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Image Quality Assessment of Fast Fourier Transform Domain Watermarked Images

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***Abstract*—Digital watermarking is the processing of embedding digital signature into the host media such as image, video, text, audio etc. During the watermarking process, images are subjected to variety of attacks such as noise in transmission channel, geometric attacks, compression, processing like filtering, etc, all this affect the visual quality of watermarked image. Thus, there is a need for image quality assessment of watermarked images in relation to the original images. Several measures of image metrics are available in the field of image processing however they are application based. This paper discusses watermarking in FFT domain and some of the image quality metric that can be applied. Experiments are conducted using the Full Reference (FR) images. We used Mean Square Error (MSE), Root Mean Square (RMS), Structural Similarity (SSIM), Image Fidelity Measure (IFM), Correlation Coefficient Index (CCI) and Peak Signal to Noise Ratio (PSNR) as our quality assessment. Result shows that CCI, SSIM, and IFM are most appropriate for measuring quality of watermarking system.**

***Index Terms*—Fast Fourier Transform, Image Watermarking, Image Quality Metric.**

I. Introduction

Digital watermarking is an approach that involves embedding of digital mark into a multimedia object (cover work: image, audio, video text) such that it is robust, secure and imperceptible to the human observer, but can be detected algorithmically. Due to digital watermark's crucial features such as; imperceptibility, inseparability of the content from the watermark, and it's intrinsic ability to undergo same transformation as experienced by the cover work, this has made it superior and preferable over other traditional methods of protecting data integrity, authentication of information resources and ownership assertion. This preference has been proven experimentally [1] to provide improved security. Image quality assessment plays an important role in digital watermarking such as assessing the imperceptibility of the watermarked image. The traditional image quality has been evaluated by human subjects' method. Though this method is reliable, however it is expensive and time consuming [2]. A great deal of effort has been made in recent years to develop objective image quality metrics that correlate with perceived quality measurement. In this paper, one of the crucial requirement of digital watermark, which is imperceptibility of watermarking system, has been assessed and analyzed using objective quality measure.

II. Watermarking in Fourier Transform

Discrete Fourier Transform DFT-domain watermarking serves as the pioneering research in transform domain watermarking. In DFT domain, watermark can be embedded in the phase or magnitude of DFT. Authors in [3]-[5] embedded the watermark in the phase coefficient. This is because the Fourier transform phase captures the most intelligible part of the original signal. Embedding watermark in the most important components of image improves the robustness since tempering with this important component in attempt to remove the watermark will severely degrade the quality of image. On the other hand, many watermarking schemes [6]-[9] embedded watermark into the magnitude of Fourier coefficient of the original image. This amplitude modulation is used because of its shift invariant properties and the cyclic translation of the image in spatial domain does not affect the DFT amplitude. More so, Fourier transform magnitude can uniquely specify almost all typical images. Fast Fourier Transform (FFT) is the fast way of implementing DFT. In this paper, FFT and DFT are used interchangeable.

III. Quality Metrics Assessment of Imperceptibility of Watermark

The watermark imperceptibility greatly depends on the size of watermark which also influences the visual degradation of the watermarked image. For fair evaluation, some objective image fidelity measure was use as evaluation criteria. Image fidelity refers to the ability of a process to render an image accurately, without any visible distortion or information loss. For example, if we cannot detect the difference between an original and a watermarked image, we conclude that the watermarking process was visually imperceptible. It is possible to develop computational measures of image fidelity based on human vision models because these types of judgments depend upon our ability to detect differences between images [10].

