Spatial, Transform and Fractional Domain Digital Image Watermarking Techniques

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Abstract - In this paper, the various digital image watermarking techniques in spatial, transform as well as fractional domain are analyzed on the basis of Peak Signal to noise ratio, root mean square error, bit error rate, structural similarity measurement index and gain factor. After comparing the presented simulation results, authors found that the fractional discrete cosine transform based watermarking gave the better performance as numbers of key/transformation angles are available while varying the factional order from 0 to 1, hence preserve more security. Authors also observed that the comparison based watermarking technique gave better performance than the threshold based technique in spatial domain and the threshold based correlation in DCT mid band gave better results as compared to the comparison of mid band DCT coefficients in transform domain

Keywords Digital Image Watermarking, Discrete Cosine transforms, Spatial Domain, Transform Domain and Fractional Domain.

I. INTRODUCTION

The exponential increase in copyright protection of digital images on the internet is mainly due to the very quick developments in watermarking and the need of ownership proof. The utilization of internet became speedily popular because of its user friendly web browser and the public started to download images from the internet for their personal and commercial interest. The use of these digital images is very economical, eliminate warehousing and deliverance is almost instant. The main problem is to prove the original ownership and to ensure the reliability of received images. The reliability and legitimacy of digital images can be guaranteed by using digital image watermarking which is a technique to embed a watermark into an original image. The most common nomenclatures used for digital watermarking are embedding in spatial and frequency domains. As no transform is applied in spatial techniques, so these are less intricate and not robust against various attacks. Schyndle, R.G.V. et al. (1994) [1]. Hwang, M.S., et al. (1999) [2]. Techniques based on transforms are robust because of the fact that when image is inverse transformed, watermark is scattered erratically over the image, making the attacker more complex to understand or modify. The basic idea behind transform domain technique is to transform the image by the means of Fourier Transform (FT) Cox, I.J. et al. (1997) [3], Fractional Fourier Transform Djurovic, I. et al. (2001) [4]. Feng, Z. et al. (2005) [5], Yu, F.Q. et al. (2006) [6]. Then, the transform coefficients are changed to embed the watermark and finally inverse transform is used to obtain the watermarked digital image. The latest technique used for Watermarking is based on the Fractional Discrete Cosine Transform (FRDCT) in the fractional domain. This approach uses the amalgamation of space/spatial and frequency domains and offers many advantages over spatial and transform domain. Stankovi´c, S. S. et al. (May 2003) [7].

This paper provides performance analysis of various digital image watermarking techniques on the basis of PSNR, RMSE, BER, SSIM and gain factor, robustness coefficient. The organization of the paper is described as follows. The brief description of the Digital Watermarking System and their parameters are described in Sections 2. Spatial, Transform and Fractional domain Digital Image Watermarking Techniques are stated in Section 3. Simulation results and discussions are presented in Section 4 and finally, conclusions are extracted and presented in section 5.

II. WORK DIGITAL WATERMARKING SYSTEMS

The algorithm used for digital watermarking is not unique. There are number of different algorithms exists for watermarking. The depending on the algorithm is being used, the watermarking categorized into different category. However, for all watermarking techniques the embedding and recovery process is same. Fig. 1 illustrates the generic embedding process. Given an image I, a key K and a watermark W (usually the seed of a random number generator), the embedding process can be defined as a mapping of the form: $I \times K \times W \rightarrow \widetilde{I}$ and is common to all watermarking methods. The detection process is depicted in Fig. 2. Its output is either the recovered watermark W or some kind of confidence measure indicating how likely it is for a given mark at the input to be present in the image under inspection.

