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## Digital Watermarking using Multiscale Ridgelet Transform

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**Abstract** - The multi-resolution watermarking method for digital images proposed in this work. The multiscale ridgelet coefficients of low and high frequency bands of the watermark is embedded to the most significant coefficients at low and high frequency bands of the multiscale ridgelet of an host image, respectively. A multi-resolution nature of multiscale ridgelet transform is exploiting in the process of edge detection. Experimental results of the proposed watermarking method are compared with the previously available watermarking algorithm wavelet transform. Moreover, the proposed watermarking method also tested on images attached by Discrete Cosine Transform (DCT) and wavelet based lossy image compression techniques.

**Keywords** - Image Denoising; Multiscale Ridgelet Transform; Ultrasound Images.

### I. INTRODUCTION

The existing literature includes several taxonomies for digital watermarking. Among these, the most common taxonomies are embedding in spatial and frequency domains. Spatial domain methods [1, 2] are less complex and not robust against various attacks as no transform is used in them. The basic idea behind spatial domain methods is the modification of pixel intensities while embedding watermark. Transform domain methods are robust as compared to spatial domain methods. This is due to the fact that when image is inverse transformed, watermark is distributed irregularly over the image, making the attacker difficult to read or modify. The basic idea behind transform domain methods is to transform the media by the means of Fourier Transform (FT) [3], Discrete Cosine Transform (DCT) [4], Fractional Fourier Transform [5, 6, 7], Wavelet Transform [8, 9, 10, 11, 12, 13] etc. Then, the transform domain coefficients are altered to embed the watermark and finally inverse transform is applied to obtain the watermarked digital media. Schyndel et al. [1] have proposed two methods in which first method is based on bit plane manipulation of the LSB whereas second method is based on the linear addition of the watermark to the image data, which is more difficult to decode, offering inherent security. Hwang et al. [2] have presented a watermarking scheme employed in spatial domain using hash functions. Cox et al. [3] have presented the most popular watermarking schemes based on the Spread Spectrum Communication. The watermark is embedded into the first  $k$  highest magnitude DFT/DCT coefficients of the image and extraction is done by comparing the DFT/DCT coefficients of the watermarked and the original image. Barni et al. [5] have proposed a watermarking algorithm, which operates in the frequency domain, embeds a

pseudo-random sequence of real numbers in a selected set of DCT coefficients.

The watermark can be reliably extracted blindly by exploiting the statistical properties of the embedded sequence. Djurovic et al. [5] have proposed fractional Fourier transform based watermarking scheme for the multimedia copyright protection. After decomposing image via FRFT, transformation coefficients are reordering in nonincreasing sequence and the watermark is embedded in the middle coefficients. Feng et al. [6] have proposed a blind watermarking algorithm in which multiple chirps are used as watermark and embedded in the spatial domain directly but detected in the FRFT domain. Yu et al. [7] have used the same logic proposed by Feng et al. [6], the only difference is that the embedding is done in FRFT domain where watermark position and the transform order are used as the encryption keys. Xia et al. [8] have added a pseudo-random sequence to the largest coefficients of the detail bands where perceptual considerations are taken into account by setting the amount of modification proportional to the strength of the coefficient itself. Watermark detection is achieved through comparison with the original un-watermarked image. Barni et al. [9] proposed a method based on the characteristics of the human visual system operating in wavelet domain. Based on the texture and the luminance content of all image sub-bands, a mask is accomplished pixel by pixel. Kundur et al. [10] proposed the use of gray scale logo as watermark. They addressed a multiresolution fusion based watermarking method for embedding gray scale logos into wavelet transformed images via saliency factor. Wang et al. [11] and Zhang et al. [12] proposed a new watermarking algorithm based on wavelet tree quantization. The detailed survey on wavelet based

watermarking techniques can be found in [13].

