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A Novel Approach to Blind Perceptual DFT Watermarking with Compressive Sensing Technique

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***Abstract*—Digital watermarking technique is becoming more important in the developing area of internet. Watermarking is used as the key solution for secure data transfer from different hackings. In this paper a novel watermarking approach based on the compressive sensing method is explained. Watermarking is done in the Fourier domain. Watermark strength is adjusted by the amplitude component and the information is holded by the phase component. The visibility threshold is finding out by using human visual system model. Here the contrast masking, frequency sensitivity and the luminance sensitivity like properties are used in the human visual model. One of the major advantages of this paper is that it does not require original image for the comparison during the decoding process. Because it is a blind watermarking method.**

Keywords- Watermarking, visibility, robustness, contrast sensitivity, Fourier, compressive sensing.

I. INTRODUCTION

Nowadays internet and related technologies are growing rapidly. At the same time, the security is a major issue in the digital data transfer. Watermarking is one of the methods for ensuring security. Experts are still facing lots of technical challenges in copyright management and protection of intellectual property rights. Watermarking provides a solution for secure transfer of multimedia content and images. Since few decades, watermarking is researched extensively in the security area of digital image technology, especially in still images. Watermarking is a process of embedding specific information into the content, without altering the basic information. All watermarking processes are commonly concentrated on four main properties, such as invisibility, the robustness, the capacity and the security. Watermarking algorithms should provide a better tradeoff between these properties. But all researches are concentrated on the security area. Security is the property which is widely researched area. The invisibility the security and the robustness are related each other. Robustness is the ability of watermark to survive against attempts to image modification and manipulation like rotation, scaling, compression, filtering, noise attacks, resizing, cropping etc. Normally watermarked image should perceptually be as close to original image as possible. Otherwise, the distortions caused by watermarked embedding process would degrade its aesthetic value. This property is known as imperceptibility. Capacity is the maximum amount of information that can be embedded in the cover work. The robustness and perceptual quality of the watermarks are inversely proportional.

Mainly two types of watermarking algorithms are used commonly: Spatial domain technique and frequency domain technique. Pixel values are operated in the spatial domain. Transform domain based on the special transformations, and process the coefficients in frequency domain to hide the data. Some of the transform domain methods are Fast Fourier Transform (FFT), Discrete Cosine Transform (DCT), and discrete Wavelet Transform (DWT) etc.

The robustness of image against distortion is increased when the watermark is placed in the perceptually significant part of the image. In an invisible watermarking, the embedded watermark should be invisible to human visual system (HVS). Watermarking techniques are based on the masking properties of human visual system. Main characteristics of human visual system are frequency sensitivity, luminance sensitive, and contrast masking. Frequency sensitivity is the difference sensitivity of the human eye to sine wave gratings at different frequencies. Luminance sensitivity is the different sensitivity of the eye to a noise signal on a contrast background, level of the noise luminance and depending on the average value of the background luminance. Contrast masking is the perception of a signal in presence of masking effect, and which depends on the relative spatial frequency, location and orientation.

In this paper, a novel approach to DFT watermarking based on the compressive sensing technology is proposed. It improves the existing methods. Here the DFT watermarking is performed on the basis of human visual system properties. Then the compressive sensing is performed in the watermarked image and it retains the robustness in the perceptual perspective.

II. OVERVIEW OF THE CONTRIBUTION

In the proposed method the watermark is embedded in the Fourier domain by compressive sensing method. The watermarked image is transmitted only after compressing the image. The compressing technology reduces the size of the content. In Fourier domain, the energy of the watermark is controlled by the magnitude and the information is hold by the phase. Here the watermarked coefficients are divided into two symmetrical square patches and this is defined as the sum of sine gratings at various visual frequencies.

