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The Watermarking Algorithm against Shearing Based on Dopplerlet-radon Transformation

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Abstract: In this study, a robust image watermarking method in two-dimensional space/spatial-frequency distributions domain is proposed which is robust against geometric distortion. This watermarking is detected by a linear frequency change. The dopplerlet-radon transformation is used to detect the watermark. The chirp signals are used as watermarks and this type of signals is resistant to all stationary filtering methods and exhibits geometrical symmetry. In the two-dimensional Radon-Wigner transformation domain, the chirp signals used as watermarks change only its position in space/spatial-frequency distribution, after applying linear geometrical attack, such as scale rotation and cropping. But the two-dimensional Radon-Wigner transformation needs too much difficult computing. So, the image is put into a series of 1D signal by choosing scalable local time windows. The watermark embedded in the dopplerlet transformation domain. The watermark thus generated is invisible and performs well in StirMark test and is robust to geometrical attacks. Compared with other watermarking algorithms, this algorithm is more robust, especially against geometric distortion, while having excellent frequency properties.

Key words: Digital watermarking, dopplerlet-radon transform, geometrical attack

INTRODUCTION

With the arrival of the information era and the broad application of E-business, there is a growing importance to protect the security of messages. As an important branch in the field of the research on the message cryptic technique, the digital watermarking technique is an efficient way to the authentication of content and copyright. This technique authenticate and protect the data by embed watermark in the original data. The watermark imbedded can be a passage, some marks or images. The traditional encryption can only assure the message security when being visited and the security of both parts when in a single-phase communication mode but to the public messages transformed in the multi phase mode a new technique and mechanism is needed. As a potential method to solve the problem, digital watermarking technique is being widely concerned and it is becoming the top research in the international academic field. Digital watermark is a special mark cryptic in the multi-media products. Digital watermark should have three basic characteristics: Insensitive, that is the embed watermark can't destroy the digital products and we can feel the exist of the watermark neither visual nor aural; robustness, that is under the usual signal processing (compressed, rejected or effected by noise) and geometric transmitting (translated, flexed or rotated), it can assure that the watermark can't be destroyed. The imbedded watermark can be done in time-space frequency and it can also be done in the transformable domain. The first method is easy to be carried out but the protecting from the attack to signal processing can't be done perfectly. However, the watermarking method under transformable domain is better (Ruanaidh and Pun, 1998; Cox *et al*., 1997; Niu *et al*., 2000).

In this study we put forward a robust digital image watermarking based on Dopplerlet-radon transformation.

This algorithm uses of the Radon-Wigner transform to detect the watermark and the two-dimensional chirp signals are used as watermarks. In the two-dimensional Radon-Wigner transformation domain, the chirp signals used as watermarks change only its position in space/spatial-frequency distribution, after applying linear geometrical attack, such as scale rotation and cropping. Compared with other watermarking algorithms, this algorithm is more robust, especially against geometric distortion, while having excellent frequency properties. But the 2D Radon-Wigner transformation needs much difficult computing and can be impossible in reality. So we introduce an algorithm based on 1D dopplerlet transform. In this algorithm, the chirp signals used as watermarks are inserted in the image and the image is put into a series of

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1D signal by choosing scalable local time windows. By using dopplerlet-radon transformation on the 1D image signal series, the watermark is detected. The shearing attack can break watermarks in one part of space support district but watermarks in another one part of space support district still can not be destroyed. Synthesizing each supporting space, the algorithm achieves the robustness to the shearing attacks (Stankovic *et al*., 2001; Zou *et al*., 2001; Bultan, 2002).

THE PRINCIPLE OF DOPPLERLET TRANSFORMATION

The Wigner distribution of the signal s (t) is defined as:

$$W_s(t,\omega)=\int_{-\infty}^{+\infty} s(t+\tau/2)s^*(t-\tau/2)\times e^{-j\omega\tau}d\tau \qquad (1)$$

where, variables t and ω represent the time and frequency, respectively. WVD has the highest resolution for a single chirp signal but its major disadvantage is the presence of artificial cross-terms caused by the quadratic multiplication nature. For a signal containing multiple linear chirps, the desired WVD auto-terms are straight lines in the Wigner plane, while the undesired cross-terms are manifested as the high-frequency oscillating characteristics. To suppress the cross-terms, we consider the Radon-Wigner Transform (RWT), which takes advantage of the above oscillating properties by integrating the WVD along lines with different chirp rate and frequency shift combinations. A large part of the WVD cross-terms is cancelled to each other through the integration and the residual part of the cross-terms can be further reduced in the Radon-Wigner plane by noting the fact that the RWT auto- and cross-terms have different characteristics.

