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# An Information Hiding Algorithm Based on Improved S-Hough Transformation

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**Abstract**

*In this paper, a robust image watermarking method with S-Hough transformation is proposed which is robust against geometric distortion. This watermarking is detected by a linear frequency change. 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. But the two-dimensional Radon-Wigner transformation needs too much difficult computing. We propose a modified Hough transformation to provide improved energy concentration of the S-transform. The proposed scheme can resolve the time-frequency localization in a better way than the standard S transformation. The watermark is embedded in the 1D improved S transformation domains. The watermark thus generated is invisible and performs well in 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*

***Keywords**: digital watermarking, improved S-Hough transform, geometrical attack*

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## 1. 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 imbed 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 imbed 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 and geometric transmitting, 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. The robustness must be better in the efficient digital watermark [1-5].

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 [6]. 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 improved S transform [7]. In this algorithm, the chirp signals used as watermarks are inserted in the image and the image is put into a series of 1D signal by choosing scalable local time

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windows. By using improved S 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 watermark extracted still can be clear and the algorithm achieves the robustness to the shearing attacks.

## 2. The Principle of Improved S-Hough Transformation

As a linear time-frequency analysis, S transform in [8] has some features similar to the nature of time-frequency domain of the Fourier transform and the wavelet transform. For example, it is a reversible transformation of non-destructive and it's inverse transform can perfectly reconstruct the original signal. So the time-frequency invariant feature ensures that the invariant features with the transformation signal for a specific application. One-dimensional S transform is:

$$S(\tau, f) = \int_{-\infty}^{+\infty} h(t) \frac{|f|}{\sqrt{2\pi}} e^{\frac{-(t-\tau)^2 f^2}{2}} e^{-i2\pi ft} dt \quad (1)$$

Where t, r are t domain variables and f is frequency domain variable. One-dimensional signal $h(t)$ is mapped from the one-dimensional time domain to the two-dimensional time-frequency plane through S transform. One-dimensional S inverse transform is:

$$h(t) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} S(\tau, f) d\tau e^{i2\pi ft} df \quad (2)$$

If S transform is local spectrum, the Fourier spectrum can be received by computing the average local spectrum through the whole time domain. So S transformation:

$$\int_{-\infty}^{+\infty} S(\tau, f) d\tau = H(f) \quad (3)$$

$H(f)$ is the Fourier transform of $h(t)$. $h(t)$ can be deduced from $S(\tau, f)$. S transform is the general Fourier transform of non-stationary time series.

S transform is the linear computation of time series $h(t)$. The transformed noise can often influence time-frequency resolution ratio. If signal $x(t)$ is equal to the sum of original data $s(t)$ and noise $n(t)$.

$$x(t) = s(t) + n(t) \quad (4)$$

After S transform:

$$S\{x(t)\} = S\{s(t)\} + S\{n(t)\} \quad (5)$$

The S transform can not creat cross terms and overwhelmingly increase the time-frequency resolution ratio. If the S transform of $h(t)$ is $S(\tau, f)$, the S transform of $h(t-r)$ is $S(\tau - r, f)e^{-i2\pi fr}$.

From Equation (3), we can know that S transform has direct connection with Fourier transform. S transform and S inverse transform are a lossless reversible procedure. S transform will not create the cross terms and has nice time-frequency energy centralization quality.

Two-dimensional S transform is based on one-dimensional S transform to develop, that formula to transform is:

$$S(x, y, k_x, k_y) = \int_{-\infty}^{+\infty} \left[ \int_{-\infty}^{+\infty} h(x', y') \frac{|k_x|}{\sqrt{2\pi}} e^{(x'-x)^2/2} e^{-i2\pi k_x x'} dx' \right] \frac{|k_y|}{\sqrt{2\pi}} e^{(y'-y)^2/2} e^{-i2\pi k_y y'} dy' \quad (6)$$

Where $h(x', y')$ is the two-dimensional image and $(x', y')$ is the space domain variables. After transformation, S transform spectrum contains 4 variables $(x, y, k_x, k_y)$. $(x, y)$ are the variables in space domain and $(k_x, k_y)$ are the variables in frequency domain, also known as the wavelength. Similar to the two-dimensional Fourier transform, the nature of the two-dimensional S transform can be seen as a cascade of two one-dimensional S transformations [9].