3. A multi-resolution nature of multiscale ridgelet transform is proposed in this paper. Experimental results of the proposed watermarking method are compared with the previously available watermarking algorithm wavelet transform.

4. The organization of the paper as follows: In section I, a brief review of image denoising and related work is given. Section II, presents a concise review of ridgelet transform. Section III, presents the thresholding methods for image denoising and proposed system framework. Experimental results and discussions are given in section IV. Based on above work conclusions are derived in section V.

## II. RIDGELET TRANSFORM (RT)

### A. Radon Transform

The Radon transform of an object  $f$  is the collection of line integrals indexed by  $(\theta, t) \in [0, 2\pi) \times R$  given by

$$Rf(\theta, t) = \int f(x_1, x_2) \delta(x_1 \cos \theta + x_2 \sin \theta - t) dx_1 dx_2 \quad (1)$$

where  $\delta$  is the Dirac distribution. The ridgelet coefficients  $CRT_f(a, b, \theta)$  of an object  $f$  are given by analysis of the Radon transform via

$$CRT_f(a, b, \theta) = \int Rf(\theta, t) a^{-1/2} \psi((t-b)/a) dt \quad (2)$$

Basic algorithm for discrete radon transform is as follows

3. Compute the two-dimensional Fast Fourier Transform (FFT) of function  $f$ .
4. Using an interpolation scheme, substitute the sampled values of the Fourier transform obtained on the square lattice with sampled values of  $\hat{f}$  on a polar lattice: that is, on a lattice where the points fall on lines through the origin.

Compute the one-dimensional Inverse Fast Fourier Transform (IFFT) on each line; i.e., for each value of the angular parameter.

### B. Discrete Ridgelet Transform (DRT)

A continuous ridgelet transform is calculated by applying 1D wavelet transform to the slices of radon transform  $R_f(\theta, \cdot)$ . In radon transform a famous projection-slice theorem is used

$$\hat{f}(\omega \cos \theta, \omega \sin \theta) = \int R_f(\theta, t) e^{-2\pi i \omega x} dt \quad (3)$$

This theorem says that the Radon transform can be obtained by applying the one-dimensional inverse Fourier transform to the two-dimensional Fourier transform of function restricted to radial lines through the origin. The relation among the Fourier, radon and ridgelet domain is depicted in Fig. 1.

To complete the ridgelet transform, apply a one-dimensional wavelet transform along the radial variable in Radon space. The sum up of above procedure is shown in Fig. 2 in the form of flow chart. The DRT of an image of size  $n \times n$  is an image of size  $2n \times 2n$ , introducing a redundancy factor equal to 4 [14, 15].

### C. Multiscale Ridgelet Transform (MRT)

Multiscale ridgelets based on the ridgelet transform combined with a spatial bandpass filtering operation to isolate different scales as shown in [14].

Algorithm:

4. Apply the 'a trous algorithm with  $J$  scales [16].
5. Apply the radon transform on detail sub-bands of  $J$  scales.
6. Calculate ridgelet coefficients by applying 1-D wavelet transform on radon coefficients.

Get the multiscale ridgelet coefficients for  $J$  scales.

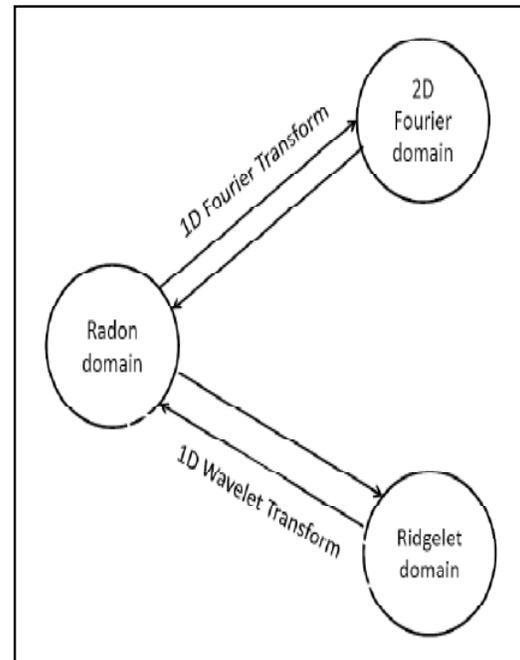


Fig. 1: Relations between transforms.