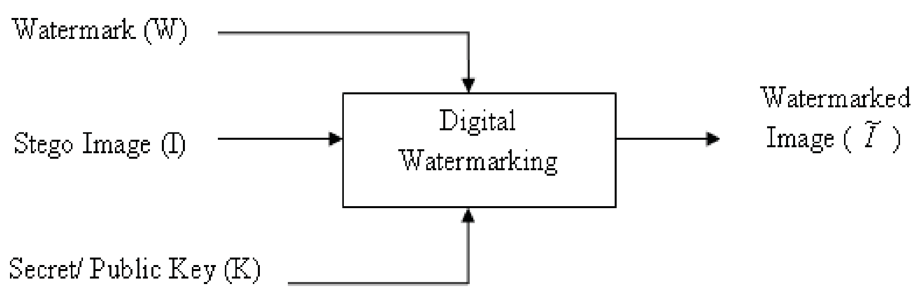


Fig. 1: Digital Watermarking Embedding Process

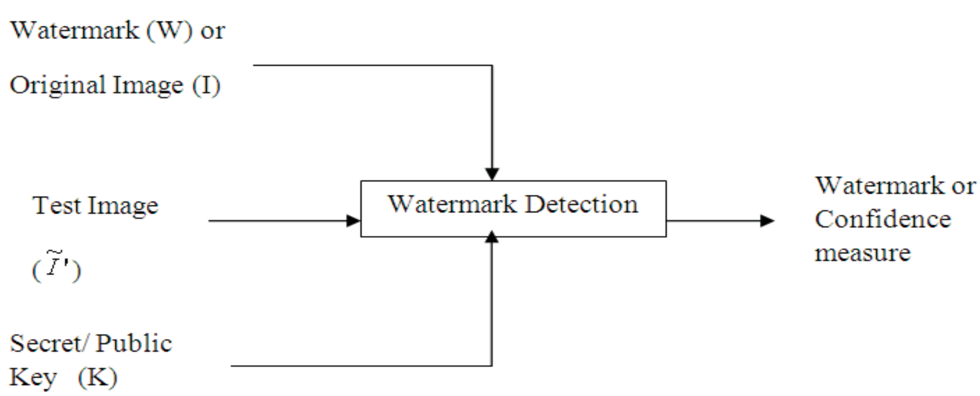


Fig. 2: Digital Watermark Recovery Process

III. DIGITAL WATERMARKING TECHNIQUES

The digital watermarking is technique of embedding the hidden information into original data. There may be different way of embedding the watermark into host data such as embedding in spatial domain, transform domain and other domain Sin-Joo Lee, Sung-Hwan Jung. (2001) [8]. The concept of digital watermarking consists of inserting information into the host signal under the condition that the modifications are not perceptible. In addition, it is desirable to put maximum energy into the watermark in order to achieve high robustness. This is a well-known concept from communication theory: to decrease the error rate, the signal energy must be maximized. In mathematical formulation, the watermark embedding process can be considered as a constrained maximization problem i.e. to maximize the watermark energy under the visibility constraint. Although the problem is straightforward to formulate, it is extremely difficult to implement because of the visibility constraint, which is usually based on a non-linear model of the human visual system. Digital watermarking is only possible because our vision system is not perfect. There are two main groups of watermark embedding technologies: coefficient-based and system-based. Coefficient-based approaches are the most obvious approaches since the embedding process is performed by a direct modification of pixel values or transform coefficient values.

3.1 Spatial Domain Watermarking

In the spatial domain watermarking, the watermark is embedded by directly modifying the pixel values of the original image. Three techniques under this category are implemented for the performance analysis: Techniques Based On Correlation Langelaar G., et al. (September 2000) [9]. Threshold based and Comparison based correlation Langelaar G., et al. (September 2000) [9]. CDMA Spread Spectrum Watermarking Langelaar G., et al. (September 2000) [9].

3.2 Transform Domain Techniques

In transform domain watermarking the object is first transformed in frequency domain and then the watermark is added into the frequency domain. Three techniques under this category are implemented for the performance: Comparison based correlation Hernández J. R. and Pérez-González F. (Jul.1999) [10]. Kutter M., et al. (Jan. 2000) [11]. Stankovi´c S. S., et al. (May2003) [7], Hernandez J.R., et al. (Jan. 2000) [12]. Comparison-based correlation in DCT mid-band Langelaar G., et al. (September 2000) [9]. Threshold-based correlation in DCT mid-band Langelaar G., et al. (September 2000) [9].

3.3 Fractional Domain Watermarking

The latest technique in Watermarking is based on fractional domain. This approach uses combination of the space/spatial and frequency domains, without introducing the multidimensional Radon-Wigner distribution Stankovi´c S. S., et al. (May2003) [7]. This technique offers many advantages over spatial and transform domain. Watermarking in fractional domain can be obtained by either using Fractional Fourier Transform or Fractional Discrete Cosine Transform (FRDCT). In this paper, the watermarking in fractional domain is implemented by using FRDCT. Since the FRDCT has the same property as DCT and DCT has many advantages over FFT. So obviously the FRDCT will give better result as compared to Fractional Fourier Transform (FRFT).

3.3.1 Fractional Discrete Cosine Transform (FRDCT)

Fractional Discrete Cosine Transform is a generalized form of Discrete Cosine Transform and it provides a tool to compute the mix time and frequency components of a signal. FRDCT share many useful properties of the regular DCT and it has a free parameter, its fraction. When the fraction is zero, we get the cosine modulated version of the input signal. When it is unity, the conventional DCT is obtained. As the fraction changes from 0 to 1 one gets the different forms of the signal which interpolate between the cosine modulated form of the signal and its DCT representation.

