A new Digital Image Watermarking based on Finite Ridgelet Transform and Extraction using ICA

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Abstract— **This paper presents a new digital image watermarking based on Ridgelet Transform (RT) and extraction using Independent Component Analysis (ICA). Ridgelet transform is a new directional multi-resolution transform and is more suitable for describing the signals with high dimensional singularities. Finite Ridgelet Transform (FRIT) is a discrete version of ridgelet transform, which is a numerical precision as the continuous ridgelet transform and has low computational complexity. Comparing with wavelets, ridgelets find more application on image watermarking, hence it represents smooth and edge parts of image with sparsity, whereas wavelets represent only point singularities. In addition, the representation of ridgelets contains more directional information. Hence, in this work, a digital image watermarking using ridgelets is attempted to obtain high robustness and good imperceptibility. The embedded watermark is extracted using ICA which is based on blind source separation technique. The main advantage of this extraction technique is that it extracts the watermark in spatial domain itself and does not require any transformation process and also it does not require the original image. Simulation results of ridgelet based watermarking are compared with wavelet based watermarking algorithm for digital images. Performance measures like Peak Signal to Noise Ratio (PSNR) and Similarity Measure are calculated to evaluate the performance of Ridgelet based watermarking against various attacks. Results reveal that performance of ridgelet is better when compared to wavelets in digital image watermarking applications.**

***Keywords*— radon transform, independent component analysis, ridgelet transform and wavelet transform.**

I. INTRODUCTION

In the last decade, much extensive attention has been paid to digital watermarking for images, video and audio, because it give a novel solution for the copyright protection of digital media. The image watermarking algorithms can be classified into two groups depending on the domain of watermark embedding i.e. the spatial domain and the frequency domain. It is widely accepted that the frequency domain watermarking algorithms can be easily exploit the perceptual models based on characteristics of Human Visual System (HVS) to achieve the best trade-off between imperceptibility and robustness to image processing, and also easy to be implemented in compressed domain. Hence, many algorithms have been developed in DCT or wavelet domain [1, 2].

Over the last decade, wavelet transform had a growing impact on many fields due to the fact that its theory is based on the local frequency representation as well as its success in applications, such as image denoising, image enhancement and digital watermark. The success of wavelet is mainly due to the good performance for piecewise smooth functions in one dimension. Unfortunately, this ability is lost when it is applied to two dimension or higher dimensions. In essence, wavelets are good at catch zeroth-dimensional (point) singularities. However, 2-D piecewise smooth signals such as images always have first-order and zeroth-order singularity. In addition, 2-D wavelet transform commonly uses separate wavelet basis, which is obtained by applying a 1-D transform separately in each dimension, so it is isotropic and lacks directional information which is a substantial aspect of describing the 1-D singularity [5,6].

To overcome the weakness of wavelets in higher dimensions, Candes and Donoho have recently pioneered on a new system of representations named ridgelets [3]. Ridgelet transform (RT) is a new transform, which deals effectively with line or super-plane singularities. The RT uses basis elements which exhibit high directional sensitivity and are highly anisotropic. It allows obtaining a sparse image representation where the most significant coefficients represent the most energetic direction of an image with straight edges. The main idea is to map a line singularity into a point singularity using the Radon transform. Then, the wavelet transform can be effectively handle the point singularity in the Radon domain. Hence, a ridgelet transform can be implemented via a radon transform with 1D wavelet transform. As the same way, a discrete version of ridgelet transform is obtained by implementing a discrete radon transform and discrete wavelet transform which is explained in section II.

In this paper, it is proposed to implement the ridgelet transform based image watermarking and extraction using ICA for digital images. An image is transformed into ridgelet coefficients by Finite Ridgelet Transform (FRIT) and the watermark is embedded in the transformed coefficients. Inverse transform is performed to obtain the watermarked image. The watermarked image should be imperceptible and robust against various image processing attacks. In the extraction process, a powerful blind source separation technique called Independent Component Analysis (ICA) is implemented to extract the watermark. Performance measures like PSNR and Similarity Measure are calculated to evaluate the performance of the proposed work. Simulation results of ridgelet transform are compared with wavelet transform and the robustness of the technique is evaluated against attacks like rotation, cropping, Gaussian noise addition, median filtering, salt & pepper noise addition and JPEG compression.

