Performance Analysis of Fractional Redundant Wavelet Transform for Watermarking Scheme

Harpal Singh, Ramneek Kaur Brar, Priyanka Kaushal

Abstract— In this paper, an algorithm for digital image watermarking which utilizes the hybridization technique is presented. The hybrid technique is formulated by combining the Redundant Wavelet Transform (RDWT) with Fractional Fourier Transform (FrFT) and Singular Value Decomposition (SVD). In this technique, watermark information is embedded in the low frequency band of Redundant Wavelet Transform. To increase the robustness, FrFT is implemented on low frequency coefficients of RDWT. Experimental results have been demonstrated on the basis of Peak Signal to Noise Ratio (PSNR), Correlation Coefficient (CC), and Gradient Magnitude Similarity Deviation (GMSD). A comparable improvement is witnessed from the results in terms of qualitative and quantitative analysis. The experimental results prove to be robust against various image processing and geometrical attacks applied on the standard test images.

Index Terms*: *Logo Watermarking; Fractional Fourier Transform (FrFT); Redundant Wavelet Transform (RDWT); Singular Value Decomposition (SVD), Gradient Magnitude Similarity Deviation (GMSD).

I. INTRODUCTION

The expeditious escalation of internet, together with rapid development in electronic commerce, online services, broad ranging evolution of digital technologies, open network access and effortlessly replicated digital media, has expanded the popularity of digital media. The present day challenge is to find ways for safeguarding the proprietorship of such digital products or media while allowing the comprehensive utilization of network technologies and internet resources. One of the most widely used solutions to enhance the security of digital data against these issues is digital watermarking[1][2] [3][4]. It is the process in which a watermark is permanently appended into the digital content without causing any serious degradation of the original digital media content, such that the watermark can withstand any inappropriate operation. Any watermarking technique must satisfy some fundamental attributes including capacity, robustness, security and imperceptibility.

Based on the type of carrier, watermarking can be classified as text watermarking, image watermarking, video watermarking and audio watermarking.

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On the basis of representation, we can classify digital watermarking as visible watermarking and invisible watermarking. Depending on the embedding domain, watermarking can be classified as spatial domain watermarking and transform domain watermarking. In spatial domain watermarking, we embed the watermark by directly modifying the pixel intensities and in transform domain watermarking, the digital content is first transformed into the frequency domain, then we alter the transform domain coefficients to embed the watermark. Finally, the inverse transform is applied to obtain the watermarked content. A number of transform domain watermarking methods have been proposed and discussed by various researchers which include techniques like Discrete Cosine Transform (DCT), Discrete Fourier Transform (DFT), Discrete Wavelet Transform (DWT), Fractional Fourier Transform (FrFT), Integer Wavelet Transform (IWT), Redistributed Invariant DWT (RIDWT), Lifting Wavelet Transform (LWT), Redundant Wavelet Transform (RDWT), etc. The proposed transform domain method involves the hybridization of RDWT [5]–[11] and FrFT [12]–[14] with matrix decomposition technique of SVD [15]–[20]. The hybridization is done to overcome the problems of shift variance in DWT and false positive problem in SVD. Diverse signal processing or geometric operations can modify the digital data, some of which have been used in the proposed scheme to test for the robustness of the watermarking technique. Lastly a comparative analysis is made between the proposed method and the Fractional Wavelet Transform (Fr-DWT) [21]–[23] technique on the basis of GMSD [24]. Many researchers and analysts have proposed and discussed various advancements in the watermarking system, some of which have been reviewed while proposing the novel proposed technique. In 2016, R. Choudhary et al. [25] used 2-level DWT for watermarking and the watermark is inserted using the variable visibility factor. N. Li et al. [26] provided an algorithm based on DWT in which the watermark used was a binary image watermark. Arnold transform is used to eliminate the spatial correlation. P. Saravanan [27] in 2016, used the hybridization technique using DWT, DFT and SVD transforms. C. Chang et al.[17], proposed a scheme based on SVD. In 2018, Neeru Jindal et al. [28] provided an exhaustive detail about the applicability and use of fractional transforms in image processing. C. Lai [20] in 2011 provided an enhanced SVD-based watermarking technique considering the human visual characteristics. In 2012, N. Kashyap [29] presented a technique based on 3-level DWT in which a multi-bit watermark is embedded by using alpha blending procedure. M. T. Taba [12] in 2013 provided a watermarking method based on the Discrete Fractional