Reference to the fast Fourier transform, the $h(n)(n = 0,1,\cdots, N)$ is the corresponding $h(t)$ discrete time series and sampling time interval is T. The discrete Fourier transform is:

$$H(\frac{1}{NT}) = \frac{1}{N}\sum_{k=0}^{N-1} h(kT)e^{-\frac{i2\pi nk}{N}} \tag{7}$$

The discrete S transformation of time series $h(t)$ is as follows:

$$S[jT, \frac{n}{NT}] = \sum_{m=0}^{N-1} H[\frac{m+n}{NT}]e^{-\frac{2\pi^2 m^2}{n^2}} e^{\frac{i2\pi mj}{N}} \tag{8}$$

When n = 0 (equivalent to zero frequency), discrete form of expression is:

$$S[jT, 0] = \frac{1}{N}\sum_{m=0}^{N-1} h[\frac{m}{NT}] \tag{9}$$

Equation (9) ensures that the time series of anti-transformation can be accurate. Of course, discrete S transformation has been limited by sampling and the length and will have a border effect in time and frequency domain.

Discrete S inverse transformation is to obtain by calculating the discrete Fourier transform. When n is not equal to 0, the summation of S matrix (S [n, m]) along the line is:

$$S[jT, \frac{n}{NT}] = \sum_{j=0}^{N-1}\sum_{m=0}^{N-1} H[\frac{m+n}{NT}]e^{-\frac{2\pi^2 m^2}{n^2}} e^{\frac{i2\pi mj}{N}} \tag{10}$$

Equation (10) can be turned into:

$$S[jT, \frac{n}{NT}] = \sum_{m=0}^{N-1} H[\frac{m+n}{NT}]e^{-\frac{2\pi^2 m^2}{n^2}} \sum_{j=0}^{N-1} e^{\frac{i2\pi mj}{N}} \tag{11}$$

The average of $S[jT, \frac{n}{NT}]$ is:

$$S[jT, \frac{n}{NT}] = \sum_{m=0}^{N-1} N\delta_{m,0} H[\frac{m+n}{NT}]e^{-\frac{2\pi^2 m^2}{n^2}} \tag{12}$$

$$\frac{1}{N}S[jT, \frac{n}{NT}] = H[\frac{n}{NT}] \tag{13}$$

Therefore, discrete inverse S transformation is:

$$h[kT] = \frac{1}{N}\sum_{n=0}^{N-1}\left\{\sum_{j=0}^{N-1} S[\frac{n}{NT}, jT]\right\} e^{\frac{i2\pi nj}{N}} \tag{14}$$

When n is equal to zero, the width of the Gaussian function is zero. Zero frequency is the average of time series and is constant. $S[jT, \frac{n}{NT}]$ is the average of $h[kT]$ when the value of n reduced to zero. That is, every value along zero n value is replaced by this value. In this way, it ensures that S transformation is completely reversible.

The generalized S-transform is given by:

$$S(\tau, f, \beta) = \int_{-\infty}^{+\infty} h(t)\omega(\tau - t, f, \beta)e^{-i2\pi ft} dt \quad (15)$$

Where, $\omega$ is the window function of the S-transform and $\beta$ denotes the set of parameters that determine the shape and property of the window function. The window satisfies the normalized condition.

$$\int_{-\infty}^{+\infty} \omega(t, f, \beta)dt = 1 \quad (16)$$

The alternative expression of (15) by using the convolution theorem through the Fourier transform can be written as:

$$S(\tau, f, \beta) = \int_{-\infty}^{+\infty} X(\alpha + f)W(\alpha, f, \beta)e^{i2\pi\alpha\tau t} d\alpha \quad (17)$$