A. Pixel based approach

In table 1, It shows some distortion measure, where $U(m,n)$ represents the pixel of host image, whose coordinates are (m,n), and $V(m,n)$ represents the pixel of watermarked image, with coordinates (m,n). The most common Image Quality Assessment are the Mean Squared Error (MSE), root MSE (RMSE) and Peak Signal to Noise Ratio (PSNR). These measures are based on difference (pixel error) between the original image, Full Reference (FR) and the distorted, watermarked image. These metrics are very popular due their simplicity. However, it is well known that these difference distortion metrics are not correlated with human vision [11]. This might be a problem in applying such metrics in digital watermarking since sophisticated watermarking methods exploit Human Visual System (HVS), one way or the other. Using the above metrics to quantify the distortion caused by a watermarking process might therefore result in misleading quantitative distortion measurements, such as shown in Fig. 1. Furthermore, these metrics are usually applied to the luminance and chrominance channels of images. If the watermarking methods work in the same color-space, for example luminance modification, this does not pose problem. However, if the methods use different color spaces, these metrics are not suitable. The limitation of simple pixel error based metrics is also experienced in applications of medical images, as reported in [12] in a private communication with [13], where the compressed diagnostic breast images with lower PSNR values are preferred by doctors over those with higher PSNR values. That is, the images favoured by PSNR do not agree with the judgment of human eyes.

B. Perceptual Quality Metrics

Due to weaknesses of the pixel-based distortion metrics, more and more research now concentrates on distortion metrics adapted to the HVS, by taking various effect into consideration [14],[15]. The perceptual quality measure exploits the contrast sensitivity and masking phenomena of the HVS such as , Masked Peak Signal to Noise Ratio (MPSNR) in [11], weighted Mean Square Error (wMSE) by [16] metric that takes into account properties in the neighborhood of each pixel. Also a Structural Similarity Index (SSIM) is proposed in [17], for measuring the similarity between two images.

C. Correlation Based

Correlation (often measured as a correlation coefficient) indicates the strength and direction of a linear relationship between two random variables. The correlation between two images (cross correlation) is a standard approach to feature detection. It can be used as a measure for calculating the degree of similarity between two images [18]. Its mathematical definition is defined in Table 1.

Table 1. Objective Image Quality Assessment Definition table

Accr.	Meaning	Equation	Measure		Explanation
			Min. value	Max. Value	
ADI	Average difference indicator	$\frac{1}{MN}\sum_{m=1}^{M}\sum_{n=1}^{N}(U(m,n)-V(m,n))$	0	1	Lower value signify closeness
MSE	Mean square error	$\frac{1}{MN}\sum_{m=1}^{M}\sum_{n=1}^{N}\lvert U(m,n)-V(m,n)\rvert^2$	0	1	Lower value signify closeness
RMSE	Root Mean Square	$\sqrt{MSE}$	0	1	Lower value signify closeness
IFM	Image fidelity measures	$1-\frac{\sum_{m=1}^{M}\sum_{n=1}^{N}\lvert U(m,n)-V(m,n)\rvert^2}{\sum_{m=1}^{M}\sum_{n=1}^{N}(U(m,n))^2}$	0	1	higher value signify closeness
PSNR	Peak signal to noise ratio	$20log_{10}\frac{Max(V(m,n))}{RMSE}$	0	∞	Higher value of PSNR indicates that the two images are similar
SSIM	Structural similarity	$\frac{4\rho_{u,v}\bar{U}\bar{V}}{(\rho_u^2)+\rho_v^2)[\bar{U}^2+\bar{V}^2]}$	0	1	1 shows that the images are similar to each other
CCI	Correlation Coefficient Index	$\frac{\sum_{m=1}^{M}\sum_{n=1}^{N}[U(m,n)-\bar{U}][(V(m,n)-\bar{V}]}{\sqrt{\sum_{m=1}^{M}\sum_{n=1}^{N}[U(m,n)-\bar{U}]^2\sum_{m=1}^{M}\sum_{n=1}^{N}[V(m,n)-\bar{V}]^2}}$	-1	+1	1 indicate that the two images are highly similar while -1 indicate that the two images are exactly opposite

