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MEDICAL IMAGE FUSION USING CURVELET TRANSFORM

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ABSTRACT

The paper analyses the characteristics of the Fast Discrete Curvelet Transform and put forward an image fusion algorithm based on Discrete Wavelet Transform and the Fast Discrete Curvelet Transform. The Curvelet Transform is a new approach in the image fusion techniques adding a new, lesser redundant, fast and simple way of dealing the images especially at the edges and curves and hence it is very suitable for the analysis of various natural images like Medical images using tomographic images like MRI and CT scan, seismic images, satellite pictures for the weather monitoring etc. The experimental results show that the method could extract useful information from the source images to fused images so that clear images are obtained. In choosing the low-frequency coefficients, the concept of local area variance was applied to the measuring criteria. In choosing the high frequency coefficients, the window property and local characteristics of pixels were analysed. Finally, the proposed algorithm was applied to experiments of multi-focus image fusion and complementary image fusion.

Keywords: Discrete Wavelet Transform, Fast Discrete Curvelet Transform, Image Fusion, Wavelets, Wrapping.

I. INTRODUCTION

Image fusion is a technology in which images of the same scene either captured from various sensors or same sensor at different times or the same time are fused together. The purpose of image fusion in Computer Vision is to get a resultant image having extracted parameters more improved than the original image. A high resolution multispectral image is formed as a result of the fusion of a low resolution multispectral image & high resolution image that will contain all types of spatial information of both types of the images. Fusion of images taken at different resolutions, intensities and by different techniques helps physicians to extract many features which may not be visible in a single image [1]. Images can be fused in three different levels which are namely pixel level fusion, feature level and decision level fusion. Out of these three techniques, pixel level is easier to work because we can directly locate it [1]. MRI is an imaging tool most commonly used in the field of radiology to visualize the internal organs of the body & it depicts greater contrast between the different soft tissues of the body whereas CT is a tomograhic medical imaging tool in which sectioning mode is employed for taking images. It is used for displaying hard tissues such as bones and cartilages. The fusion of both types of images using DWT and FDCT will produce a resultant image in which soft tissues and hard bones can be seen together with improved extracted parameters.

II. LITERATURE SURVEY

Curvelet Transform is developed from the wavelet transformation but it overcomes the inherent limitation of wavelet in expressing the direction of the edges in the image. In 1998, Candes put forward Ridgelet analysis and implemented the Radon transformation to map one dimensional singularity of the image but mostly edges of natural images are curved and it is not effective to analyse the whole image by a single scale Ridgelet, so image need to be divided into blocks and then Ridgelet was implemented on each block but it resulted in greater data redundancy. To remove this, Donoho put forward Curvelet transform in which the image was decomposed into sub bands and then adopted different blocks of the sub band image with the different scales. [2] Curvelets are based on multiscale Ridgelets combined with the spatial band pass filtering operation to isolate different scales which filter the multiscale Ridgelet which are not in the frequency range of the filter and thus Curvelets have prescribed frequency band.[3] The depth of multiscale pyramids and the index of the dyadic sub bands has a special relationship and the side length of the localizing window is doubled at the every other dyadic sub band maintaining the fundamental property of the Curvelet transform which states that element of length $2^{-j/2}$ serve for the analysis and synthesis of j^{th} sub band $[2^j, 2^{j+1}]$ [8].Curvelets being local both in x,y and k_x,k_y are direction selective with orientation is proportional to $(scale)^{-1/2}$.[4]

III. CURVELET TRANSFORM

In recent years, the Curvelet transform has been redesigned in an effort to make it easier to use and understand and also to improve the carrier implementations and to make it faster, reliable, simpler and less redundant than the existing methods. Two such methods are
A. Curvelet via USFFT B. Fast Discrete Curvelet Transform via wrapping

The FDCT wrapping has the effective computational complexity 6 to 10 times than that of the FFT operating on the array of the same size making it ideal for the large scale scientific applications. [5]

3.1 TILLING

It is the process in which the image is divided in such a way to form overlapping tiles which are smaller in dimensions to transform the curved lines into the smaller straight lines in sub bands Δ_1 & Δ_2. This improves the ability of the Curvelet transform to handle the curved and bent edges. Curvelets can be represented and localized in the position (spatial domain), scale (frequency domain) & orientation. [6]

IV. PROPOSED ALGORITHM FOR THE MEDICAL IMAGE FUSION

The proposed algorithm can be divided into following steps [1]
A. Discrete Wavelet Transform
B. Fast Discrete Curvelet Transform via wrapping.