For multi-component signals with approximately equal magnitudes, RWT transformation in the Radon-Wigner plane is effective. However, when the magnitudes of the signal components are significantly different, the method may not be effective because the cross-terms between stronger signal components may be larger than the auto-terms of weaker components. In this case, a weaker signal may be shaded in the presence of strong cross-terms and can hardly be detected. In the image, the watermarking signals are composed by a lot of chirp signals. So, the 2D Radon-Wigner transformation needs much difficult computing and can be impossible in reality. Then we choice the 1D dopplerlet transform to achieve our algorithm. In this case, the method we introduced above can be used to detect the watermarking signal component and then remove It from the original. This procedure is repeated until all the watermarking signal components are detected.

The procedure of dopplerlet decomposition of a signal is first to estimate the chirp rates $\alpha_1, \alpha_2,..., \alpha_{N_0}$ of s (t) over different segments and the respective chirps:

$$u_i(t)=\exp\left\{j\left(\frac{1}{2}\alpha_i t^2\right)\right\} \qquad (2)$$

are then constructed. For a given frame $\{h_k'(t), k \in Z\}$ and N0 chirp rates, a new dopplerlet frame $\{h_k(t)\, u_i(t), k, i \in Z\}$ is obtained. Based on this dopplerlet frame $\{h^k(t)\, u_i(t)\}$, s (t) is divided as:

$$s(t)=\sum_{i=1}^{N_0}\sum_k C_{i,k}\,\zeta_i h_k(t)u_i(t) \qquad (3)$$

where, $C_{i,k}=\langle s(t), h_k'(t)u_i(t)\rangle$ is the frame decomposition and $\{h_k'(t), k \in Z\}$ is the dual frame of $\{h_k(t), k \in Z\}$; $\langle\,\rangle$ represents the inner product, ζ_i are arbitrary weights satisfying: $\sum_{i=1}^{N_0}\zeta_i=1,\ 0\le\zeta_i\le 1$. To have an efficient frame decomposition, $\{h_k(t), k \in Z\}$ should include functions with different time and frequency bandwidths and centre (mean) locations. For example, the following modulated Gaussian functions:

$$h_k(t)=\left(\frac{\gamma_k}{\pi}\right)^{\frac{1}{4}}\exp\left\{-\gamma_k(t-t_k)^2+j\left[\phi_k+\frac{\beta_k}{2}(t-t_k)\right]\right\} \qquad (4)$$

are usually used, where γ_k, ϕ_k are parameters that control the envelope and phase of the dopplerlet and β_k and t_k denote the frequency and time centre, respectively.

Next, we consider how to construct the dopplerlet frame. Radon-Wigner transform can be used to estimate these chirp rates. For a given signal s (t), chirp rate α_1 is obtained by searching the largest peak in the Radon-Wigner plane after taking the RWT of the signal. We then obtain the dopplerlet frame $\{h_k(t)\, u_1(t)\}$ by modulating the frame $\{h_k(t)\}$ with:

$$u_1(t)=\exp\left(j\frac{\alpha_1}{2}t^2\right)$$

We next estimate which element in the modified frame $\{h_k(t)\, u_1(t)\}$ optimally matches the signal s (t) and denote this element as $u_1(t)h_{k_1}(t)$ where:

$$h_{k_1}(t)=\underset{k}{\operatorname{argmin}}\left\{\left\| s(t)-\frac{\langle s(t), u_1(t)h_k'(t)\rangle}{\|h_k(t)\|}u_1(t)h_k(t)\right\|\right\} \qquad (5)$$

To define signal $s_1(t)$ as:

$$s_1(t) = s(t) - \frac{\langle s(t), u_1(t) h_k'(t) \rangle}{\|h_k(t)\|} u_1(t) h_k(t) \tag{6}$$