This paper is outlined as follows: In section II, the concept and motivation of ridgelets in continuous domain as well as in finite discrete domain are reviewed. Section III discusses the implementation of the proposed work and section IV presents the simulation results. Conclusions are drawn in section V.

II. Ridgelet Transform

Ridgelet transform is a new transform, which deals effectively with line or super-plane singularities. The following section gives a general review of the continuous ridgelet transform theory.

A. Continuous Ridgelet Transform

This section briefly review the ridgelet transform and showing its connections with other transform in the continuous domain. Given an integrable bivariate function $f(x)$, its continuous ridgelet transform (CRT) in R^2 is defined by

$$CRT_f(a,b,\theta)=\int_{R^2}\psi_{a,b,\theta}(x)f(x)dx \tag{1}$$

where the ridgelets $\psi_{a,b,\theta}(x)$ in 2-D are defined from a wavelet-type function in 1-D $\psi(x)$ as

$$\psi_{a,b,\theta}(x)=a^{\frac{-1}{2}}\psi((x_1\cos\theta+x_2\sin\theta-b)/a) \tag{2}$$

The above equation implies that the ridgelet is oriented at an angle θ and is constant along the lines $x_1\cos\theta+x_2\sin\theta=C$, where C is a constant.

For comparison, the separable continuous wavelet transform (CWT) in R^2 of $f(x)$ can be written as

$$CWT_f(a_1,a_2,b_1,b_2)=\int_{R^2}\psi_{a_1,a_2,b_1,b_2}(x)f(x)dx \tag{3}$$

where the wavelets in 2-D are tensor products

$$\psi_{a_1,a_2,b_1,b_2}(x)=\psi_{a_1,b_1}(x_1)\psi_{a_2,b_2}(x_2) \tag{4}$$

of 1-D wavelets, $\psi_{a,b}(t)=a^{\frac{-1}{2}}\psi((t-b)/a)$

As can be seen from equations (1) and (3), the CRT is similar to the 2-D CWT except that the point parameters (b_1,b_2) are replaced by the line parameters (b,θ). In other words, these 2-D multiscale transforms are related by:

Wavelets: $\psi_{scale,point-position}$,

Ridgelets: $\psi_{scale,line-position}$,

As a consequence, wavelets are very effective in representing objects with isolated point singularities, while ridgelets are very effective in representing objects with singularities along lines. In fact, one can think of ridgelets as a way of concatenating 1-D wavelets along lines. Hence, the motivation for using ridgelets in image processing tasks is appealing since singularities are often joined together along edges or contours in images. In 2-D, points and lines related via the Radon transform, thus the wavelet and ridgelet transforms are linked via the Radon transform. More precisely, the Radon transform is denoted as

$$R_f(\theta,t)=\int_{R^2}f(x)\delta(x_1\cos\theta+x_2\sin\theta-t)dx, \tag{5}$$

then the ridgelet transform is the application of a 1-D wavelet transform to the slices of the Radon transform,

$$CRT_f(a,b,\theta)=\int_R\psi_{a,b}(t)R_f(\theta,t)dt. \tag{6}$$

Figure 1 shows the relation between radon and ridgelet transform, where the application of 1-D wavelet transform to the slices of the radon transform results in ridgelet transform.

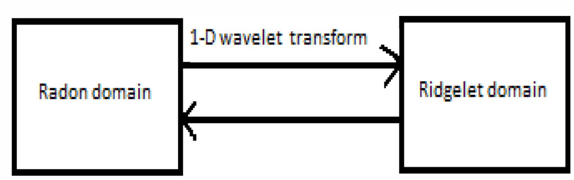


Fig.1. Relation between transforms.

Finite Ridgelet Transform (FRIT) is a discrete version of ridgelet transform proposed by Do and Vetterli [4], which is as numerical precision as the continuous ridgelet transform and has low computational complexity. As suggested above, a discrete FRIT can be obtained via a Discrete Finite Radon transform (FRAT) and a 1-D discrete wavelet transform suitable for signals of prime length as shown in Figure 2.