The performance of proposed watermarking technique is evaluated both quantitatively as well as qualitatively on various images. Quantitative evaluation is performed by using PSNR by considering the human visual system & Correlation Coefficient. The PSNR is used to investigate the amount of error which was introduced while embedding the watermark. The Correlation coefficient is used to determine the closeness of extracted watermark to the original watermark. Original & watermarked images are presented for qualitative analysis in Figure 3.The robustness of the techniques is also tested by using well known attacks i.e. contamination of additive white Gaussian noise, Salt & Pepper noise & DCT Compression. The results are also taken by increasing the value of attacks shown in Figure 4, 5, 6 and table 1 and observe that the watermark can also be recovered at high value of attacks. Visual & high value of quantitative results shows that a less error was introduced in embedding algorithm and also a good quality watermark was extracted by using the proposed watermarking method shown in Figure 3. Table 1shows the correlation coefficient between the original and extracted watermark after increasing the attack values. It is clear from the results presented in table 2 that the proposed watermarking method improves the PSNR in comparison to other existing method.

IV. SIMULATION RESULTS AND DISCUSSIONS

We have analyzed the various Digital Image Watermarking techniques in terms of PSNR, RMSE, BER, Gain factor and watermark size. The algorithms are tested on the reference image (Barbara image of 512×512 pixels) for a gain factor (G) and fractional order (a) in spatial, frequency and fractional domain respectively. Two different watermarks shown in figures 5(a) of size 12×9 pixels and 5(b) of size 50×20 pixels are used for embedding in the original image. The graphs for Gain factor (G) vs. different parameters are presented for each watermarked image with small and normal size watermark is shown in figures 6(a)-6(f). The presented graph shows that robustness can be increased by increasing the gain factor, which reduces the PSNR in dB and hence the quality of image reduces. PSNR does not take aspects of the Human Visual System (HVS) into effect so images with higher PSNR's may not necessarily look better then those with a low PSNR. The optimal robustness as well as the image quality can be maintained by choosing the gain factor (G) equals to 5. It is also observed that when the size of watermark is decreased, the PSNR increases and RMSE decreases. However, bit error rate also decreases. In fractional domain, fractional order a=0.91 and 0.92 can be judged as the optimum order for watermarking. By calculating the SSIM, one can easily find the various keys for watermarking in fractional domain shown in Table 1. The recovered watermark for other techniques and corresponding SSIM are also presented.

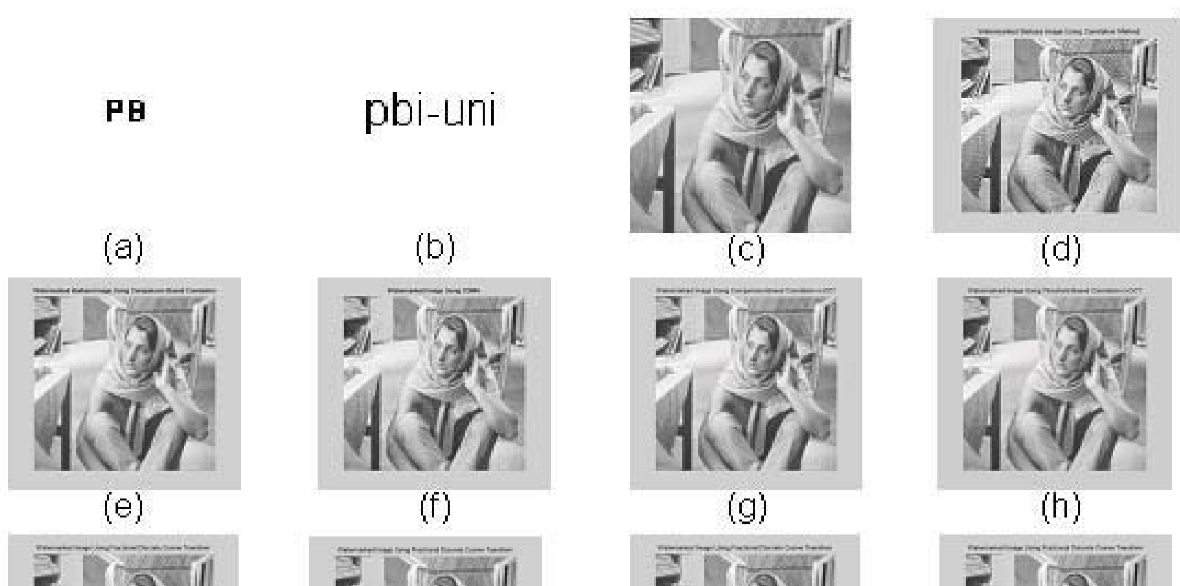
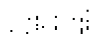