By repeating the same procedure of s (t) to s_1 (t), we obtain the chirp rate α_2 corresponding to the second largest component of s (t). Let:

$$u_2(t) = \exp(j\frac{\alpha_2}{2}t^2)$$

we obtain

$$h_{k_2}(t) = \arg\min_k \left\{ \left\| s_1(t) - \frac{\langle s_1(t), u_2(t) h_{k_2}'(t) \rangle}{\|h_k(t)\|} u_2(t) h_{k_2}(t) \right\| \right\} \tag{7}$$

and

$$s_2(t) = s_1(t) - \frac{\langle s_1(t), u_2(t) h_{k_2}'(t) \rangle}{\|h_k(t)\|} u_2(t) h_{k_2}(t) \tag{8}$$

Repeating the above procedure, all signal components can be obtained and signal s (t) can be expressed as $s(t)=\sum_i s_i(t)$. Based on the above decomposition, the instantaneous frequencies of all signal components can be obtained.

The 2D Radon transformation is the projection of the image intensity along a radial line oriented at a specific angle. Radon expresses the fact that reconstructing an image, using projections obtained by rotational scanning is feasible. His theorem is the following: The value of a 2-D function at an arbitrary point is uniquely obtained by the integrals along the lines of all directions passing the point. The Radon transformation shows the relationship between the 2-D object and its projections. Suppose a 2-D function f (x, y). Integrating along the line, whose normal vector is in θ direction, results in the g (s, θ) function which is the projection of the 2D function f (x, y) on the axis s of θ direction. When s is zero, the g function has the value g (0, θ) which is obtained by the integration along the line passing the origin of (x, y)-coordinate. The points on the line whose normal vector is in θ direction and passes the origin of (x, y)-coordinate satisfy the equation:

$$\frac{y}{x} = \tan(\theta + \frac{\pi}{2}) = \frac{-\cos\theta}{\sin\theta} \Rightarrow x\cos\theta + y\sin\theta = 0 \tag{9}$$

The integration along the line whose normal vector is in θ direction and that passes the origin of (x, y)-coordinate means the integration of f (x, y) only at the points satisfying the previous equation. With the help of the Dirac function δ, which is zero for every argument except to 0 and its integral is one, g (0, θ) is expressed as:

$$g(0,\theta) = \iint f(x,y) \cdot \delta(x\cos\theta + y\sin\theta)\,dxdy \tag{10}$$

Similarly, the line with normal vector in θ direction and distance s from the origin is satisfying the following equation:

$$(x\text{-}s.\cos\theta\ .\ \cos\theta + (y\text{-}s.\sin\theta).\ \text{Sin}\theta = 0 \Rightarrow x\cos\theta + y\ \sin\theta - s = 0 \tag{11}$$

So the general equation of the Radon transformation is acquired:

$$g(s,\theta) = \iint f(x, y).\ \delta(x\cos\theta + y\ \sin\theta - s)\ dxdy \tag{12}$$

The inverse of Radon transform is calculated by the following equation:

$$f(x,y) = \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \rho \cdot R_\theta(s(x,y))\,d\theta \tag{13}$$

where, R_θ is the Radon transformation, ρ is a filter and

$$s(x, y) = x\cos\theta + y\ \sin\theta \tag{14}$$

The imbedding and test of digital watermark: We consider how to construct a watermark to insert into the image. In the Srdjan Stankovic and Igor Djurovic's paper, the two-dimensional chirp signals are used as watermarks and in the algorithm two-dimensional Radon-Wigner transformation is applied to additionally concentrate the energy of the watermark signal and shows perfect robustness to the geometrical attacks. But the computing of two-dimensional Radon-Wigner needs too much time and could be very difficult. This algorithm is very impractical and the ordinary computer could not finish this work. So we want to look for a new time-frequency distributions domain algorithm to solve this problem.