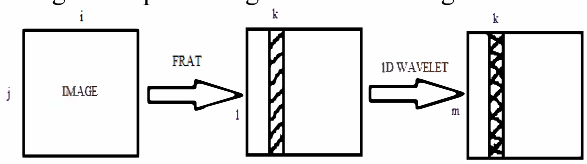


Fig. 2. Diagram of the finite ridgelet transform

The FRAT is defined as summations of image pixels over a certain set of lines. Those lines are defined in a finite geometry in a similar way as the lines for continuous radon transform in the Euclidean geometry [4]. Denote $Z_p = \{0,1,2,......p-1\}$, where p is a prime number. Note that Z_p is a finite field with modulo p operations. For later convenience, we denote $Z_p^* = \{0,1,2,......p\}$.

The FRAT of a real function f on the finite grid Z_p^2 is defined as

$$r_k[l] = FRAT_f(k,l) = \frac{1}{\sqrt{p}} \sum_{(i,j)\in L_{k,l}} f[i,j] \quad (7)$$

Here $L_{k,l}$ denotes the set of points that make up a line on the lattice Z_p^2, or more precisely

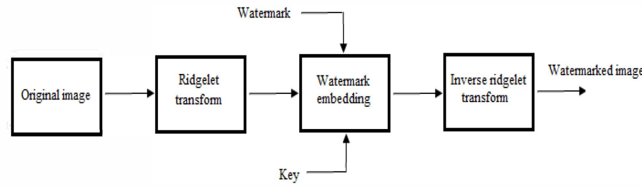
$$L_{k,l} = \{(i,j) : j = ki + l (\bmod p), i \in Z_p\}, 0 \le k < p,$$
$$L_{p,l} = \{(l,j) : j \in Z_p\} \quad (8)$$

Due to the modulo operations in the definition of lines for the FRAT, these lines exhibit a wrap around effect in the transform. In other words, the FRAT treats the input image as one period of a periodic image. It is observed in FRAT domain, the energy is best compacted if the mean is subtracted from the image $f[i,j]$ prior to taking the transform as given in eqn. (7), which is assumed in the sequel. The factor $\frac{1}{\sqrt{p}}$ is introduced in order to normalize the l_2-norm between the input and output of the FRAT.

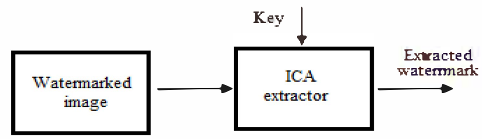
With an invertible FRAT and applying (6), we can obtain an invertible discrete ridgelet transform by taking the discrete wavelet transform on each FRAT projection sequence, $(r_k[0], r_k[1], ... r_k[p-1])$, where the direction k is fixed. The overall result is called as ridgelet transform as shown in Fig.2.

III. Implementation Of The Proposed Scheme

In this paper work, ridgelet transform is implemented for a gray scale Lena image of size 256x256. A binary image of size 64x64 is taken as watermark and it is embedded in the ridgelet coefficients along with a random key. Fig. 3 explains the embedding and extraction process of the proposed watermarking scheme.



a)Embedding process



b)Extraction process

Fig. 3. Diagram of the proposed watermarking scheme

As shown in the above figure, the original image is first transformed into radon coefficients using FRAT as explained in the previous section. Then these coefficients are 1D wavelet transformed along columns, where each column is a projection vector of radon transform. This entire process is termed as ridgelet transform where the watermark is embedded into the resultant ridgelet coefficients.

To obtain the watermarked image, an Inverse Ridgelet Transform (IFRIT) is performed. The PSNR between the original and watermarked image is calculated to evaluate quality of the watermarked image in terms of imperceptibility. To evaluate the robustness of the proposed scheme, various attacks like noise addition, filtering, cropping and JPEG compression are performed on the watermarked image.

On the extraction process, a blind source separation technique called Independent Component Analysis (ICA) is used to extract the watermark. A basic ICA model is given by

$$X = AS \rightarrow \overline{S} = WX \quad (9)$$

Where X - mixture signal,
A -mixing matrix,
S -independent source,
W -demixing matrix

ICA is a statistical technique for obtaining independent sources S from their linear mixtures X , when neither the original sources nor the actual mixing A are known. This is achieved by exploiting higher order signal statistics and optimization techniques. The result of the separation process is a demixing matrix W , which can be used to obtain the estimated unknown sources $\overline{S}$ from mixtures. Appo Hyvarinen and Erkki Oja have proposed an ICA called FastICA algorithm and it is based on a fixed-point iteration scheme [7].