4.1 DWT

Wavelet should have Finite Energy & each wavelet has a unique image decomposition and reconstruction characteristics that lead to different fusion results. The wavelet has two parameters namely scale and translation. The Discrete wavelet transform has discrete values for its time and scale. DWT is based on discrete time signals or samples and preserve the key features of CWT. DWT is a signal processing tool that decomposes the signal into several other signals of different scales with different time frequency resolutions. DWT is considered more suitable to study the signals which have low frequency components and limited duration impulse components. DWT is highly dependent on type of Mother Wavelet. The results may be completely changed with mother wavelet selected type. DWT is affected with sampling rate and its relevance to signal spectrum. Here, we are experimenting with Haar & Daubechies wavelets. [9]

The low pass output is given as

$$W(n,j) = W(m,j-1) * low\ filter\ (2n - m) \quad (1)$$

And the high pass output is

$$W_h(n,j) = W(m,j-1) * high\ filter\ (2n - m) \quad (2)$$

Where J is total number of octave, j is the current octave, N is the total no. of inputs, n is the current input such that $1 \leq n \leq N$, l is the width of the filter, and $W(n,j)$ represents the DWT except for $W(n,0)$ is the input signal. The number of wavelet coefficients plays a large role in the time taken to compute the wavelet transform. Since every input sample must be multiplied by each wavelet coefficient, the number of coefficients should be kept minimum. More coefficients allow for a better approximation. The inverse wavelet transform reconstruct the signal from wavelets which perfectly matches the original signal. DWT decomposes the image into respective frequency layers. At each level we are getting one low level frequency and three high level frequencies namely LL, LH, HL & HH [7]. Further, these frequency bands are subjected to FDCT wrapping and fusion for each frequency layers supported by inverse transformation to get back the validated fused image with extracted parameters.

4.2 FDCT

In wrapping, the Curvelets are translated at each scale and angle and a rectangular grid is assumed and the Cartesian Curvelets are defined as [5]

$$C(j,l,k) = \int \tilde{f}\,(w)\widetilde{U}_j(S_{\theta l}^{-1}w)ei^{<b,w>}dw \quad (3)$$

The corresponding periodization of the windowed data

$$d[n_1,n_2] = \widetilde{U}_{j,l}[n_1,n_2]\tilde{f}[n_1,n_2] \quad (4)$$

This reads

$$Wd[n_1,n_2] = \sum_{m_1 \in Z}\sum_{m_2 \in Z} d[n_1 + m_1L_{1,j}, n_2 + m_2L_{2,j}] \quad (5)$$

The wrapped windowed data is defined as the restriction of $Wd[n_1,n_2]$ to the indices n_1,n_2 inside a rectangle with the sides of length $L_{1,j} \times L_{2,j}$ near the origin $0 \le n_1 \le L_{1,j}$ & $0 \le n_2 \le L_{2,j}$. There is one to one mapping in between the wrapped data and the original indices. So, the wrapping transformation is simply re indexing the data and it becomes possible to express the wrapping of the array $d[n_1,n_2]$ around the origin even more simply using the modulo function