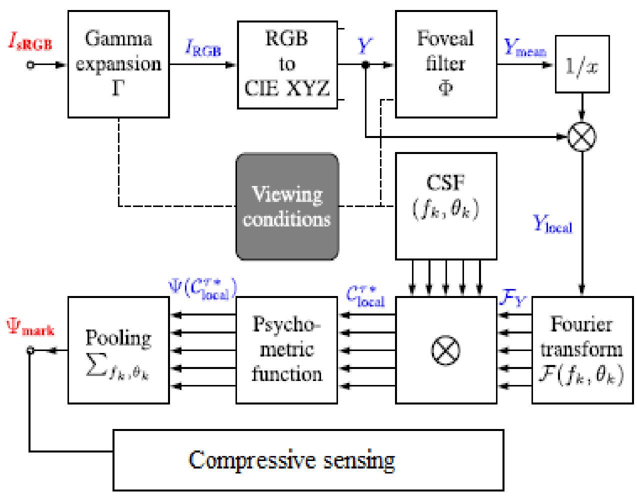

Fig. 1. The proposed compressive sensing HVS model estimates the probability of watermark embedded in the image and applies the compressive sensing method.

The proposed method reduces the size of the content. First gamma expansion is applied in the normal image. Then the RGB image is converted into CIE XYZ component. After filtering the image the mean value is obtained. The Fourier transform is obtained after multiplying the XYZ component and the mean value. Psychometric function is obtained from the viewing condition and Fourier transform. The compressive sensing is applied at the end of embedding process.

III. SETTING THE VISIBILITY THRESHOLD

Watermark strength is an important parameter in the watermarking embedding process. When the watermarking strength is increased above a particular value, then the visibility of the watermark is also increased. So finding threshold value of watermarking strength is a crucial step. In this paper human visual system model is used to find the visibility threshold. The HVS automatically determine the optimal watermarking threshold.

Most of the practical application does not implement all the properties of the human visual system. Computational models of HVS estimate the elements like masking effect, contrast sensitivity function, subband decomposition into visual channels, contrast sensitivity etc. Here visual channels are avoided due to their higher complexity. From some of the previous work, experts noted that the masking effect do not occurred in some area of uniform image. So the masking effect is also not taking in account. The proposed method met the invisibility. It is explained in Fig.1.

A. Modeling Viewing Condition.

Inputs of a human visual system model are taken as the viewed image and the viewing conditions. Let *I*sRGB*(x, y)* is taken as the image to be watermarked, $0 \le x < Rx$, $0 \le y < Ry$, where *Rx* and *Ry* are the horizontal and vertical resolutions. Let Sx and *Sy* are the displayed size of the input image in meters. *L* is represented as the display illumination. It is set as the typical value of LCD monitors. The viewing distance d is expressed as the multiplicative factor of image height.

B. From Pixel Values to Perceived Contrast.

Physical luminance is taken as the input of the contrast sensitivity. For display purpose the digital images are primerly gamma encoded. The typical value of gamma is used for display. The typical value is 2.2, the standard RGB (sRGB) color space will thus be used. Gamma expansion is first applied to IsRGB in order to transform the original sRGB pixel values into linear RGB values. In a second step, IRGB is converted into the CIE XYZ color space. Let IXYZ is taken as the obtained image. its component Y is proportional to the physical luminance and will thus be used for contrast computation and watermark embedding.

When Michelson's formula is applied to sine grating of peak amplitude A*peak*, defined the contrast as,

$$C(x,y) = \frac{A_{peak}}{Y_{mean}(x,y)} \qquad (1)$$

Where is the mean illuminance of the area supporting the sine grating. Within the normalized luminance space, the local contrast of a sine grating is taken as

$$C_{\text{local}} = A_{\text{peak}}. \qquad (2)$$

C. Contrast Sensitivity.

The contrast sensitivity is affected by numerous factors. Contrast sensitivity function describes (CSF) describe the sensitivity to contrast level as a function of visual frequency. The sine grating is become visible above the contrast threshold.

