A dataset of 1000 images was watermarked, printed and scanned for the experiment. Scanned images were enhanced by means of an unsharp filter and blind deconvolution filter. The watermark detection rate was measured and compared before and after the enhancement. The results show that the enhancement filtering improves the watermark detection rate by almost 10 %.

Keywords:

Image Watermarking, Unsharp Filter, Deconvolution, PS process, Watermark Detection Rate

1. Introduction

With today's availability of digital information, as well as powerful media devices, there is a ubiquitous copyright infringement of digital images, which brings extensive loses to their rightful owners. To mitigate this problem, numerous image watermarking methods have been developed. These methods are only partially successful, and the interest of the research community for the problem of digital image protection has never been greater.

There are many different ways to implement a watermark in an image. One of the most popular approaches is the implementation of watermark in the Fourier transform domain. This approach has two advantages in comparison to the spatial domain methods. First, it possesses strong robustness to geometric attacks, and second, it has a property to distribute the energy of the watermark over the entire image (Poljicak et al, 2011). This enables the implementation of stronger watermarks with less perceptual impact. On the other hand, according to Raja et al, fast Fourier transform (FFT) methods introduce round-off errors, which can result in the loss of quality and errors in watermark extraction (*Raja et al, 2011*). However, other authors state that this disadvantage is much more important for hidden communication than for watermarking (*Cheddad et al, 2010*).

Due to their resistance to geometric attacks and the distribution of energy, FFT watermarking methods are developed to create robust watermarking schemes resistant to the degradation attacks of the watermarked image in the transmission channel, such as the Print-scan process (PS process). The robustness of the watermarking method to PS process would enable the use of the method in the protection of printed images, thus enabling the use of digital watermarks in the protection of analog media. However, the PS process is very difficult to model. It engenders a number of linear (translation, rotation and scaling) and non-linear attacks (pixel distortions and noise addition). These attacks are not only user and equipment dependent, but also time-variant (*Solanki et al, 2004*). For this reason there are few watermarking methods robust to the PS process, all of which use the Fourier transform domain. Examples can be found in (*He & Sun, 2005*) and (*Kang et al, 2010*). There are also some multiple domain methods that use the advantages of different domains to create very robust watermarking scheme. A good example of a multiple domain method is presented in (*Pramila et al, 2008*).

The effectiveness of watermarking methods is usually given as a watermark detection rate in images once the images have gone through some kind of image processing – attack. Attacks on a watermarked image can be intentional or unintentional, but any kind of attack will most probably decrease the detection rate of the method. However, we believe that the watermark detection rate of a method can be increased by means of image processing techniques for image enhancement, such as unsharp mask filtering and blind deconvolution.

In this paper we investigate the influence of image enhancement on the detection rate of the DFT-based image watermarking method. A database of 1000 images was used for the test. The images were watermarked, printed and scanned. The detection rate is calculated after PS process and compared to the detection rate after processing by means of image enhancement techniques.

2. Watermarking method

A base for our research is the DFT-based watermarking method with optimal implementation radius. The details of the method, as well as the detection rate after different attacks, are already published in (*Poljicak et al, 2011*). This paper will thus provide only the outline of the method.

2.1 ENCODING

The watermark is embedded in a cover work in the magnitude coefficients of the Fourier domain. The block diagram of the encoder is shown in Figure 1. First, luminance values of the cover work are transformed in the Fourier domain. Then, by means of the secret key that represents the seed for the pseudo-random (PRND) number generator, the watermark is generated and implemented in the cover work, which can be expressed with this equation:

$$M_w(x,y) = M(x,y) + \alpha * W(x,y) \qquad (1)$$

where x and y are image coordinates, M is the magnitude of the cover image, W is the watermark matrix, α is the implementation coefficient, and Mw is the magnitude of the watermarked image.

Finally, the watermarked magnitude coefficients (*Fig. 2*) are combined with unaltered phase coefficients and transformed back to the spatial domain. The result is the watermarked image.