$$Wd[n_1 \bmod L_{1,j}, n_2 \bmod L_{2,j}] = d[n_1,n_2] \quad (6)$$

4.3 Steps of the algorithm is as follows

4.3.1) Apply the 2D FFT to obtain the Fourier samples $f[n_1,n_2]$obtained after applying DWT
4.3.2) For each scale j & angle l, form the product $\tilde{U}j,l[n_1,n_2]\tilde{f}[n_1,n_2]$
4.3.3) Wrap this product to obtain $\tilde{f}_{j,l}[n_1,n_2] = W(\tilde{U}_{j,l}f)[n_1,n_2]$ When $0 \le n_1 \le L_{1,j}$ & $0 \le n_2 \le L_{2,j}$ for $\theta = (-\pi/4, \pi/4)$
4.3.4) Apply the inverse of 2D FFT to each $\tilde{f}_{j,l}$ collecting the discrete coefficients. $c^D(j,l,k)$
Let us consider a rectangle $R_{j,l}$ of the size $R_{1,j}$ and $R_{2,j}$ aligned with the Cartesian axes and containing the parallelogram $P_{j,l}$. The rectangle divides the image into size n. The coefficients $c^{D,0}(j,l,k)$ arises from the discrete convolution of a Curvelet with the signal $f(t_1,t_2)$ regularly down sampled to select only one out of every $n/R_{1,j} \times n/R_{2,j}$ pixel. [5] Apply 2D inverse FFT to get the oversampled Curvelet coefficients consisting of

$$C^{D,0}(j,l,k) = \frac{1}{n^2}\sum_{n_1,n_2 \in R_{j,l}} \tilde{f}[n_1,n_2]\, e^{2\pi i(k_1 n_1/R_{1,j} + k_2 n_2/R_{2,j})} \quad (7)$$

The basic idea of the wrapping is to replace $R_{1,j}$ and $R_{2,j}$ in the equation by $L_{1,j}$ & $L_{2,j}$. a relabeling of the frequency samples is taken in the form

$$n_1' = n_1 + m_1 L_{1,j} \quad (8)$$

$$n_2' = n_2 + m_2 L_{2,j} \quad (9)$$

The 2D inverse FFT of the wrapped array therefore reads

$$C^D(j,l,k) = \frac{1}{n^2}\sum_{n_1=0}^{L_{1,j-1}}\sum_{n_2=0}^{L_{2,i-1}} W(\tilde{U}_{j,l}, \tilde{f})\,[n_1,n_2] e^{2\pi i(k_1 n_1/L_{1,j} + k_2 n_2/L_{2,j})} \quad (10)$$

While performing the wrapping process, the phase factor is unchanged.

4.4 Wrapping process

Let $\varphi^D_{j,l}$be the mother Curvelet at scale j and angle l

$$\varphi^D_{j,l}(x) = \frac{1}{2\pi^2}\int e^{i<x,w>\tilde{U}_{j,l}(w)}\, dw \quad (11)$$

Where $\varphi_{j,l}$denotes periodization over the unit square $[0, 1]^2$

$$\varphi_{j,l}(x_1,x_2) = \sum_{m_1 \epsilon Z}\sum_{m_2 \epsilon Z}\varphi^D_{j,l}(x_1+m_1, x_2+m_2) \quad (12)$$

The coefficient in the east, west quadrants are given as

$$C^D(j,l,k) = \frac{1}{n^2}\sum_{t_1=0}^{n-1}\sum_{t_2=0}^{n-1}\varphi_{j,l}\left(\frac{t_1}{n} - \frac{k_1}{L_{1,j}}, \frac{t_2}{n} - \frac{k_2}{L_{2,j}}\right) \quad (13)$$

For the north and south quadrants, the role of $L_{1,j}$ and $L_{2,j}$ are reversed. Fast Discrete Curvelet transform via wrapping process is basically used to window the data in prescribed frequency as well as the window resulting in the sampling process of the signal on the same grid as the data. Curvelets incur distortion in the form of the sampled frequency in the digital transform domain which is altogether a minor issue. The Curvelets decay fast as the result of periodization in the space. [5]