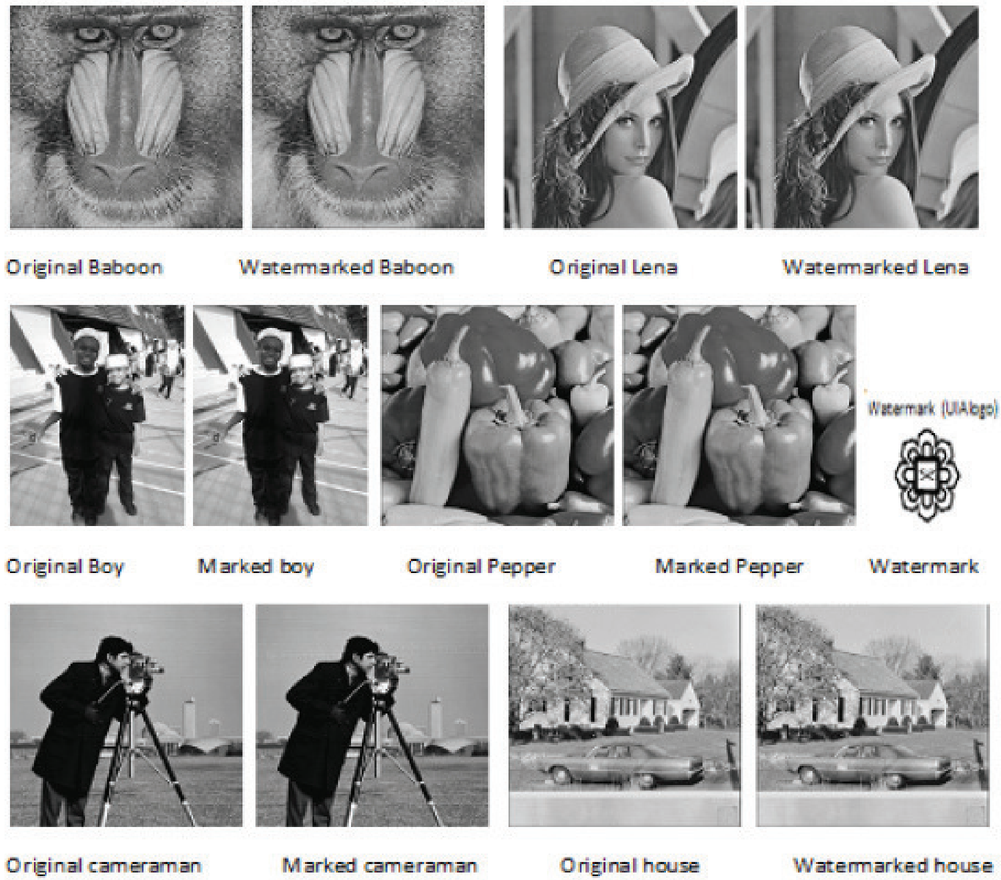

Figure 1. Host Images, watermarked version and the watermark (UIA logo)

IV. Methodology and Evaluation Criteria

A. The watermark Embedding Procedure

Let $f(x_1,x_2)$ of size MxN grayscale be the host image. For $x_1 = 0$, 1... $M-1$ and $x_2 = 0, 1 \ldots N-1$, It DFT is given by:

$$I(k_1,k_2) = \sum_{x1=0}^{M-1} \sum_{x2=0}^{N-1} f(x_1 x_2) e^{-j2\pi(\frac{k_1 x_1}{M} + \frac{k_2 x_2}{N})}$$

Let $Mag(k_1,k_2)$ = | $I(k_1,k_2)$ | is the magnitude, $P(k_1,k_2)$ be the phase of $I(k_1,k_2)$ and $W(k_1,k_2)$ be the watermark. We embedded in the Fourier magnitude by modifying it.

$$Mag'(k_1,k_2) = Mag(k_1,k_2) + f(Mag(k_1,k_2), W(k_1,k_2), \beta)$$

The watermarked image $f'(x_1,x_2)$ is the inverse Fourier transform of $Mag(k_1,k_2)$ and $P(k_1,k_2)$ in our case, FFT is used. Therefore,

$$f'(k_1,k_2) = IFFT(I'), I'(Mag', F)$$

Host images and it watermarked version is shown in Figure 1. In this study, digital watermarks were embedded in the mid-frequency of Fourier magnitude of the image. Different images have different capacity, so the amount of information that can be embedded invisibly is different.