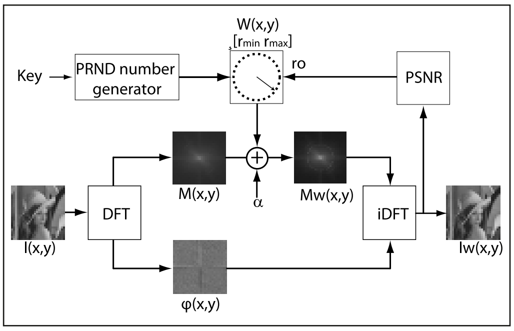

Figure 1. Block diagram of the encoder

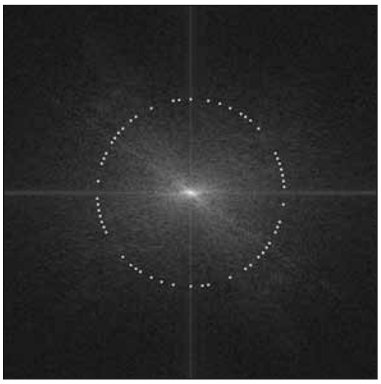

Figure 2. Embedded watermark in the spectra of the Fourier domain (intensities of the watermark coefficients are exaggerated to be visible on the print).

2.2 DECODING

A decoder makes a blind iterative search for the implemented watermark. The original image is thus not required for detection. The only requirement is the key used for the generation of the watermark. Block diagram of the decoder is shown in figure 3.

In order to test the existence of a watermark in an image, the image is resized to 512*512 pixels using bilinear interpolation. After scaling the image is transformed to the Fourier domain. The row-vectors are then extracted from the magnitude coefficients of the image from radii rmin to rmax. Each extracted vector is resized and normalized. After normalization, cross covariance is calculated between the extracted vector, and the row-vector generated with a pseudo-random generator using the original key as a seed. The cross-covariance of two vectors is actually a cross-correlation of the vectors with the removed mean value. The watermark detection is positive if the maximum value of cross-covariance exceeds a predefined detection value.

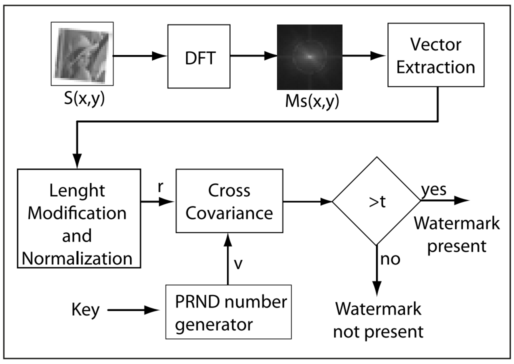

Figure 3. Block diagram of the decoder

3. Image enhancement techniques

In this paper we are considering a case in which the degradation of a watermarked image is introduced by the PS process. PS process is hard to model, and there are several different approaches to the problem. Lin and Chang have modeled the PS process with an Inkjet printer, as the geometric distortion coupled with change of pixel values due to non-linearity of the conventional PS system (*Lin & Chang, 1999*). Furthermore, the degradation of an image in the PS process for closely related colors can be modeled as additive Gaussian noise (*Poljicak et al, 2010*). Kang et al. state that the distortion of image DFT coefficients includes both non-linear distortion and additive random noise and geometric transformations such as rotation, translation, scaling and cropping (*Kang et al, 2003*). In all models above mentioned, the PS process, in its simplest form, can be considered as a low-pass filtering in which the high-frequency components of an image are attenuated. Therefore, in order to mitigate the degradation of a watermarked image in the PS process, debluring filters such are unsharp filter and blind deconvolution filter should be used.