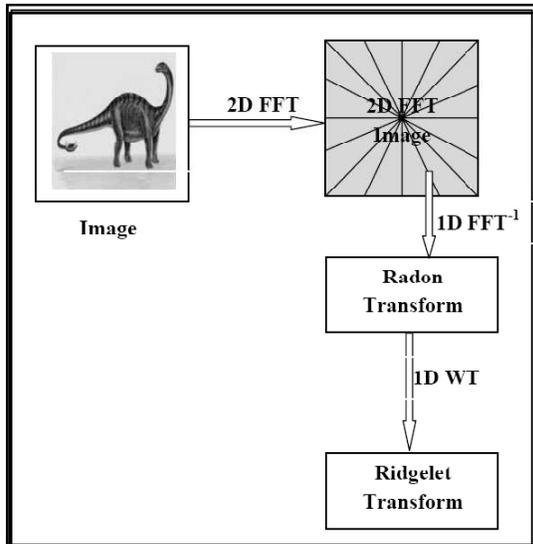


Fig. 2: Flowchart of Discrete ridgelet transform.

### III. WATERMARKING SCHEME

#### A. Watermark Embedding

In the embedding part shown in Fig. 4, the original image and the watermark are first decomposed using Multiscale ridgelet Transform. Then, the Multiscale ridgelet coefficients  $W_{MRT}(low)$ , of the low-resolution representation of the watermark  $W$ , are embedded in the largest Multiscale ridgelet coefficients  $I_{MRT}(low)$  of the low-resolution representation of the original image  $I$ , in the following way:

$$I'_{MRT}(low) = I_{MRT}(low)(1 + \alpha W_{MRT}(low)) \quad (4)$$

Spectrum analysis of the images reveals that most of the information in image is located in this low-resolution representation, which represents the smooth parts of the image. It is also known that human eyes are very sensitive to small changes in smooth part of the image. However, with the appropriate choice of the scaling parameter  $\alpha$ , the invisibility of the watermark could be adjusted. Conversely, in case of possible attacks, the low-resolution representation of the watermark will still be preserved within the low-resolution representation of the image, which makes the watermark robust.

Other coefficients of the watermark are embedded in the higher frequency components of the image, which represent the edges and textures of the image. Using above Eq. (4) either will produce watermarked image that is not robust to image operations that perform low pass filtering (for small values of  $\alpha$ ) or will create visible defects in the images (for larger values of  $\alpha$ ). So in order

to increase the robustness of the watermark, following equation is used:

$$I'_{MRT}(high) = I_{MRT}(high) + \beta W_{MRT}(high) \quad (5)$$

Since human eyes are not sensitive to small change in the edges and the textures of the image, invisibility of the watermark is kept. The watermarked image is obtained by applying inverse Multiscale ridgelet transform to the coefficients  $I'_{MRT}$ . The watermarked image may then be subject to any number of distortions due to intentional or unintentional image processing operations.

#### B. Watermark Extraction

In the decoding process shown in Fig. 4, MRT of the suspected image  $\bar{I}$  and of the original (unwatermarked) image is performed. Multiscale ridgelet coefficients of the low-resolution representation of the extracted watermark are obtained as:

$$\bar{W}_{MRT}(high) = \frac{1}{\alpha} \left[ \frac{\bar{I}_{MRT}(high)}{I_{MRT}(high)} - 1 \right] \quad (6)$$

and wavelet coefficients in other frequency subbands as:

$$\bar{W}_{MRT}(low) = \frac{1}{\beta} \left[ \bar{I}_{MRT}(low) - I_{MRT}(low) \right] \quad (7)$$

With inverse Multiscale ridgelet transform of  $\bar{W}_{MRT}$  the extracted watermark  $\bar{W}$  is obtained.