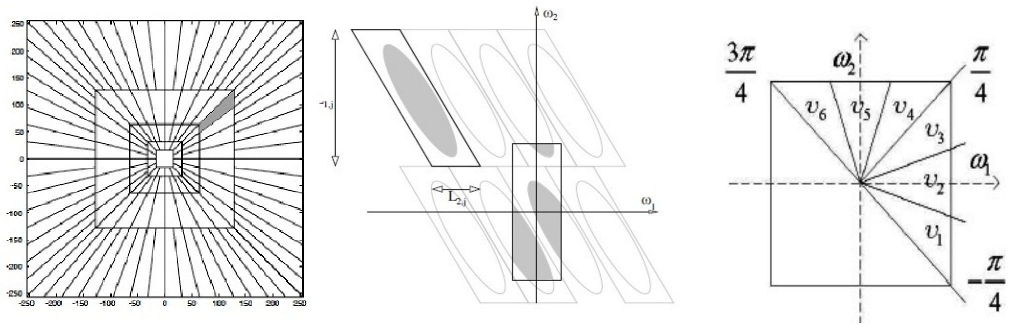


Fig. 1: a) Digital tilling b) Wrapping data into the rectangle c) Angle function for Curvelet window

V. PROPOSED WORK

In the proposed work, we are focusing on the Curvelet transform in the image fusion applications along with the Discrete Wavelet transform based fusion to get better results. Along with the general images, we are experimenting with the medical images in our work such as MRI & CT images to be fused together with the help of Curvelet transform and Discrete Wavelet transform. For that purpose, the methodological approach will be like this

A. The images are registered

B. Then Wavelet transform is being carried out to decompose the image into proper frequency levels.

C. Then a detailed analysis is made applying the Curvelet transform to the frequency components obtained after Discrete Wavelet Transform.

D. Then the images are subjected to the local area variance and fusion is carried out.

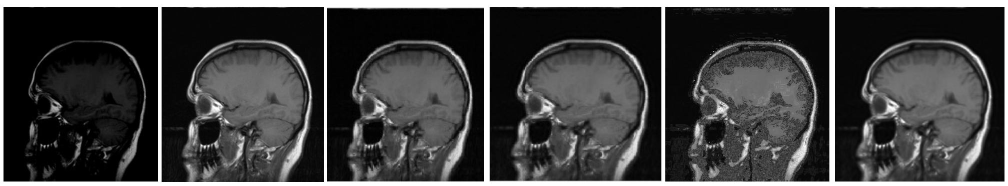
E. Finally, the image is reconstructed applying the inverse transformation. [1]

VI. PLATFORM USED

The work is being carried out with the help of MATLAB 10 & above versions with Intel(R) Core(TM) i5-2430M CPU @ 2.40Ghz with installed memory RAM 4.00 GB on 64-bit operating system.

VII. SIMULATION RESULTS

The results obtained after the fusion of images with various methods are listed in the table below. The methods which are adopted for the fusion of three sets of medical CT scan and MRI images are DWT based fusion, FDCT based fusion and the fusion which is based on the proposed method in which DWT and FDCT are used together as per the proposed algorithm steps for the fusion purpose. The values of RMSE obtained after DWT based fusion are higher than that of the fusion based on FDCT but in case of the proposed method, the values of RMSE obtained are very less than DWT and FDCT respectively which shows that proposed method gives better results. Similarly, the values of PSNR obtained from the proposed method are greater than that of DWT based fusion and FDCT based fusion respectively. The proposed method is carried by taking two different wavelets namely daubechies and haar for the purpose of the evaluation of results. The results obtained by the proposed method using haar wavelet are better than any other methods adopted here for the fusion. The size of the images taken in each case is 256   256 pixels.



a b c d e f

Fig. 2: Set 1 a) CT_1 b) MRI_1 c)Fused DWT image d) Fused FDCT image e) Proposed method fused image using db3 wavelet f) Proposed method fused image using haar wavelet

Table 1: Simulation results for Multifocus Image fusion (set 1)

Fusion methods	RMSE	PSNR	Entropy	Ccc	Std deviation
DWT	52.9294	30.8938	-0	0.848214	51.5482
FDCT	52.7691	30.907	6.31793	0.850905	51.3805
Proposed using db3 wavelet	0.72609	49.5209	6.29758	0.801373	50.7245
Proposed using haar wavelet	0.027063	63.807	6.29941	0.83894	50.7478

