Compressive Sensing Based Watermarking Methods for Copyright Authentication: A Review

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Abstract

Digital watermarking enables the possibility of providing copyright protection and authentication of multimedia data in a networked environment. CS is new paradigm in sparse representation and recovery of data . This paper presents a review on various Compresssive sensing based methods of watermarking. CS- DCT and CS-DWT based methods of watermarking applied both on monochrome and color images are discussed. Further, Waterking based on CS method in tampering identcication and OMP based recovery methods are also discussed. Tthis paper also covers the various performance measures that are used to evaluate these methods of watermarking.

Keywords

Watermarking, Compressive Sensing, Image Tampering Localization, Sparse Domain, Payload Capacity, SSIM

I. Introduction

Digital media is the need of people for today's life as the alternate of paper media. Further due to the immense advancement in technology and its use, digital media requires copyright protection, and authentication claiming by the owners or authors, while transferring data through the internet Digital watermarking[1,5] is the solution this problem of copyright protection and authentication of multimedia data in a networked environment. This makes possible to associate or embed a digital unique code called *watermark* associated to the owner, and thereby proving the possession of the owner during the watermark extraction process. In other words, Watermarking is a process of secure data from threats, in which owner identification (watermark) is merged with the digital media at the sender end and at the receiver end this owner identification is used to recognize the authentication of data. Watermarking techniques have been developed to fulfill this requirement copyright protection and authentication.

For the watermark to be really effective[1,5] it should be Unobtrusive, Readily extractable, Robust, and Unambiguous and Innumerable. As integral part of watermarked images, watermark protects the rights of their owners in Copy Right Identification, User Identification or Finger printing, Authencity Determination, Automated Monitoring and Copy Protection[3]

Although there are various spatial and frequency domain based methods of Watermarking, the paper covers only the recent and latest techniques of watermarking methods based on Compressive Sensing(CS). Compressive sensing is applied on the cover image to obtain the measurements, later the watermark is embedded into these measurements. The watermark is a pseudo random sequence of binary numbers or logo of identification of owner. The watermarked image is subjected to several attacks[2,9] during transmission. Now the recovered watermarked image is tested for robustness in terms of bit correct rate (BCR) and also the PSNR is computed.In addition, Payload, BER, SSIM are also considered to be performance measures[2,3] of the watermarking technique.

The paper is organized as follows: Section 2 deals with the related work in watermarking in spatial and frequency domains. Section 3, covers the basics of CS theory. Section 4 gives a review of various CS based watermarking methods. Section 4 discuss with various performance measures used in watermarking using CS. Finally section 5 gives the conclusions.

II. Watermarking in Spatial and Frequency Domain:

Watermarking can be implemented both in spatial and in frequency domain.

Spatial domain techniques[5]: These watermarking slightly modify the pixels of few randomly selected subsets of an image. Modifications might include flipping the low-order bit of each pixel. The main disadvantage of spatial domain techniques is that it can be easy be hacked and attacked. Few of these methods include

i). **Least Significant Bit Coding (LSB)**[17]: Applying the bit plane coding on the image signifies that the least significant bits of an image carry information that cannot be perceived by the human eye. Embedding the most significant bits of message into the LSB's of cover image makes the watermarking possible without causing much distortion to the cover image. However this method is not robust as it is easily prone to attacks like JPEG compression.

ii) **Predictive coding schemes :** A predictive coding scheme was proposed by Matsui and Tanaka[5] for grayscale images. In this method the correlation between adjacent pixels are exploited. A set of pixels where the watermark has to be embedded is chosen and alternate pixels are replaced by the difference between the adjacent pixels. This can be further improved by adding a constant to all the differences. A cipher key is created which enables the retrieval of the embedded watermark at the receiver. This is much more robust as compared to LSB coding.

Frequency domain techniques[4,17] : In these techniques, the image is represented in the frequency domain using DCT or DWT, i.e., transformation is applied to the input image and then watermark is embedded in the transformed image at few K largest transformation coefficients using equation

$$[(I_W)_M] = [I_M] + \alpha[W_M] \quad M=1\ldots\ldots K$$

Then the Watermarked image is obtained by applying inverse transformation. At the receiver, find the inverse transformation , extract the these largest K watermarked coefficients. Then compute the correlation coefficients γ and compare this with the threshold for authenticity decision.

SVD based watermarking methods: In SVD transformation, a matrix can be decomposed into three matrices that are of the same size as original matrix. [] The singular values of the host image are modified to embed the watermark image by employing multiple singular functions. Watermark is embedded and extracted by adjusting value between selected coefficients and actual output

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trained by support vector regression. SVD factorization is done on different nonoverlapping blocks by taking wavelet transform.

III. Theory Of CS:

The basic model for CS is shown in fig. 1.1 which involves three major aspects: sparse representation, measurements taking and signal recovery via l_1 minimization[13].