Fourier Transform in which the detection of the watermark is based on coding the 0 and 1 with different PN sequence code. In 2012 Y. Chen et al. [30] used the hybridization of DFRFT, DWT and SVD in which the watermark is embedded by transforming the singular values. In 2013, S. Bansal [13] used the Fractional Fourier Transform to extract the false watermark and solve the problem of false positive in SVD. In 2014, H. Singh et al. [22] discussed a multi-resolution logo watermarking method by means of fractional M-band wavelet transform (Fr-M-band-WT) and SVD. H. Singh et al. [23] in 2014 proposed a logo watermarking method based on fractional M-band dual-tree complex wavelet transform (Fr-M-band-DT-CWT). In 2013, G. Bhatnagar et al. [9] provided a watermarking technique based on the hybridization of redundant fractional wavelet transform, reversible extension transform and singular value decomposition (SVD) in which two watermarks are embedded. D. Hien [31] provided a watermarking system in which RDWT is used for watermark embedding and independent component analysis (ICA) is applied for watermark extraction. In 2018, F. Ernawan et al. [5] discussed a blind watermarking method based on the hybridization of RDWT with SVD. This algorithm also makes use of techniques like modified entropy of the image and Arnold chaotic map.

II. THE REDUNDANT WAVELET TRANSFORM (RDWT)

The redundant wavelet transform (RDWT) has been proposed as a solution to the major shortcoming found in DWT [26][25] i.e. shift variance. Shift variance takes place because of the down sampling procedure carried out in DWT after each filtering level which leads to wavelet coefficients being significantly changed even for minor shifts in the image. It leads to inaccurate extraction of the cover and watermark image. In RDWT, the low pass signal is not down sampled with each filter bank iteration. Instead, the filters are themselves up sampled prior to performing convolution at each level. In RDWT, the original image and the subbands have the same size which helps in keeping the important texture of the image at same spatial locations in each subband. The redundancy of RDWT provides an over complete frame expansion which increases the robustness to noise. A large logo watermark can be embedded using RDWT, increasing the robustness.

III. THE SINGULAR VALUE DECOMPOSITION (SVD)

In digital watermarking, SVD [15] can be used to embed the watermark onto the singular matrix of the frequency domain coefficients of an image, which is unsusceptible to the changes caused by watermarking attacks. This technique is widely used because of its good stability and its immunity against interfering signals. But we cannot apply SVD alone on an image because of two important reasons. One being the exhaustive computations involved when SVD is applied alone and the other reason is the problem of false positive in SVD. That is why it is preferred to implement SVD in hybridization with other transforms. The SVD based techniques which embed the watermark by modifying the singular values instead of singular vectors have the advantages of stability and robustness but they are vulnerable to False Positive Problem (FPP) in which a counterfeit watermark is detected from the digital content, which is an another watermark. The scaling factor has an important role in SVD based watermarking systems to control the imperceptibility and robustness of the watermark. For higher values of the scaling factor, high robustness is achieved at the cost of image quality and for the lower values of the scaling factor, transparency is improved at the cost of robustness against watermarking attacks. Thus there exists a trade-off between robustness and imperceptibility.

IV. THE FRACTIONAL FOURIER TRANSFORM (FRFT)

The fractional Fourier transform [14] is a generalized form of the Fourier transform and has become a substantial and foreseeable tool for time-varying and non-stationary signal processing. The FrFT domain can be well thought-out as a combination of time and frequency domains. The important property of FrFT is that the signal is completely in time domain if the transform order is 0 and in completely frequency domain if the transform order is $\frac{\pi}{2}$. Further, we can achieve higher dimensional FrFT simply by consecutively taking one dimensional FrFT in all directions, owing to the seperability of the transform. One of the most important advantage of using FrFT in watermarking systems lie in the fact that it depends on the transform orders, which can be used as keys for watermark extraction process.