Fig. 5: Shows original watermarks, original Image and watermarked images (a) Small Watermark of size 12×9 (b) Normal Watermark of size 50×20 (c) Original Barbara Image (d) Watermarked Image using Threshold based Correlation (e) Watermarked Image using Comparison based Correlation (f) Watermarked Image using CDMA Spread Spectrum with (g) Watermarked Image using Comparison-based Correlation in DCT mid-band (h) Watermarked Image using Threshold-based Correlation in DCT mid-band (i) Watermarked image using FRDCT (a=0.4) (j) Watermarked image using FRDCT (a=0.9) (k) Watermarked image using FRDCT (a=0.91) (l) Watermarked image using FRDCT (a=0.92)

Table1. Structural Similarity Index Measurement and Recovered Watermark of various Watermarking techniques

Recovered Watermark	**SSIM Value**	**Technique**
Recovered Message pbi-uni	0.7075	Comparison Based Correlation
Recovered Watermark pbi-uni	0.7825	Threshold Based Correlation in Spatial Domain
Recovered Watermark pbi-uni	1	CDMA Spread Spectrum Water-marking
Recovered Watermark pbi-uni	1	Comparison-based correlation
Recovered Watermark pbi-uni	0.8428	Comparison-Based Correlation in DCT mid-band
Recovered Watermark pbi-uni	0.8342	Threshold-Based Correlation in DCT mid-band
Recovered Message pbi-uni	0.7038	FRDCT based watermarking (a=0.4)
Recovered Message pbi-uni	0.9519	FRDCT based watermarking (a=0.9)
Recovered Watermark pbi-uni	1	FRDCT based watermarking (a=0.91)
Recovered Message pbi-uni	0.9696	FRDCT based watermarking (a=0.92)

Recovered Message 	0.3165	FRDCT based watermarking (a=0.98)

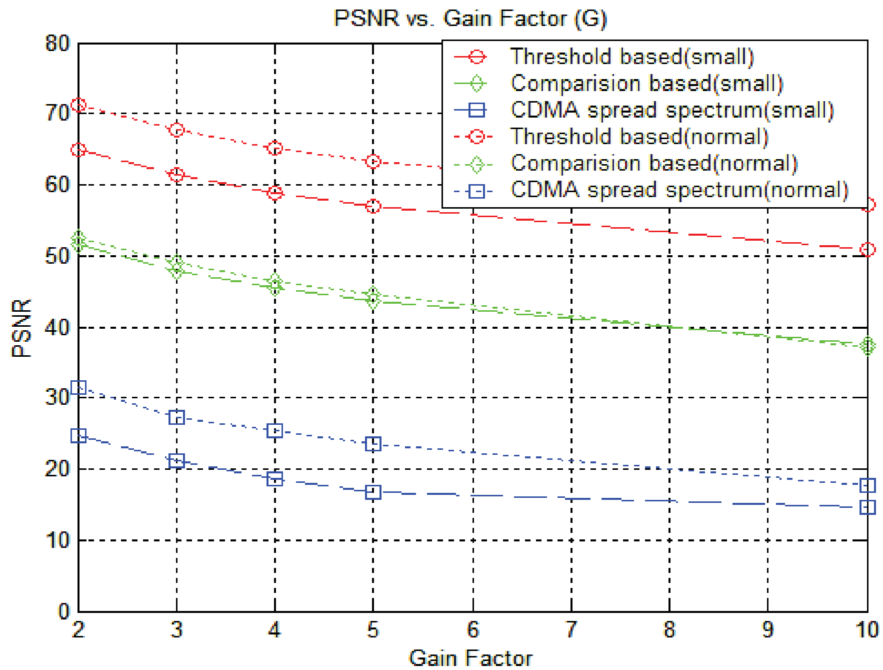


Fig. 6(a): Simulation result of Barbara image in terms of different PSNR vs. Gain factor (G) using different size watermark