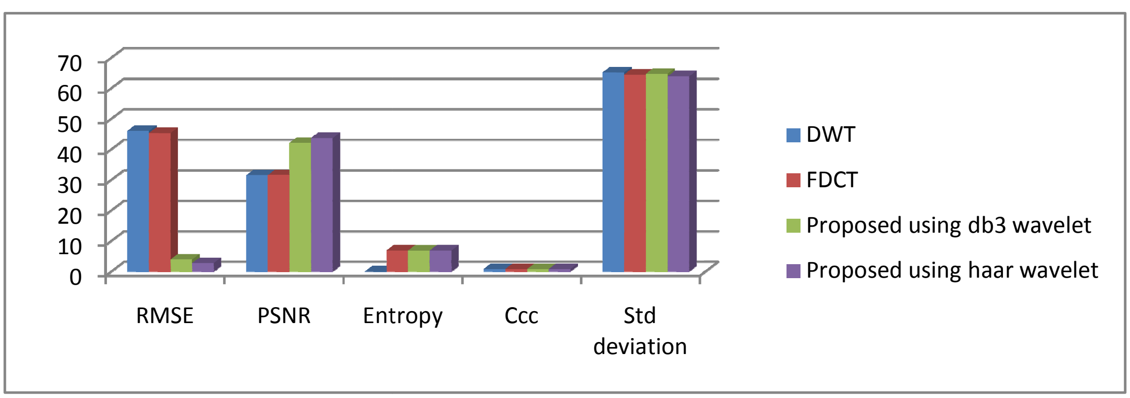


Fig. 3: Graphical analysis of Multifocus Image fusion (set 1)

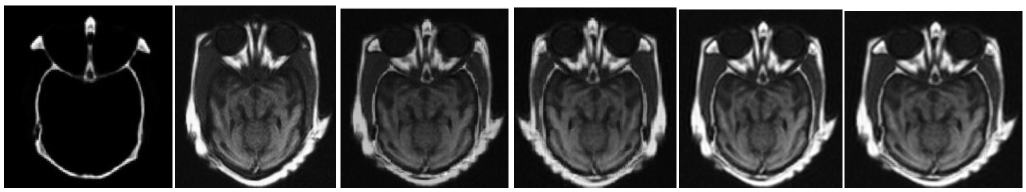


Fig. 4: Set 2 a) CT_2 b) MRI_2 c) Fused DWT image d) Fused FDCT image e) Proposed method fused image using db3 wavelet f) Proposed method fused image using haar wavelet

Table 2: Simulation results for Multifocus Image fusion (set 2)

Fusion methods	RMSE	PSNR	Entropy	Ccc	Std deviation
DWT	75.7166	29.3389	0.00162641	0.41221	60.9559
FDCT	75.6446	29.343	6.76334	0.404031	60.3697
Proposed using db3 wavelet	2.7249	43.7773	6.71257	0.378675	59.7936
Proposed using haar wavelet	2.5753	44.0225	6.75037	0.392444	59.5916

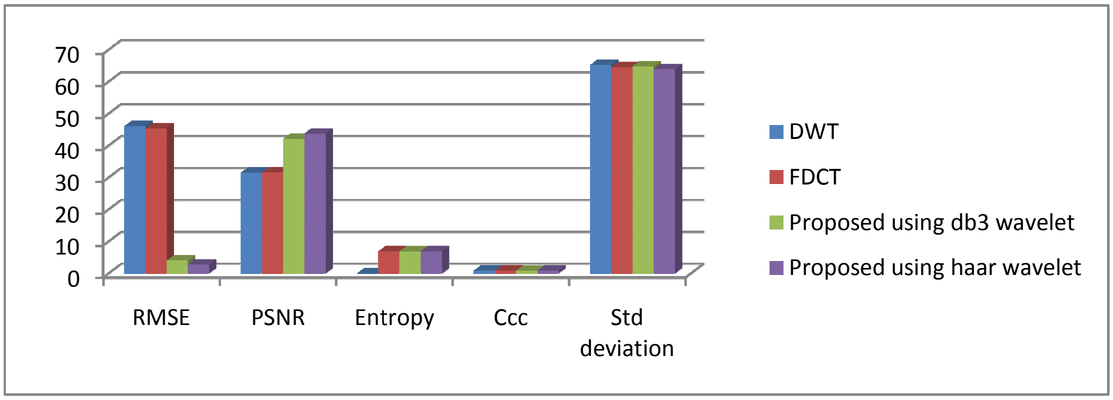


Fig. 5: Graphical analysis of Multifocus Image fusion (set 2)