The degree of similarity of the extracted watermark with the original watermark is calculated using a performance measure called Similarity Measure given by

$$SimMeas(X, X') = \frac{X.X'}{\sqrt{X'.X'}} \qquad (10)$$

where X is the original watermark and X' is the extracted watermark.

IV. SIMULATION RESULTS

Simulation is carried using Matlab 7 software. Lena image of size 256x256 is taken as original image, where a binary text image of size 64x64 is considered as watermark are shown in Fig.4 and Fig.5, respectively.

In wavelet transform, the original image is decomposed up to second level and the watermark is embedded in the middle frequency sub band along with the key. Inverse discrete wavelet transform is performed to obtain the watermarked image and it is shown in Fig.6.

In ridgelet transform, the image is represented in radon coefficients using discrete radon transform and a 1-D wavelet transformed is performed on the radon coefficients to obtain the ridgelet coefficients. Then the watermark is embedded into the ridgelet coefficients in the same way as in wavelet transform. An inverse ridgelet transformed is performed via inverse radon transform to obtain the watermarked image and it is shown in Fig.7.

On comparing the two watermarked images, the later one is visually and statistically better than the former one. The reason is line singularities are easily captured by ridgelets and are treated in the embedding process to ensure imperceptibility. It is proved by the high PSNR values which are tabulated in Table 1.

To check the robustness of the proposed scheme, various attacks like rotation, cropping, Gaussian Noise addition, Median Filtering, Salt & Pepper noise addition and JPEG compression are performed over the watermarked image obtained using ridgelets and the results are presented in Fig.8-13 correspondingly. The results infer that the energy retained after attacks are considerably high and it is proved by high PSNR values that are tabulated and compared with wavelets in Table 1. It is noted that a considerable difference in the values show the better performance of ridgelets over wavelets.

In the extraction process, the ICA detector extracts the watermark from the watermarked mixture that contains original image, watermark and key. The extracted watermarks from both watermarked images (Fig.6 and Fig.7) are shown in Fig.14 and Fig.15 respectively. Here also, the ICA extracts watermark better from Fig.7 when compared to Fig.6., due to the presence of redundant data in ridgelet transform, where wavelet transform lose its in its 2-D decomposition. Similarity measure calculated between the original watermark and the extracted watermark is also tabulated in Table 1 for WT and RT.

Fig. 4. Original image

Fig. 5. Watermark

Fig.6. Watermarked image by wavelet transform

Fig.7. Watermarked image by ridgelet transform

Fig. 8. Rotated by 30 deg.

Fig.9. Cropped 15 %

Fig. 10. Gaussian noise added

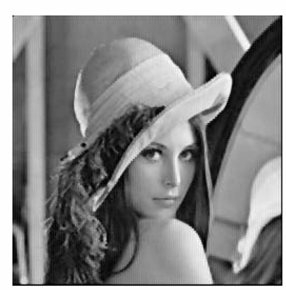


Fig.11. Median filtered (5x5)

Fig. 12. Salt & Pepper noise added

Fig. 13. JPEG compressed

Fig. 14. Extracted watermark from wavelet transform

Fig. 15. Extracted watermark from ridgelet transform

Table 1. Performance comparison of ridgelet transform with wavelet transform for image watermarking

Sl. No.	**Attacks**	**PSNR (dB)**		**Sim. Meas.**	
		WT	**RT**	**WT**	**RT**
1.	Rotation	18.27	23.18	0.8221	0.8764
2.	Salt & Pepper noise added	19.80	21.29	0.8322	0.8884
3.	Gaussian noise added	20.91	22.32	0.8511	0.9001
4.	Median filtered	21.23	24.82	0.8692	0.9231
5.	Cropping	13.27	19.88	0.7913	0.8195
6.	JPEG compressed	18.87	23.93	0.8244	0.9123

V. Conclusion

An attempt is made in this paper to implement a digital image watermarking based on ridgelet transform and extraction by ICA. The advantage of ridgelets is its sparse representation of line singularity in images, where wavelets represent only point singularity. This feature of ridgelet made the watermarking system more robust to attacks and retains the energy level as high as possible. Simulation results confirm that the performance of ridgelets is superior to wavelets and is well suited for image watermarking applied for copyright protection and authentication purpose.

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