Where:

$$X(\alpha + f) = \int_{-\infty}^{+\infty} h(t)e^{-i2\pi(\alpha + f)t} dt \quad (18)$$

And $$W(\alpha, f, \beta) = \int_{-\infty}^{+\infty} \omega(t, f, \beta)e^{-i2\pi\alpha t} dt \quad (19)$$

The variable $\alpha$ and f in the above expression have the same units. In this scheme we retain the window function as the same Gaussian window because it satisfies the minimum value of the uncertainty principle. We have introduced an additional parameter into the Gaussian window where its width varies with frequency as follows:

$$\sigma(f) = \frac{\delta}{|f|} \quad (20)$$

Hence the generalized S-transform becomes:

$$S(\tau, f, \delta) = \int_{-\infty}^{+\infty} h(t) \frac{|f|}{\sqrt{2}\pi\delta} e^{-\frac{-(\tau - t)^2 f^2}{2\delta^2}} e^{-i2\pi ft} dt \quad (21)$$

Where the Gaussian window becomes:

$$\omega(t, f, \delta) = \frac{|f|}{\sqrt{2}\pi\delta} e^{-\frac{-t^2 f^2}{2\delta^2}} \quad (22)$$

And its frequency domain representation is:

$$W(\alpha, f, \delta) = e^{-\frac{2\pi^2\sigma^2\delta^2}{f^2}} \quad (23)$$

The Hough transformation is widely applied in line detections on two dimensional noisy images, and has been mainly studied on the ground using camera images as in [5]. It is robust not only for noise but for line disconnections. It needs heavy computation except for straight lines. The line detection procedure is as follows.

At first, the line equation is defined as:

$$\rho = x\cos\theta + y\sin\theta \tag{24}$$

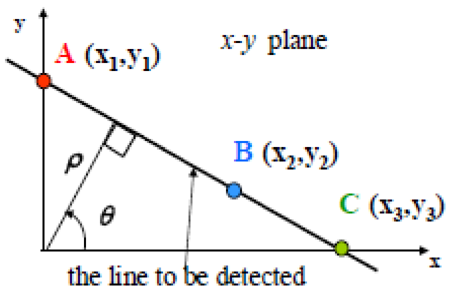


Figure 1. Line Configuration on the Image

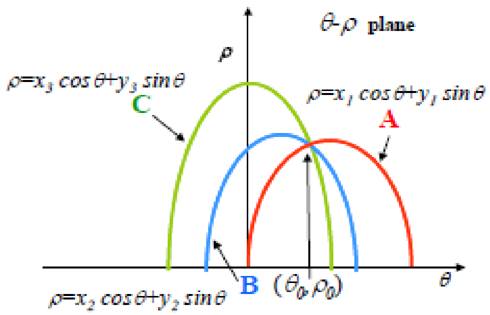


Figure 2. Parameter Curves on the Parameter Space

## 3. 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 [10-11].

We imbed the watermark in the S transformation domain of image. In Stockwell's paper, the S transformation is introduced and can detect linear frequency-modulated signals. But 2D S transformation needs expensive computing. Obviously, it is necessary to apply one-dimensional improved S 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:

$$W(n) = \cos[2\pi(f_1 + k_1 nT)nT] + \cdots + \cos[2\pi(f_m + k_m nT)nT] \tag{25}$$

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 imbed watermark is as followed:

$$D_0'(i,j) = (D_0(i,j) + W(n)), D_1'(i,j) = (D_1(i,j) + W(n)) \tag{26}$$

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 S-Hough transformation on the 1-D signal and detect the linear frequency-modulated signals that are the watermarks.