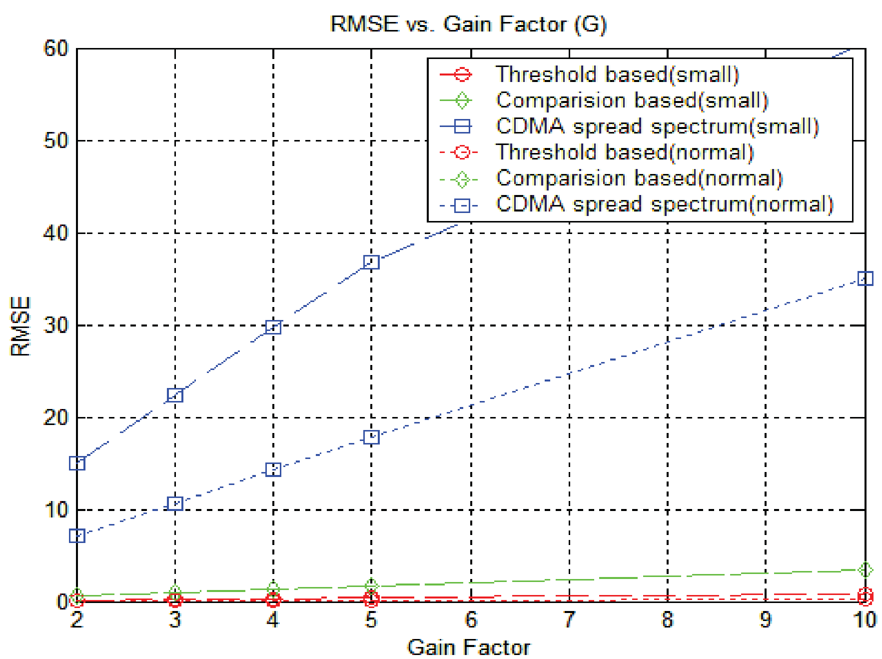


Fig. 6(b): Simulation result of Barbara image in terms of different RMSE vs. Gain factor (G) using different size watermark

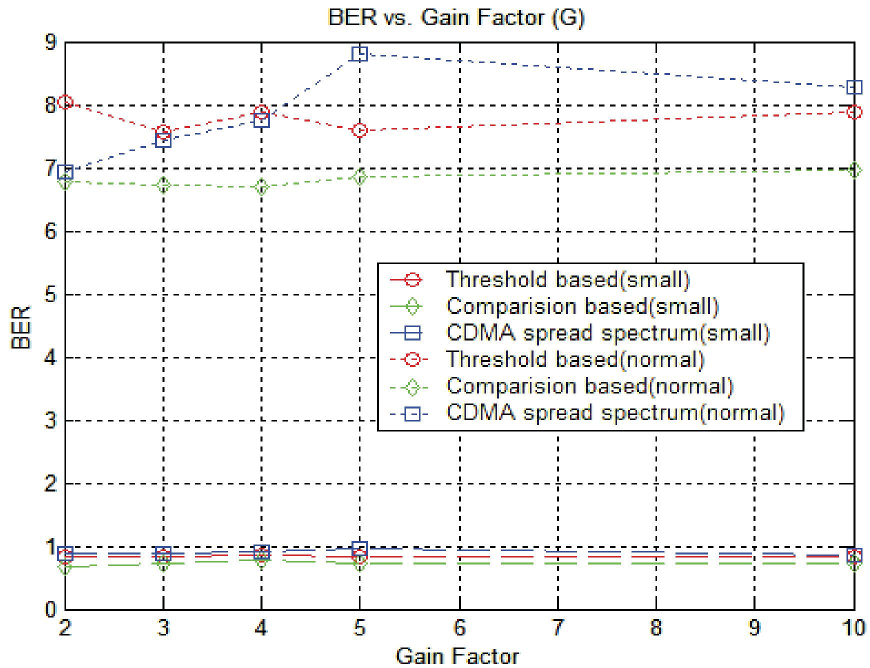


Fig. 6(c): Simulation result of Barbara image in terms of different BER vs. Gain factor (G) for different size watermark

V. CONCLUSION

In this paper, we have discussed the basic concepts in Digital Image Watermarking including the analysis of various techniques in terms of PSNR, RMSE, BER, SSIM, Gain factor and watermark size. The size of watermark also affects the PSNR, MSE and BER. By reducing the size of watermark, the PSNR increases while MSE and BER decreases. The authors found that comparison based watermarking technique with gain of 5 performed marginally better than even the threshold based with gain of 35 in spatial domain. The threshold based correlation technique in the DCT mid band gave better results for smaller gain factor as compared to the comparison of mid band DCT coefficients in transform domain. Finally, the FRDCT based watermarking is found as the better technique because of the highest PSNR, lowest BER and number of keys are available for embedding like at a=0.91 and 0.92.

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