B. Evaluation Criteria

One of the requirement of watermarking is imperceptibility. It should be noted that the main goal of watermarking is to embed securely in a completely undetectable region. That is, a third party who is not the intended recipient should not be able to distinguish in any sense between cover-objects and the watermarked image. The imperceptibility of watermark is one of the most important measures that evaluate the performance of the watermarking algorithm. The criteria used in the objective image quality measure is Full Reference (FR) quality assessment with respect to imperceptibility of the watermark. That is, the availably of the original image which is considered to be distortion free or perfect quality. For a fair evaluation of the metrics, one should use a wide range of picture sizes, from few hundred to several thousand pixels, and different kind of images.

That is why in this paper, images of different size and types under same and different conditions are employed.

V. Result and Discussion

The output obtained for pixel based image quality assessment, MSE, RMSE, and ADI, Perceptual based such as CCI, IFM and SSIM and for PSNR in measuring imperceptibility of the watermarked image is shown in Table 2. It shows the measure of imperceptibility obtained between a watermarked image and the host image for 5 different images namely baboon, Lena, boy, pepper, cameraman and house as shown in Fig. 1. Images of sizes 512x512, 480x640 and 256x256 were used as Full Reference (FR) images. The visibility of a watermark is affected by image texture, edges and luminance. The watermarks are less visible if it is in an area that has high spatial frequency meaning a lot of texture as shown in baboon and pepper. If the area is flat digital watermarks are more easily noticed. For MSE and RMSE, it only measures gray-level difference between pixels of the host and the watermarked images without considering correlation between the neighboring pixels. That is why the watermarked images with MSE and RMSE have significantly different visual quality compare to the value obtained. The result has also proven that, for all the images irrespective of the sizes, the performance of pixel based metric are not suit- able for measuring imperceptibility of watermark especially MSE and RMSE because the results diverge visually compare to the images in Figure 1. The result obtained was due to the facts that MSE and RMSE works satisfactorily when the distortion is mainly caused by contamination of additive noise. However does not take into account the viewing conditions and visual sensitivity with respect to image contents. Only gray-value differences between corresponding pixels of the original and the watermarked version are considered. Pixels are treated as being independent of their neighbours. Moreover, all pixels in an image are assumed to be equally important. This is of course, far from being true. In fact, pixels at different positions in an image can have very different effects on the human visual system (HVS). Results of SSIM, CCI and IFM for all images is between 0.9906 and 0.9999 as shown in Table 2, which indicates that the watermarked images are very similar to the host image by it definition in Table 1. The visual subjective measure also buttresses this point.

VI. Conclusion

In summary, this paper has examined some common Image Quality Assessment metrics for watermarked images. In the analysis, results showed that CCI, SSIM and IFM are powerful tools that show superior performance over others for assessing watermark imperceptibility. These tools can be use for various images of different sizes and texture. In all the experiment performed, CCI has the highest imperceptible value. MSE and RMSE failed to provide correct results in evaluating quality of watermarked images. The result showed these assessments were in apparent contradiction with subjective judgments, and this is corrected by using other powerful tools like the Correlation and perceptual based metric. This suggested that caution should be taken when using metrics such as MSE and RMSE have obvious value in comparing pixel to pixel algorithms, but do not always have the same interpretation value when dealing with the visual quality of an image. Visual image evaluation, such as the SSIM index, IMF and CCI provides alternatives that have application to watermark images, which will allow proper evaluation of imperceptibility.

Table 2: Test images showing their sizes and performance results of metrics used.

Size of image	Time in sec.	Performance Metrics							
		Test Image	MSE	RMSE	ADI	PSNR in dB	IFM	CCI	SSIM
512x512	3.1824	Baboon	0.3377	0.5811	0.2371	46.4038	0.9927	0.9993	0.9943
512x512	3.0420	Lena	0.2749	0.5243	0.0632	46.1042	0.9989	0.9997	0.9906
480x640	2.9796	boy	0.2227	0.4719	0.0543	47.3467	0.9991	0.9999	0.9933
512x512	3.1356	Pepper	0.8189	0.9049	0.1377	44.9200	0.9967	0.9997	0.9887
256x256	1.4508	Cameraman	0.3935	0.6273	0.0644	43.0337	0.9983	0.9999	0.9928
512x512	3.0264	House	0.7298	0.8543	0.1133	43.0252	0.9971	0.9994	0.9903

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