V. THE FRACTIONAL REDUNDANT WAVELET TRANSFORM

In this paper, the hybridization of RDWT, FrFT and SVD has been used to suggest a robust watermarking technique. The watermark embedding and extraction algorithms have been discussed in the further sections. Fig.1 and Fig.2 show the block diagrams if the embedding and extraction processes.

A. Watermark Embedding Algorithm

1. Load the host image and the watermark.
2. Convert the host image from RGB to gray.
3. Apply RDWT and decompose the image into sub bands. Select the lower sub band.
4. Apply 2-D FrFT to the selected sub band.
5. Apply SVD to FrFT2D (LL).
6. Convert the watermark from RGB to gray and apply SVD to the lower frequency sub band.
7. Obtain the modified FrFT2D coefficients by applying inverse SVD.
8. Obtain the modified sub bands of inverse RDWT by applying inverse FrFT2D to modified FrFT2D coefficients.
9. To get the watermarked image, apply inverse RDWT.
10. Watermarked image is achieved.

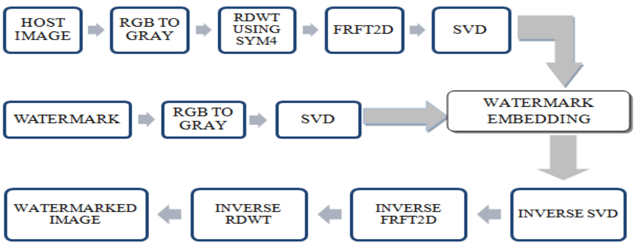

Fig.1. Block diagram for the watermark embedding algorithm.

B. Watermark Extraction Algorithm

1. Select the low frequency sub band after RDWT is applied to the watermarked image.
2. FrFT2D is applied to the selected low frequency sub band.
3. Obtain the singular values of the watermark by applying SVD to the transform responses of the host and the watermarked images.
4. Collect the extracted watermark by applying inverse FrFT2D and inverse RDWT.

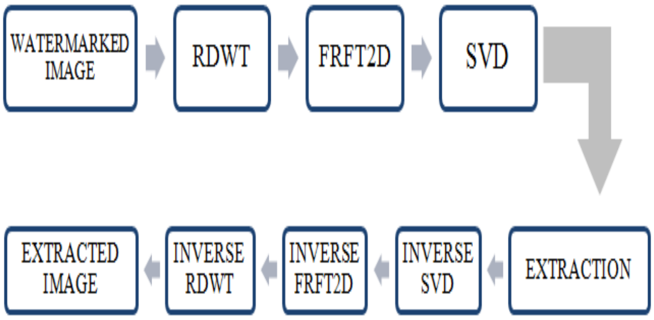

Fig.2. Block diagram for the watermark extraction algorithm.

VI. EXPERIMENTAL RESULTS AND DISCUSSION

To demonstrate the robustness and imperceptibility of the suggested technique, we have used 11 test images and 3 logo watermarks but the experimental results have been shown for only 3 test images and IEEE logo watermark, shown in fig.3. The watermarked image quality is measured in terms of 3 image quality metrics which are PSNR, Correlation Coefficient and GMSD.

PSNR- It is used to indicate the similarity between the two images. The higher values indicate the greater similarity and lower degradation.

Mathematically PSNR between the host image *I(t)* and the watermarked image *J(t)* is calculated using (1) and (2).

$$PSNR = 20\log_{10}\left(\frac{255}{RMSE}\right) \quad (1)$$

RMSE is the square root of mean square error and is defined as:

$$RMSE = \sqrt{\frac{1}{T}\sum_{1}^{T}\left(I(t) - J(t)\right)^2} \quad (2)$$

Correlation Coefficient - It is the numerical measure of correlation between two variables. The Correlation Coefficient (CC) is calculated using the normalized original watermark *I'(t)* and normalized attacked watermark *J'(t)* as:

$$NCC = \sum I'(t)\, J'(t)$$

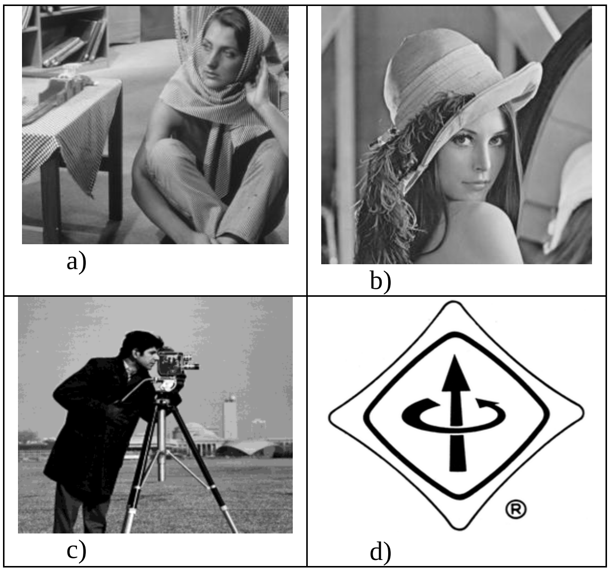

Fig.3. Test images (a,b,c) and the watermark used (d).

The PSNR, CC, and GMSD values are calculated in matlab using both in-built functions and user defined functions for PSNR and CC. the GMSD has been calculated in matlab itself using a specifically designed function for GMSD. The results are given in table 1.

Table 1. Image quality metrics.

Metric	Images		
	(a)	(b)	(c)
PSNR (dB)	40.598924	40.220409	40.733817
CC	1	1	1
GMSD	0	0	0

The imperceptibility of the suggested technique is judged objectively through the image quality metrics as discussed above and the subjective analysis is made by comparing the histograms of the original and the watermarked images, shown in fig.4.

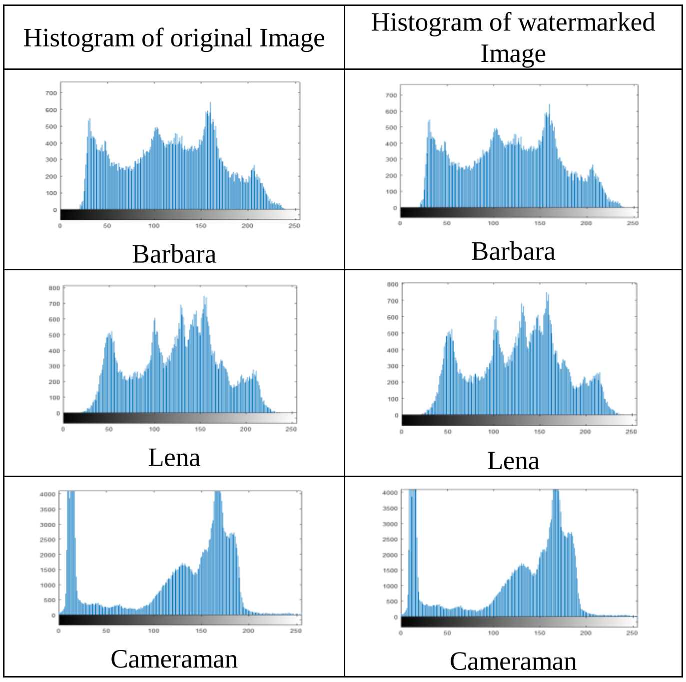

Fig.4. Comparison between the histograms of original and watermarked images.

It is clear from fig.4 that the overall shape of the histograms of both the original image and the watermarked image is similar which means that the tonal distribution is similar for both the images. This proves the imperceptibility of the presented watermarking system.