#### C. Similarity measurement

The extracted watermarks can be compared with original watermark subjectively. Beside subjectively judgment for the watermark fidelity, we have defined an objective measure of similarity between the original watermark and the extracted watermark in the following way:

$$SIM = \frac{\sum_i \sum_j W(i, j) \bar{W}(i, j)}{\sum_i \sum_j [\bar{W}(i, j)]^2} \quad (8)$$

For instance, applying any image processing operation to the watermarked image that performs lowpass filtering (compression, resizing), will result in loss of multiscale ridgelet coefficients in higher frequency bands of the watermark. In this case, multiscale ridgelet coefficients in lower frequency subbands to be used to determine whether suspected image contains watermarks.

### IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

For evaluation of the proposed method, the image Lena of size 256x256 is used as test image (Fig. 4 (top left)), and image pattern of size 256x256 (Fig. 4 (top

right)) is used as watermark. A two level multiscale ridgelet transforms of the test image Lena and one level multiscale ridgelet of the watermark is obtained. Choice of  $\alpha = 0.00045$  and  $\beta = 0.006$  seems to give the best results in sense of robustness versus visibility. Watermarked Lena images obtained with proposed watermarking method is shown in Fig. 4(b). It can be seen that there is almost invisible difference between the watermarked and the original image, thus proving that the requirement of watermark invisibility is satisfied. In following, some geometric manipulations and

compressions are applied to the watermarked image in order to test algorithm robustness.

The wavelet transform based watermarking also implemented to compare the performance of the proposed method with the wavelet transform based watermarking. Fig. 5 (bottom right) extracted watermark using wavelet transform based algorithm. From Fig. 4 and 5, it is clear that the proposed method is showing better performance for watermark extraction.

