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Biometrics inspired watermarking based on a fractional dual tree complex wavelet transform

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ABSTRACT

In this paper, a novel biometrics inspired watermarking technique is proposed. For this purpose, a newly proposed mathematical transform, namely the fractional dual tree complex wavelet transform (FrDT-CWT), and singular value decomposition (SVD) are used. The core idea is to use biometrically generated keys in the embedding process of a gray-scale watermark. Therefore, this paper first proposes a method for generating keys from biometrics efficiently. The host image is first randomized by Hessenberg decomposition and a chaotic map, followed by embedding in the FrDT-CWT domain by modifying the singular values of the randomized image. Further, in order to prevent the ambiguity problem of SVD-based techniques, a verification step is introduced to verify the watermarked image. Finally, a reliable extraction process is proposed to extract the watermark from the possibly attacked watermarked image after verification. The security, attack, and comparative analysis confirms the high security, efficiency, and robustness of the proposed watermarking technique.

1. Introduction

Both the success and the substantial proliferation of web technologies have created an environment in which some crucial issues for digital media such as illegal copying, distribution, editing, and authentication have become very easy. The phenomenon has led to an increasing need for developing some standard solutions to prevent these issues. One of the technical solutions is to provide law enforcement and copyright protection for digital media which can be achieved practically by digital watermarking. Digital watermarking refers to a technique that imperceptibly inserts an authorized mark information (watermark) into the digital media. This hidden information can be retrieved by the contrary process for a variety of purposes [1]. In recent years, several watermarking algorithms have been proposed in the literature. These algorithms can be broadly classified in two categories, according to the embedding domain: the spatial domain and the transform domain. Spatial domain approaches [2] are the simplest, and the earliest algorithms were based on the modification of pixel intensities. These algorithms are generally fragile to numerous attacks. On the other hand, transform domain approaches insert the watermark into the transform coefficients; examples include the Fourier transform [3], cosine transform [4], wavelet transform [5–8], fractional Fourier transform [9–11], and dual-tree complex wavelet transform [12].

Recently, a new transform, a singular value decomposition (SVD)-based [13,14] watermarking technique, and its variants have been proposed. These approaches work on the simple concept of finding the SVD of a cover image or the SVD of each block of the cover image and then modifying the singular values to embed the watermark. Further, some researchers have presented hybrid watermarking schemes in which they have combined SVD with the other existing transforms [15–21]. The main reason behind the hybridization is the fact that SVD-based scheme withstands a variety of attacks but it is not resistant to geometric attacks such as rotation, cropping, etc. Hence, to improve the performance, hybridization is needed. It was however first argued by Zhang and Li [22] that SVD-based schemes fail under ambiguity attacks, i.e. by taking recourse to the reference matrices of the watermark, the same can be extracted from a possibly distorted watermarked image, and this fact is again proved in [23]. The fact that SVD subspace can preserve major information of an image leads to the above-mentioned drawback. Thereafter, other authors have also discussed the same drawback, and have given its solution to some extent [17,24–26].

The main motive of this work is to develop and implement a new concept in an SVD-based hybrid watermarking scheme which cannot fail under ambiguity attacks. The core idea of the possible solution is to introduce a key concept in the SVD-based scheme

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such that, even if someone has knowledge of the full embedding process, then without these keys he/she can never extract the watermark. In the proposed work, these keys are generated by the biometrics of the owner/user of the digital media. Recently, biometrics has emerged as a promising technology for personal identification and authentication [27,28]. Biometrics is gaining increasing interest of research as well as corporate communities due to its highly secure and trustworthy characteristics. Generally, biometrics refers to methods that can be used to uniquely recognize individuals based upon one or more intrinsic physical or behavioral characteristics. In information technology, in particular, biometrics is used as a tool for efficient and reliable identity management and access control [29]. Therefore, the development of a digital media security system is proposed in this work which will use the biometrics as an actuating factor to strengthen the security. The key concept is introduced by the recently proposed fractional transform, namely the fractional dual tree complex wavelet transform (FrDT-CWT) [30]. The FrDT-CWT is a realization of the DT-CWT in the fractional Fourier domain. The FrFT has a unique property of describing the information of the spatial and frequency domain due to the rotation of the time–frequency plane over an arbitrary angle. In contrast, the DT-CWT has a multiresolution property. A combination of these two domain results in the FrDT-CWT, which exhibits the multiresolution property, describing the spatial as well as the frequency domain information. The transform orders of the FrDT-CWT act as the key in the proposed scheme and therefore are generated by the biometrics of the owner/user. Therefore, an efficient way to generate keys from biometrics images is also suggested which is based on the speeded-up robust features (SURF) technique. The SURF technique transforms an object into a large collection of local feature vectors, each of which is invariant to translation, scaling, and rotation, affine, or three-dimensional (3D) projection, and partially invariant to illumination changes.