We embed the watermark in the dopplerlet transformation domain of image. In Stockwell's paper, the dopplerlet transformation is introduced and can detect linear frequency-modulated signals. But 2D dopplerlet transformation needs expensive computing. Obviously, it is necessary to apply one-dimensional dopplerlet transformation on image and additionally concentrate the energy of the watermark signals. We select the linear frequency-modulated signals as watermark. The digital watermark is W with the sum of many linear frequency-modulated signals with different frequency:

Fig. 1: Watermarked image

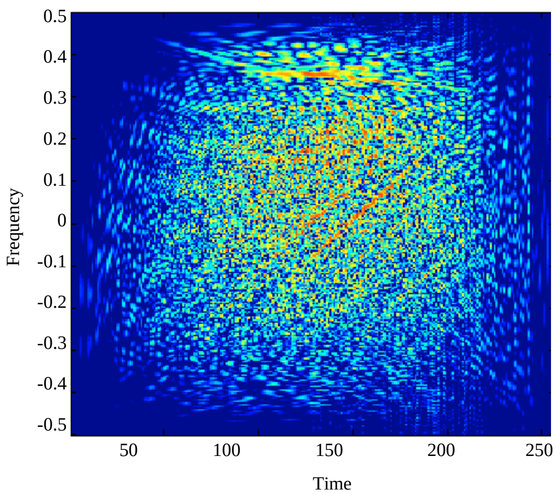

Fig. 2: Watermark with Wigner method

$$W(n) = \cos[2\pi(f_1+k_1nT)nT]+...+\cos[2\pi(f_m+k_mnT)nT] \quad (15)$$

The length of W is n and then choose D0 and D1 two areas with the same size of watermark in wavelet transformation middle frequency domain LH_0 and HL_0 of digital image frame C_{ij}. The method to embed watermark is as followed:

$$D'_0(I, j) = (D_0(I, j)+W(n)),\ D'_1(I, j) = (D_1(I, j)+W(n)) \quad (16)$$

Then we synthesize wavelet to get watermark image. All the frames be done the same way as above-mentioned calculate ways. When withdrawing watermark, we carry on wavelet decomposition again and withdraw a 1-D signal from the known domains. We make dopplerlet transformation on the 1-D signal and detect the linear frequency-modulated signals that are the watermarks. In

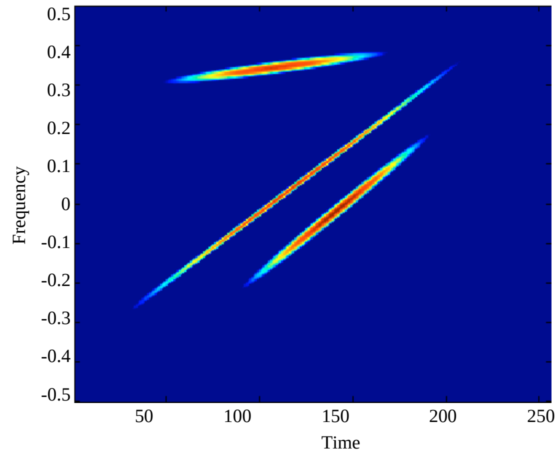

Fig. 3: Watermark with Dopplerlet transformation

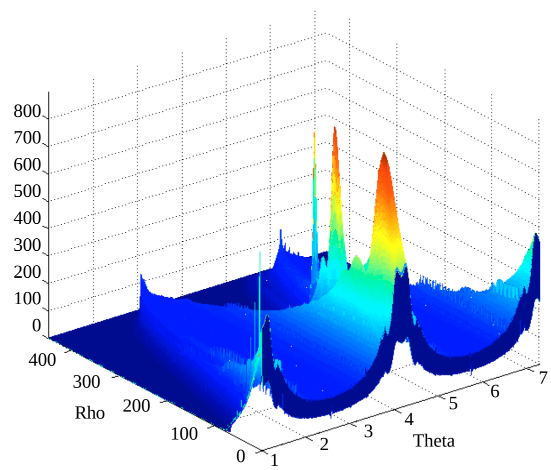

Fig. 4: Watermark with Dopplerlet-Radon transformation

this study, we use standard 256×256 gray image Lena as an original image. Applying Haar wavelet transformation in the algorithm, the image after imbedded the two linear frequency-modulated signals with different frequency as watermark is shown in Fig. 1. The picture frame decomposition adding watermark cuts pictures in the different position and the different size. After cutting an attack withdraw watermark. We cut 75% of the image random, then withdraw watermark. Then extracted watermark result by using wigner transformation is shown such as Fig. 2. Then we use the dopplerlet-radon transformation to detect the watermark shown as Fig. 3 and Fig. 4. According to the result of the experiment, it can be seen that the watermarking image can still be extracted well even the original image is shearing attacked by 75% by dopplerlet-radon transformation. This proves the efficient of the method used above. In the testing process, this algorithm can be used in the reality.

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