3.1 UNSHARP FILTER

Unsharp filter is a linear or non-linear filter that augments high-frequency components. There are different approaches to implement unsharp filter, but the most common way is by means of a negative Laplacian to extract high-frequency components in an image, which are then superimposed on the original image. Unsharp filter is mathematically defined as:

$$g(x,y) = f(x,y) - \nabla^2 f(x,y) \quad (2)$$

Where g(x,y) denotes an enhanced image, f(x,y) an original image, and ∇^2 Laplacian operator defined as:

$$\nabla^2 f(x,y) = \frac{\partial^2 f(x,y)}{\partial x^2} + \frac{\partial^2 f(x,y)}{\partial y^2} \quad (3)$$

Where f(x,y) represents an original image.

3.2. BLIND DECONVOLUTION

Blind deconvolution is a deconvolution technique that is used for the enhancement of blurred image from a single or a set of "blurred" images when a point spread function (PSF) is poorly determined or unknown (*Lam & Goodman, 2000*). It is based on the assumption that, due to the imperfections of imaging (scanner, camera, microscope), the image is convolved with the PSF. PSF is the mathematical function that describes the path distortion of a theoretical point source of light through the imaging system. So as to estimate the image before degradation, degraded image should thus be convolved with the invers of the PSF. In practice, it is impossible tom find true PSF, so an approximate estimation is usually used. Most blind deconvolution algorithms are therefore iterative, whereby each iteration tries to come closer to the real PSF of the imaging system.

4. Experiment

The results were obtained by means of the evaluation of detection value (correlation) from dataset of 1000 images which came through the process of PS process. The values of watermarked images after printing and scanning are compared to the values of the same images after they had been enhanced with unsharp and deconvolution filters.

During the process of watermarking, the implementation factor for each image was chosen to produce a watermarked image with the PSNR value around 40 dB. The histogram of PSNRs obtained is shown in figure 4. This value was chosen to provide watermarked images that are perceptually indistinguishable from original images. An example of watermark embedding is shown in figure 5.

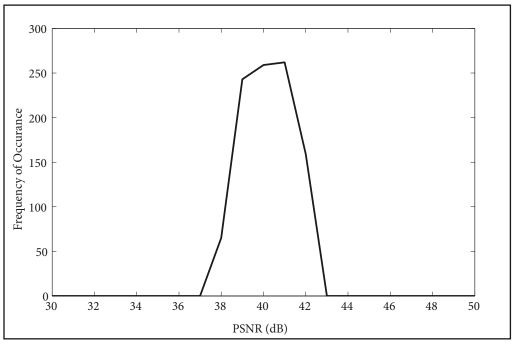

Figure 4. Histogram of the PSNR values of watermarked images

Figure 5. Example of watermark embedding; a) original image, and b) watermarked image (PSNR=41dB)

For the evaluation of the influence of enhancement techniques on the performance of a detector, detection rate, watermark detection probability and ROC curves were used. Detection rate was calculated upon images before and after enhancement filtering. For the detection of a watermark in an image, correlation of extracted vector with the generated vector has to exceed a value set as the threshold. The probability of the detection of a watermark in an image thus depends on the threshold value. For that reason, the function of the probability of the detection for different threshold values is also calculated.

In order to show the performance of the detector without the influence of the predefined threshold value, ROC curves were used. A ROC curve is a graphical plot of the probability of true detection versus the probability of false detection (Lin et al, 2001.)

Table 1. Detection rates of the images for threshold value of 0,30.

PS process	Unsharp filter	Deconvolution filter
81,5%	89,5 %	89.0 %

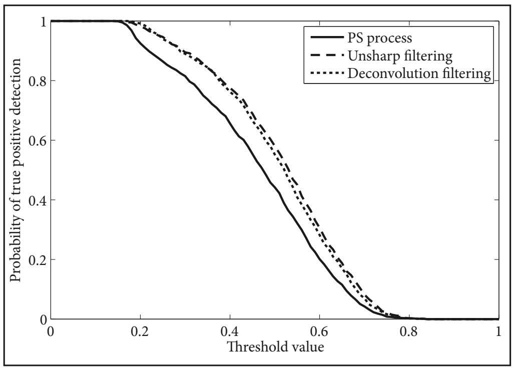

Figure 6. Probability of true positive detection before and after enhancement filtering