In this paper, 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 Figure 3. 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, such as Figure 4 and Figure 5. Then we imbedded three linear frequency-modulated signals into the image. The results are shown in Figure 6 and Figure 7 with S transform and S-Hough transform algorithm. It can be seen that the watermarking image can still be extracted well even the original image is shearing attacked by 75%. This proves the efficient of the method used above. In the testing process, this algorithm is superior to the S transformation algorithm.

Figure 3. Watermarked Image

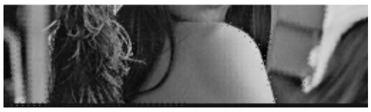

Figure 4. Sheared by 75% Upside

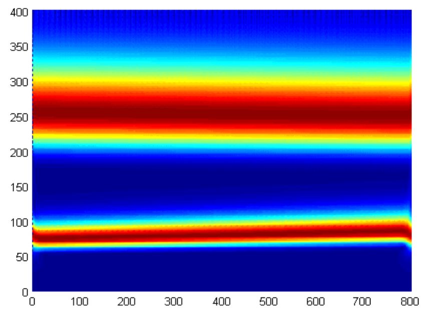

Figure 5. Watermark with Improved S Method

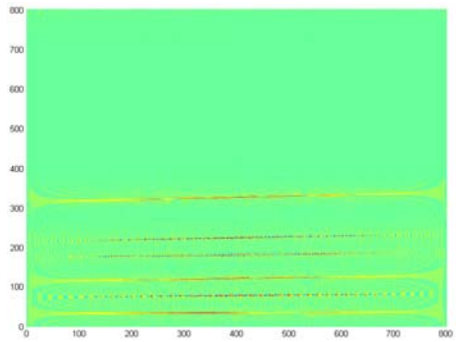

Figure 6. Watermark with Wigner Transformation

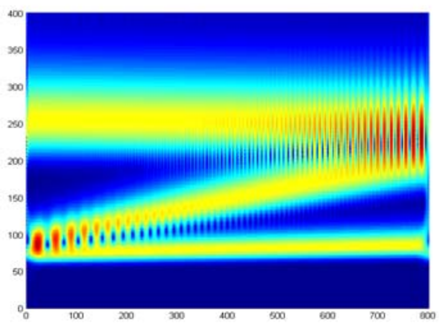

Figure 7. Watermark with S Transformation

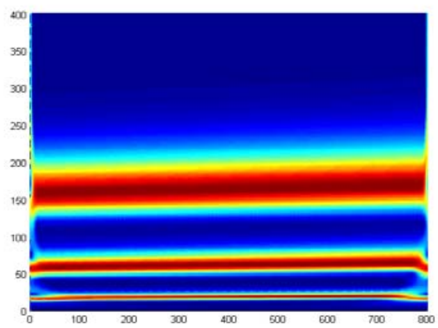

Figure 8. Watermark with Improved S Method

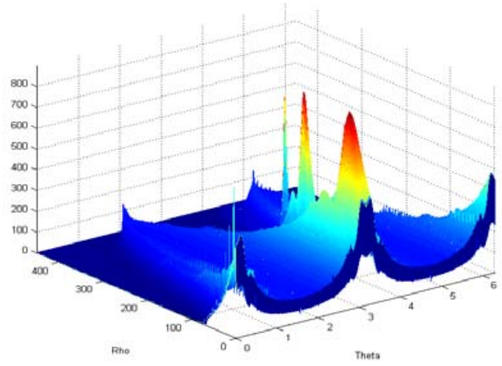


Figure 9. Watermark with S-Hough Transformation

## 4. Conclusion

In this paper, a robust watermarking method against shearing based on S-Radon transform is introduced. The proposed method makes use of the person's sense of vision characteristics and wavelet transformation to achieve the improved S-Hough transform on the image. The linear frequency-modulated signals are selected as watermarks and are added in middle frequency coefficients in the transformation matrix. Based on 1D S transform and Hough transformation, the watermark is extracted. The method improves the validity of watermarking and shows excellent advantage against shearing attack.


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