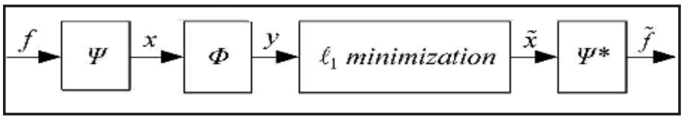

Fig 1: Block Diagram of Compressive Sensing

Input f is the original non-sparse signal, x is sparse with respect to the orthogonal basis Ψ, y represents a small number of non-adaptive CS measurements taken by random measurement matrix Φ, $\tilde{x}$ and $\tilde{f}$ denote the recovered coefficients and signal, respectively. The resultant CS measurements are used for the recovery of original signal. In any real-world application, y will be inevitably corrupted by at least a small amount of noise n. With the quantized samples y, Candès and Tao [13,15] have shown that if the Uniform Uncertainty Principle (UUP) is satisfied, the original signal can be reconstructed by solving the convex optimization problem as shown in equation

$$Min \|\psi^T f\|_{l_1} \; s.t \; \|\phi \psi^T f - y\|_{l_2} \leq \varepsilon \qquad (1.1)$$

Where ε is the noise term, y is the received CS measurements, $\tilde{f}$ and is the recovered non-sparse signal.

To achieve such a system of measurements a stable measurement matrix and recovery algorithm has to be designed.

Stable Measurement Matrix: It is required to ensure that the measurement matrix ϕ is incoherent with the sparsifying basis in the sense that the vectors $\{\phi_j\}$ cannot sparsely represent the vectors $\{\psi_i\}$ and vice versa [13]. Further this matrix has to follow Restricted Isometric Property (RIP). If the elements of ϕ are taken as independent and identically distributed (i.i.d) random variables, with zero mean and 1/N - variance Gaussian density. Then, the measurements y are merely M different randomly weighted linear combinations of the elements of x.

Different CS recovery algorithms: CS theory says that from M measurements the signal can be recovered exactly below equation is satisfied.

$$M \geq Const.K.logN \qquad (3.4)$$

Where Const is over measuring factor greater than 1.Once the signal is represented by linear measurements in some orthonormal basis as y, in order to get back the signal X a number of reconstruction algorithms are used. As mentioned in [34] there are different reconstructions algorithms existing in literature. There are at least five major classes of computational techniques for solving sparse approximation problems.

a) **Basis pursuit** : The reconstruction algorithm is defined by a convex optimization problem. Solve the convex program with algorithms that exploit the problem structure. Most popular of this is l1 minimization.

b) **Greedy pursuit:** Iteratively refine a sparse solution by successively identifying one or more components that yield the greatest improvement in quality

c) **Bayesian framework:** Assume a prior distribution for the unknown coefficients that favors sparsity. Develop a maximum a posteriori estimator that incorporates the observation. Identify a region of significant posterior mass or average over most-probable models.

d) **Non convex optimization:** Relax the ‘0 problem to a related non convex problem and attempt to identify a stationary point.

IV. Compressive Sensing Based Watermarking Methods :

When transmitting the images there may be loss of bits in the channel to an extent that the image cannot be recovered at the receiver end. In order to make the data immune to noise channel coding techniques are used. But in this case more bandwidth is required which is a drawback. Instead input image is represented using few measurements using CS theory, and then the watermark is inserted in these measurements, which can recovered at the receiver end by using compressive sensing concept. Some of the related works of watermarking using CS include:

Watermarking with CS and DSC: G. Valenzise etal[16], demonstrated the use of Compressive-sensing based watermarking for Tampering localization identication. In this method a compact representation of the image is first produced by assembling a feature vector consisting of pseudo-random projections of the decimated image. These quantized projections are then encoded to form a hash[16], which is robustly embedded as a watermark in the image. In recovering the watermark, the random projections are obtained which are used to estimate the distortion of the received image. If tampering can be expressed by sparse representation in other basis transformation, a map of the introduced modification is recovered. Compressive Sensing and Distributed Source Coding (DSC) principles are used to reduce the size of the hash of a 1024 x1024 image, to about 4,000 bits.

2.**CS-DCT based Watermarking**[11]: In this method, CS based watermarking is extended to color images. Instead of applying the compressive sensing concept to cover image, it was applied to the watermark image. The sparse watermark vector is embedded into the mid band DCT coefficients of cover image. Komal et. al. [11] extended the above technique to color images. Instead of applying the compressive sensing concept to cover image, it was applied to the watermark image. The sparse watermark vector is embedded into the mid band DCT coefficients of cover image. The mid frequency bands are chosen because low frequencies coefficients have most visual information of image and also have high energy while the high frequency coefficients are sensitive against attacks likes compression and noise. The results using this method have shown that DCT – CS theory based watermarking technique is quite good when compared to existing DCT watermarking technique in term of payload capacity of embedding data.