- This paper proposes the use of a recently introduced transform, namely the fractional dual tree complex wavelet transform, for the aim of secure digital image watermarking.
- This paper proposes an efficient way to generate keys and transform orders from the biometrics of the user/owner.
- A new invertible randomization process for gray-scale images is proposed exploiting the characteristics of a nonlinear chaotic map and Hessenberg decomposition.
- Further, this technique is an attempt to rectify the drawback of SVD in image watermarking by introducing a verification step based on Tsallis entropy.

The remainder of the paper is organized as follows. In Section 2, an introduction to a nonlinear chaotic map, Hessenberg decomposition, singular value decomposition, and SURF is given. The definition of the fractional dual tree complex wavelet transform is given in Section 3, followed by the proposed biometrics inspired watermarking technique in Section 4. The experimental results and security analysis are briefly described in Section 5. Finally, the concluding remarks are given in Section 6.

2. Mathematical preliminaries

In this section, the main terminologies are given which are used in the proposed biometrics inspired watermarking technique to achieve the desired goal. These terminologies are as follows.

2.1. Nonlinear chaotic map

A chaotic system is a deterministic nonlinear system with pseudo-stochastic property [31]. Due to their interesting properties such as non-periodicity, unpredictability, initial parameter sensitivity and Gauss-like statistical characteristics, many chaotic systems serve as a stochastic signal/sequence generator nowadays. In this work, we have used piecewise nonlinear map in order to create a digital sequence. Mathematically, a piecewise nonlinear map (PWNLCM) $\mathcal{F} : I \to I$, where $I = [0, 1]$ and denoting the length of the region, described as [32]

$$\mathcal{F}(x_{k+1}) = \begin{cases} \left(\dfrac{1}{I_{i+1} - I_i} + a_i\right)(x_k - a_i) \\ \quad - \dfrac{a_i}{I_{i+1} - I_i}(x_k - a_i)^2, & \text{if } x_k \in [I_i, I_{i+1}) \\ 0, \quad \text{if } x_k = 0.5 \\ \mathcal{F}(x_k - 0.05), & \text{if } x_k \in (0.5, 1], \end{cases} \tag{1}$$

where $x_k \in [0, 1]$ and I_i is the subinterval of $[0, 1]$ such that $0 = I_0 < I_1 < \cdot < I_i < \cdot < I_{n+1} = 0.5$. The parameter $a_i \in (-1, 0) \cup (0, 1)$ tune sequence in the ith interval such that

$$\sum_{i=0}^{n-1} (I_{i+1} - I_i) a_i = 0. \tag{2}$$

2.2. Hessenberg decomposition

Hessenberg decomposition [33] is the factorization of a general matrix A by orthogonal similarity transformations into the form

$$A = QHQ^T, \tag{3}$$

where Q is an orthogonal matrix and H is an upper Hessenberg matrix, meaning thereby $h_{ij} = 0$ whenever $i > j + 1$. Hessenberg decomposition is typically computed using Householder matrices. The Householder matrix (P) is an orthogonal matrix of the form

$$P = I_n - 2uu^T/u^T u,$$

where u is a non-zero vector in R^n and I_n is the $n \times n$ identity matrix. There are $n-2$ steps in the overall procedure when A is of size $n \times n$. Therefore, Hessenberg decomposition is computed as

$$H = (P_1 P_2 \cdots P_{n-3} P_{n-2})^T A (P_1 P_2 \cdots P_{n-3} P_{n-2}) \tag{4}$$

$$\Rightarrow H = Q^T A Q \tag{5}$$

$$\Rightarrow A = QHQ^T. \tag{6}$$

2.3. Singular value decomposition

Singular value decomposition (SVD) [33], one of the most useful tools of linear algebra, is a factorization and approximation technique which effectively reduces any real or complex matrix into smaller and invertible matrices. Mathematically, SVD of a rectangular matrix A is expressed as

$$A = USV^T, \tag{7}$$

where S is a diagonal matrix with non-negative real numbers on the diagonal arranged in decreasing order. The diagonal entries of S are known as the singular values of A. On the other hand, U and V are unitary matrices. The columns of U are left singular vectors whereas the columns of V are right singular vectors of A. It is important to note that the singular values specify the luminance of the matrix whereas the corresponding pair of singular vectors specify the geometry of the matrix.

2.4. Speeded-up robust features (SURF)

The speeded-up robust features (SURF) technique has been developed for both the detection and description of local features [34,35]. Its main advantages are repeatability, distinctiveness, and