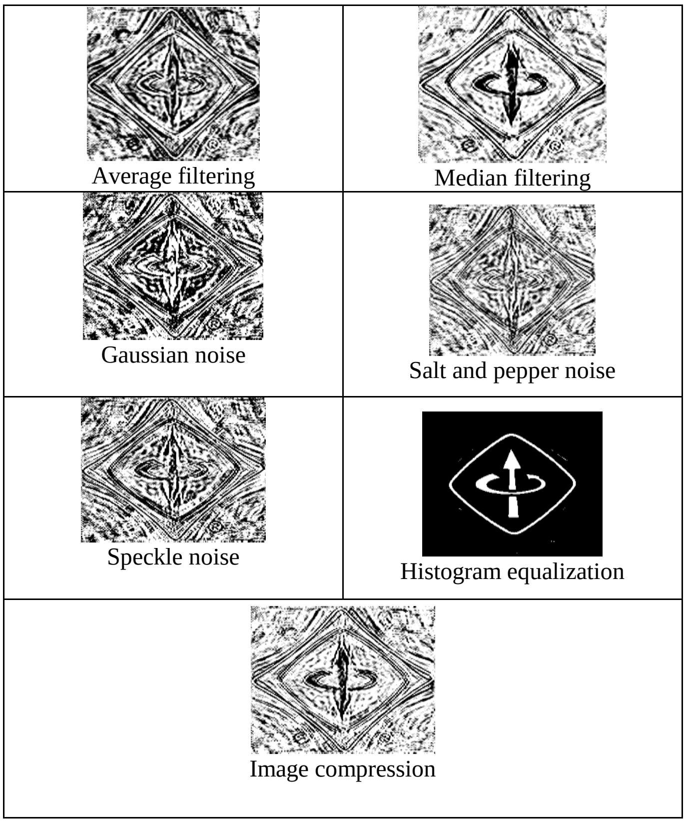

Fig.5. watermarks extracted after the application of various attacks.

Table 2. Correlation coefficient scores for average filtering, median filtering, Gaussian noise, salt and pepper noise.

Images	Correlation coefficient between original watermark and extracted watermark – Attacks			
	Average filtering	Median filtering	Gaussian noise	Salt and pepper noise
Barbara	0.330232	0.704068	0.238137	0.593791
Lena	0.321268	0.70909	0.251762	0.614352
Cameraman	0.524616	0.846188	0.224676	0.437694

Table 3. Correlation coefficient scores for other attacks.

Images	Correlation coefficient between original watermark and extracted watermark – Attacks		
	Speckle noise	Histogram equalization	Image compression
Barbara	0.451671	-0.996922	0.617636
Lena	0.464435	-0.998883	0.591002
Cameraman	0.348047	-0.993765	0.849191

Table 4. GMSD scores for average filtering, median filtering, Gaussian noise, salt and pepper noise.

Images	GMSD between original watermark and extracted watermark – Attacks			
	Average filtering	Median filtering	Gaussian noise	Salt and pepper noise
Barbara	0.330232	0.704068	0.238137	0.593791
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Table 5. GMSD scores for other attacks.

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Attack analysis – The robustness of the algorithm is further investigated by studying the effects of watermarking attacks on the watermarked images. To demonstrate the effect of attacks, we compare the original and the extracted watermark both visually as well as quantitatively using CC and GMSD. The visual results are shown for only 1 image in fig.5; and quantitative results for 3 images are given in tables 2, 3, 4 and 5 which are calculated using matlab.

Table 6. GMSD comparison between Fr-DWT and the suggested Fr-RDWT for average filtering, median filtering, Gaussian noise, salt and pepper noise.

Algorithm	Comparison of GMSD scores between Fr-DWT and Fr-RDWT techniques for test image- Barbara			
	Attacks			
	Average filtering	Median filtering	Gaussian noise	Salt and pepper noise
Fr-DWT	0.330839	0.396404	0.265917	0.382519
Fr-RDWT	0.330232	0.339637	0.238137	0.330014

Table 7. GMSD comparison between Fr-DWT for other attacks.

Algorithm	Comparison of GMSD scores between Fr-DWT and Fr-RDWT techniques for test image- Barbara		
	Attacks		
	Speckle noise	Histogram equalization	Image compression
Fr-DWT	0.356414	0.028352	0.407956
Fr-RDWT	0.280809	0.034298	0.338452

Further, the technique is compared with the Fractional Wavelet Transform (Fr-DWT) on the basis of GMSD. For low distortion and high image perceptual quality, the GMSD score must be lower. It is clear from the tables 6 and 7 that GMSD values for the presented watermarking system are lower as compared the other method and hence suggested algorithm proves to be comparably better in terms of qualitative as well as quantitative analysis.

VI. CONCLUSION

In this paper, a robust digital image watermarking algorithm is suggested which is based on the hybridization of Fractional Fourier Transform (FrFT), Redundant Wavelet Transform (RDWT) and Singular Value Decomposition (SVD). The performance of the technique is analyzed with different host images in terms of PSNR, Correlation Coefficient and GMSD. After investing the results, the presented watermarking scheme illustrates a significant improvement as compared to the existing Fr-DWT method under various attacks on the watermarked image.

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