A simplified formula for initial CSF incorporates the oblique effect and the influence of the surround luminance. Here the Fourier watermark embedded technique modifies frequency coefficients whose orientations are oblique. Therefore depending on the sensitivity variation with the orientation of the visual pattern, oblique effect should be implemented. At binocular viewing, Barten's simplified CSF formula is represented as,

$$\begin{aligned}\text{CSF}(f,\theta) = 5200 \cdot e^{-0.0016 \cdot f^2\left(1+\frac{100}{L}\right)^{0.08}} \\ \cdot \left(1 + \frac{144}{\Theta^2(I)} + 0.64 \cdot f^2 \cdot \left(1 + 3\sin^2(2\theta)\right)\right)^{-0.5} \\ \cdot \left(\frac{63}{L^{0.83}} + \frac{1}{1 - e^{-0.02 f^2}}\right)^{-0.5}\end{aligned} \qquad (3)$$

Where *f* is the visual frequency in cycle per degree (CPD), *L* is the adaptation luminance and is assumed to be equivalent to the display illumination.

From Eqn. (2) and Eqn. (3), one may now obtain the threshold amplitude of a sine grating

$$A^{T}_{\text{peak}}(f,\theta) = C^{T}_{\text{local}}(f,\theta) = \frac{1}{\text{CSF}(f,\theta)} \qquad (4)$$

D. Psychometric Function

The relation of the parameter of a physical stimulus to the subjective responses is explained by the psychometric function. From Daly's Weibull parametrization,

$$\Psi\left(\mathcal{C}_{\text{local}}^{\tau*}\right) = 1 - e^{-\left(\mathcal{C}_{\text{local}}^{\tau*}\right)^{\beta}}, \tag{5}$$

Where $C^{\tau*}_{local} = C_{local} / C^{\tau}_{local}$ is the ratio between the locally normalized contrast and its threshold value given in Eqn. (4). β is the slope of the psychometric curve, its value is usually obtained from experimental data. Typical values for β range from 1.3up to 4. Moreover, the psychometric function is typically applied locally, contrary to our model which applies it in the Fourier domain, hence globally. For both these reasons, it is proposed to use β = 2, for low value which provides a large transition area between invisible and visible domains.

E. Watermark Frequency Pooling

In watermarking, multiple Fourier coefficients causing the super imposing of multiple sine gratings. Estimation of single sine grating is provided by the CSF, for that summation model is required to estimate the combined visibility level of all embedding gratings.

Let $C_{\tau*local}(f_k, \theta_k)$ denote the contrast threshold ratio of G_k. The probability that the watermark is perceived by an observer computes as

$$\Psi_{\text{mark}} = 1 - \prod_{k=0}^{N-1} \left(1 - \Psi\left(\mathcal{C}_{\text{local}}^{\tau*}(f_k, \theta_k)\right)\right), \tag{6}$$

Now, by work on the entire watermark to individual grating. Assume that all embedding gratings are sharing the same probability of detection. By solving Eqn. (6)

$$\psi = 1 - \left(1 - \Psi_{\text{mark}}\right)^{1/N}. \tag{7}$$

$$A_{\text{peak}}(f_k, \theta_k) = \mathcal{C}_{\text{local}}^{\tau}(f_k, \theta_k) \cdot \left[-\ln\left(\left(1 - \Psi_{\text{mark}}\right)^{1/N}\right)\right]^{1/\beta} \tag{8}$$

F. Compressive Sensing

There are three processes in CS sparse representation, construction of measurement matrix and reconstruction of the signal. The core of CS is using a small amount of information to restore the original signals.

Consider a real valued, finite length $l1$, one dimension, and discrete signal **x**, which can be viewed as an Nx1 column vector in the R_N. Any signal in the R_N can be represented as the linear combination of the column vectors in the basis matrix Ψ.

$$x = \Psi\ \alpha \tag{9}$$

Where α is the N x 1 column vector of weighting coefficients, the signal **x** is K-sparse if only K of coefficients α are none-zero. The signal **x** is compressible if the representation in Eqn. (9) has just a few large coefficients and many small coefficients.