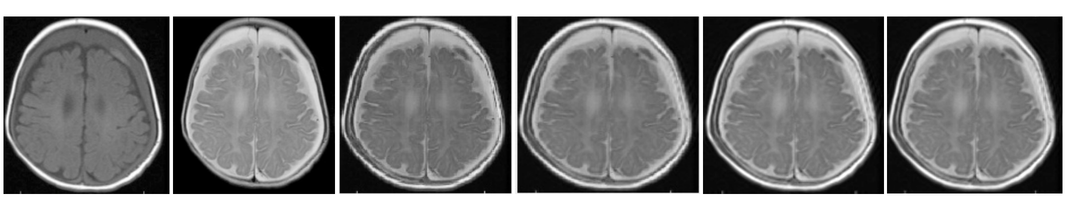


Fig. 6: Set 3 a) CT_3 b) MRI_3 c) Fused DWT image d) Fused FDCT image e) Proposed method fused image using db3 wavelet f) Proposed method fused image using haar wavelet

Table 3: Simulation results for Multifocus Image fusion (set 3)

Fusion methods	RMSE	PSNR	Entropy	Ccc	Std deviation
DWT	46.0198	31.5014	0.02245	0.838738	65.1832
FDCT	45.3644	31.5637	6.9044	0.843308	64.5248
Proposed using db3 wavelet	4.0031	42.1068	6.88099	0.802366	64.7586
Proposed using haar wavelet	2.7677	43.7096	6.90268	0.840918	63.941

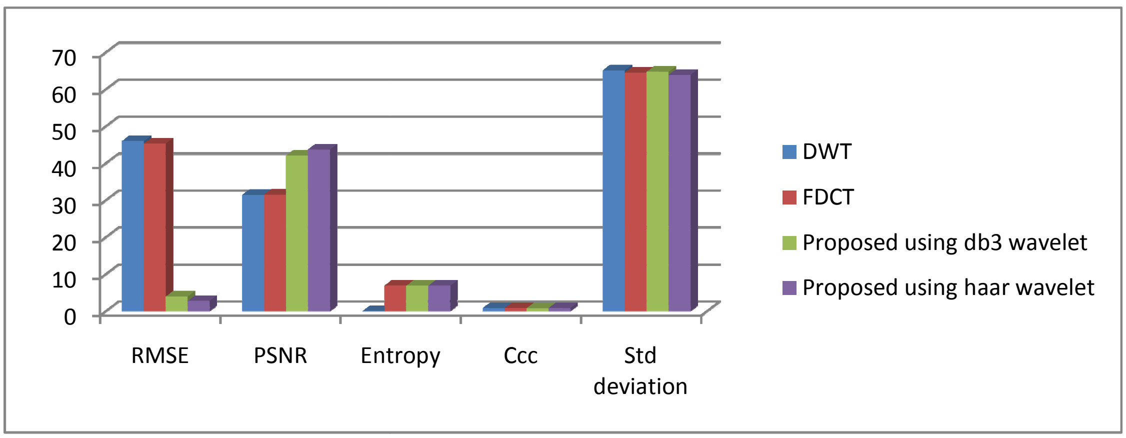


Fig. 7: Graphical analysis of Multifocus Image fusion (set 3)

VIII. CONCLUSION

The Curvelet transform plays a vital role in image fusion. Considering the parameters like PSNR, entropy, standard deviation, quality measure Q of the image is improved using Curvelet transform while the RMSE of the fused image gets reduced using the proposed method which is desirable. So, we can say that, in computer vision the fusion algorithm proposed in this paper gives better image fusion results and in the objective evaluation criteria, the characteristics of fused parameters are superior to traditional methods.

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