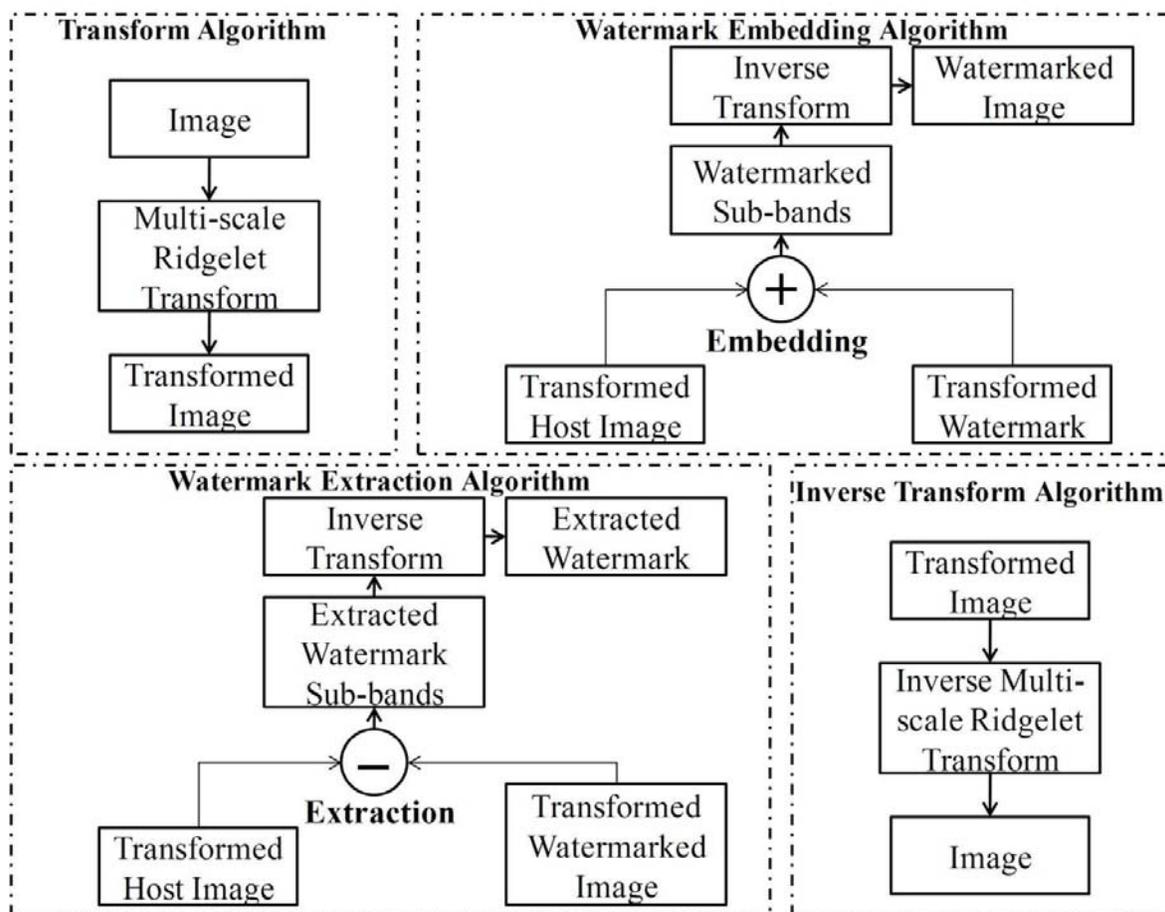


Fig. 3: Proposed watermarking algorithm

#### A. Robustness to DCT and DWT based compression

Image compression can be considered as the most common signal processing operation performed on images. Resistance to this operation is good test for watermarking robustness. Since, DCT [17, 18] is base of current international standard for still image compression, JPEG, and since DWT [18] is expected to be base of up-coming image compression standard JPEG2000, resistance to DCT and DWT based compression schemes are investigated in this experiment.

The MATLAB code is implemented by us is used for this purpose. The different compression ratios are chosen for this purpose. Extracted watermarks are shown in Fig. 6, suggesting that the proposed watermarking method is robust to lossy compression. Increasing the compression ratio leads to visible distortion of the image and digital watermarking becomes less meaningful. Even then, watermark could be detected with the proposed watermarking algorithm, if subjective and objective measurements are applied to low-resolution representation of the extracted watermark.

**B. Robustness to resizing**

In this experiment image is reduced to 50% of its original size. For this purpose MATLAB function “*imresize*” is used. In this process fine detail are lost since subsampling of the image requires a lowpass spatial filtering operation. In order to recover the watermark, reduced image using the same function is rescaled back to the same size of the original image. Fig. 7 shows the extracted watermark.

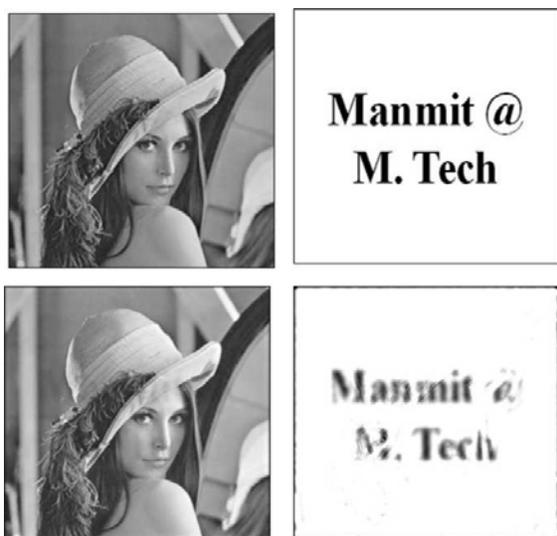


Fig. 4: Watermarking results of the proposed method (left top) test Lena image, (bottom left) the watermarked image, (right top) the watermark, (bottom right) extracted watermark ( $SIM = 0.996$ ).