Hsiang et. al.[10] proposed basic watermarking technique based on DCT and compressive sensing. The input image is transformed into the sparse domain by applying DCT. The orthonormal basis function is the DCT and inorder to obey the incoherence principle of compressive sensing, the sensing matrix is taken to be the noiselets. The coefficients of measurement matrix Y are paired (non overlapped) and watermark W is embedded according to the following equation

$$y'_{2m} = \begin{cases} y_{2m-1} + w, & if \; |y_{2m} - y_{2m-1}| < T_E \\ y_{2m} & Otherwise \end{cases}$$

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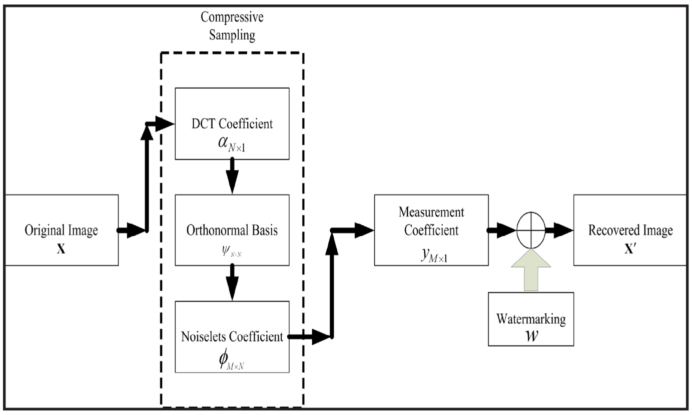

Figure 2: *Watermark embedding using compressive sensing[10]*

Watermarked image X' is obtained by using the least squares method. Watermark extraction is similar to the embedding process. Decoding thresholds T_{D1} and T_{D2} need to be selected according to the embedding threshold T_E.

$$w' = \begin{cases} 0, & \text{if } \left|y'_{2m} - y'_{2m-1}\right| < T_{D1}; \\ 1, & \text{if } T_{D1} \leq \left|y'_{2m} - y'_{2m-1}\right| < T_{D2}; \\ \text{undefined}, & \text{otherwise}. \end{cases}$$

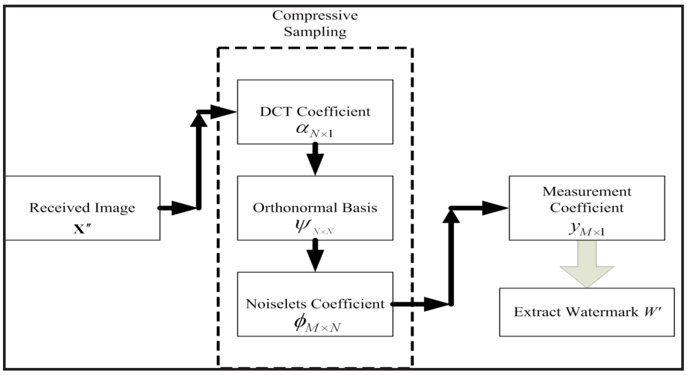

Figure 3: *Watermark extraction using compressive sensing[10]*

K. DeergaRao *et.al.* [12] proposed a technique in which DWT is used instead of DCT. Two level decomposition is performed on the input image and watermark is embedded into the HL2 subband. By selecting an appropriate random measurement matrix, CS measurements are obtained on all high frequency wavelet coefficients excluding high frequency coefficients(HL2) into which the watermark is embedded. Two algorithms are proposed i.e., in algorithm2, CS measurements are obtained over all coefficient, while in algorithm1, HL2 coefficients are kept aside during CS measurements. Orthogonal matching pursuit (OMP) is used to recover the wavelet coefficients. CS random matrix with i.i.d gaussian entries is selected as the measurement matrix. The results show that PSNR of extracted cover image and watermarked image of algorithm 1 is better over algorithm2.

In [18] method of watermarking based on CS, the author has done the recovery by two approaches, i.e., by simple method of Orthogonal Matching Pursuit(OMP) and OMP-partially known support OMP-PKS [18]. The difference between the OMP and the OMP-PKS is that the OMP-PKS has a prior knowledge support about some coefficients of the sparse image and the other coefficients are unknown support. The results show that the OMP-PKS recovery performance is superior to that of the OMP reconstruction algorithm. It is observed that the recovered Lena and extracted watermark images have a good quality i.e. high PSNR at lower measurement rates(N/M) by using the OMP-PKS than the OMP.

V. Performance Measures:

The watermarking methods are accessed based on performance of various parameters against the attacks during transmission. Few of the attacks [2,5] over the watermarked image include rotation, cropping, addition of various noise and compression techniques . Further the CS based watermarking methods are tested against the attack of vector quantisation[18].The quantitative measures like Bit Error Rate (BER), Peak Signal to Noise Ratio (PSNR), Structural similarity index measures (SSIM) and Payload Capacity percentage are used to evaluate the watermarking technique to compare with existing watermarking technique based on DCT domain. The evaluation of all the above parameters are discussed in [3].

VI. Conclusions

Compressive sensing is a new paradigm of signal compression and recovery. This paper discusses the various CS-DCT, CS-DWT based watermarking methods. It is that observed that midband coefficents are used in CS-DCT to embed the watermark. These methods are observed to give better payload and PSNR performance. Further watermarking of color images using CS are also discussed.

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