5. Results

The experiment showed that the use of enhancement techniques can improve the detection rate of a watermarking method considerably. Table 1 features detection rates before and after enhancement, when threshold value is set to 0,30. This threshold value is chosen because the lowest detection value for the dataset of unprocessed images (detection value immediately upon watermark embedding) was 0,30. The results from the table show that, the detection rate for images that had been degraded in PS process and then enhanced with unsharp filter increased by 10 percent, from 81,5 % before unsharp filtering to 89,5 % after filtering, when this particular watermarking method was used. Similar results were obtained for deconvolution filter with only slightly worse overall improvement of the detection rate than compared to the first case when unsharp filter was used.

Since the detection rate of a watermarking method depends on the threshold value chosen, it is better to show the influence of the enhancement filtering on the detection probability curve because it shows the probability of true positive detection for any given threshold value. Figure 6 clearly shows the improvement of detection probability when image enhancement techniques are used.

To avoid the influence of the threshold value altogether, the influence of the enhancement techniques on the performance of the detector is shown as a ROC curve on figure 7. ROC curve shows the influence of the probability of false positive detection on the probability of true positive detection. The probability of false positive detection is the probability that the detection value for unwatermarked image will be higher than threshold value chosen (*Poljicak et al., 2011*). Since the probability of false positive detection is hard to determine empirically (for higher detection values) on real watermarking systems, it should be modeled by means of a theoretical model such as the one proposed in (*Xang et al., 2003*) and (*Miller & Bloom, 2005*). In this paper the same model for the estimation of the probability of false positive detection was used.

Figure 7 shows considerable improvement of the detector performance when image enhancement techniques are used. When images are enhanced, the probability of the true positive is kept above 0.8 for much lower false positive probability (10^{-5}) than in the case without an enhancement (10^{-3}).

It should be noted that since unsharp filter is computationally much simpler than deconvolution filter, it is much faster during processing. On a dual core 2GHz processor unsharp filtering of an average image took about 0.75 seconds, while for the same image blind deconvolution with 10 iterations took about 5 seconds.

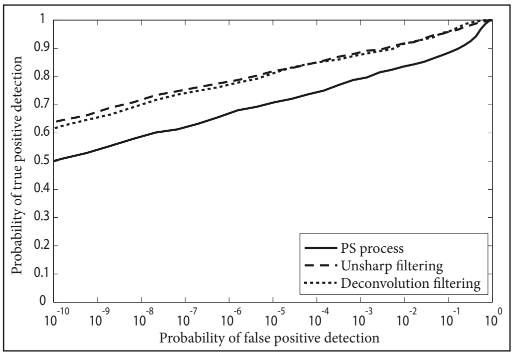

Figure 7. ROC curve

We compared our method with the methods proposed in (*Kang et al., 2003*) and (Solanki et al. 2004). The main benefits of the proposed method and the image enhancement techniques are low computational demands, the possibility to be used with different printing methods (ink-jet, laser, printing press, etc.) and high robustness to different attacks.

Simplicity is another advantage of our method. It takes only about 1 s for watermark extraction, whereas the method proposed in (*Kang et al. 2003*) takes 29 s for the extraction. Solanki et al. state that their method is only suitable for a laser printer reproduction, and our method works equally well with other kind of reproduction devices and techniques. Furthermore, our method requires a much lower scanning resolution for watermark extraction (150 dpi) than the method proposed by Solanki et al. (600 dpi).

6. Conclusion

We can conclude that the use of image enhancement techniques can considerably improve the detection rate of the image watermarking methods. It is clear that the image enhancement before detection not only improves overall detection rate, but also enables the use of higher threshold values, which in turn gives better detection performance with smaller probability of false positive detection. Furthermore, we conclude that unsharp filtering is more appropriate than blind deconvolution since it gives slightly better results with considerably faster computation. The type of enhancement filtering should be chosen according to the type of the attack on a watermarked image.

Future research will be focused on the determination of the most appropriate enhancement technique for different types of attack, such as JPEG compression, median filtering and print-cam process.

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