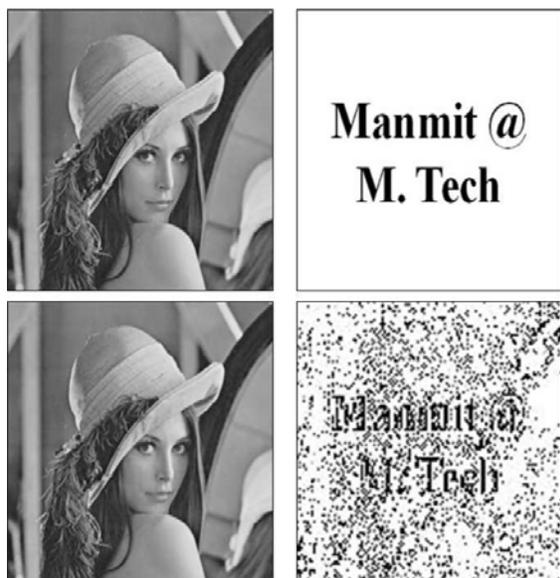


Fig. 5: Watermarking results of the wavelet transform method (left top) The test Lena image, (bottom left) the watermarked image, (right top) the watermark, (bottom right) extracted watermark ( $SIM = 0.906$ ).

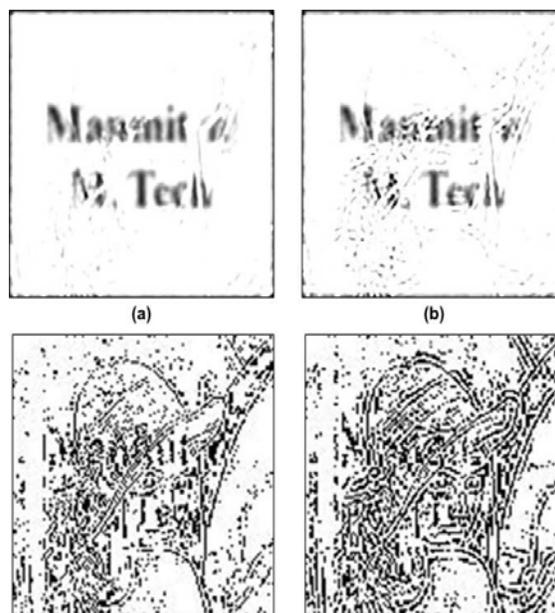


Fig. 6: Extracted watermarks of DCT compressed version of the watermarked image shown in Fig. 4 (left bottom): (a) with compression ratio 8:1, (b) with compression ratio 11.38:1 using proposed method and (c) and (d) using wavelet transform method.

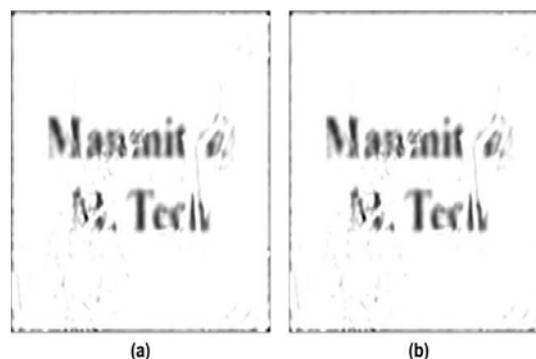


Fig. 7: Extracted watermark of rescaled watermarked image shown in Fig. 4(bottom left) where 50% reduction and enlargement is done.

**V. CONCLUSIONS**

In this paper, a watermarking method was presented using multiscale ridgelet transform. Experimental results demonstrated that the watermarked image based on proposed method is best compared to wavelet transform method. Moreover, proposed watermarking method is robust to DCT and DWT based lossy image compression schemes, and geometric manipulations like image resizing.

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