Compressive sensing based on a compressed representation directly without experiencing the procedure of N sampling. General measurement process can be described as computing inner products between the signal **x** and a group of vectors which are arranged as the row vectors of the $M \times N$ ($M<N$) measurement matrix.

$$\Phi.y = \Phi x \tag{10}$$

The measurement result is denoted as the M×1 column vector **y**, and then by substitution Eqn. (9) in Eqn. (10), **y** can be written as:

$$y = \Phi\ \Psi\alpha = \Theta\alpha \tag{11}$$

Where Θ is the sensing matrix, main problem is to design a stable measurement matrix Φ such that the information in the signal **x** is not damaged during the dimensionality reduction from N to M. Next aim is a reconstruction algorithm to recover the signal **x** from the measurement **y**. This is a complex optimization problem because the process of getting x from y is an undetermined problem.

$$\min ||x||_{l1} \text{s.t } y = \Theta\ x \tag{12}$$

This is a reconstructing process which is computing a minimum 1 norm of x with a constraint condition.

$$y = \Theta\ x \tag{13}$$

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G. Watermark Extraction

Here the watermarking algorithm is blind, so it does not require original image for the decoding process. Typically watermarking is done when the correlation exceed some given threshold level. Watermarking detection involves normal peak detection and template matching. Detection peak may be seen as the outliers. Various methods are used for the outlier detection. Grubbs' test is one of the common methods used for that. It is robust and low computational cost. Its correlation matrices are normally distributed. This method removes one outlier at a time, which is up to a predefined maximum number of times.

IV. RESULT ANALYSIS

Recently lots of works has been done in compressive sensing technology. But majority of the works are non-blind watermarking. Here a new method of DFT watermarking with compressive sensing is proposed. It mainly reduces the size and it is robust against some attacks. The following results show the output of compressive sensing watermark against normal DFT watermark. Some of the attacks like noise attacks, filtering attacks and compression attacks are shown here.

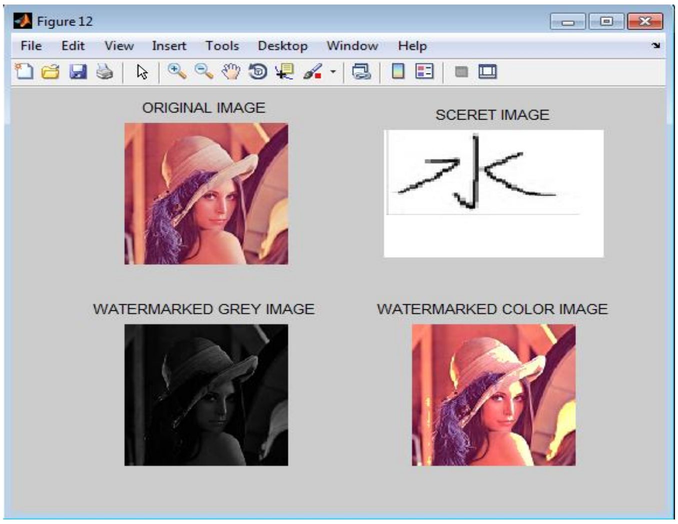

Fig.2. Watermarking of Lena image

(a) Filtered image and recovered watermark of CS and DFT
Fig.3. Filtering attack

(b) Noise image and recovered watermark of CS and DFT.
Fig .4. Noise attack

(c) Compressive image and recovered watermark of CS and DFT
Fig.5.compression attack

V.CONCLUSION

In this paper a novel DFT watermarking with compressive sensing is proposed. First, during the watermark embedding, a square patch of coefficient is embedded in the transfer domain. And then the watermarked image is transferred after applying compressive sensing approach. The watermark strength is optimized perceptually. In Fourier domain the magnitude consists of the watermark strength and the phase consist of the information. The compressive sensing approach is robust against the various attacks. Image compression schemes based on HVS models for frequency, luminance and contrast sensitivity provide more flexibility to a broader range of images.

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