An Image Enhancement Method Based on Curvelet Transform for CBCT-Images

Shahriar Farzam, Maryam Rastgarpour

Abstract—Image denoising plays extremely important role in digital image processing. Enhancement of clinical image research based on Curvelet has been developed rapidly in recent years. In this paper, we present a method for image contrast enhancement for cone beam CT (CBCT) images based on fast discrete curvelet transforms (FDCT) that work through Unequally Spaced Fast Fourier Transform (USFFT). These transforms return a table of Curvelet transform coefficients indexed by a scale parameter, an orientation and a spatial location. Accordingly, the coefficients obtained from FDCT-USFFT can be modified in order to enhance contrast in an image. Our proposed method first uses a two-dimensional mathematical transform, namely the FDCT through unequal-space fast Fourier transform on input image and then applies thresholding on coefficients of Curvelet to enhance the CBCT images. Consequently, applying unequal-space fast Fourier Transform leads to an accurate reconstruction of the image with high resolution. The experimental results indicate the performance of the proposed method is superior to the existing ones in terms of Peak Signal to Noise Ratio (PSNR) and Effective Measure of Enhancement (EME).

Keywords—Curvelet transform, image enhancement, CBCT, image denoising.

I. Introduction

CBCT images are corrupted by noise introduced due to many factors, for instance the CT imaging devices during acquisition and quantization or during compression and transmission. This degradation of images aesthetically affects the processes of feature recognition, segmentation, edge detection, etc. For the correct interpretation of these images, restoration techniques are employed [1]-[4]. Image denoising is one of the important fields in the restoration arena. The purpose of denoising is to obtain a good estimate of the original image from its degraded version and at the same time to preserve complex structures of images such as edge [5].

Enhancement can be done either in the spatial domain or in the frequency domain. Spatial domain methods are those in which the intensity of the pixel is manipulated in the image domain itself by convolving it with a filter function [6]. Thus, FDCT is gaining much popularity, and a lot of work has been done to denoise and enhance images using FDCTs [7]-[13]. This transform map an image to a sparse vector that contains only a few large magnitude coefficients which correspond to

the important information in the image. The basic idea behind enhancement using this transform is to uniformly threshold the transform coefficients by deciding a suitable threshold [14].

In this paper, we show an image enhancement transform and applied to enhance CBCT images. Curvelet is employed to denoise and enhance these images by decomposing images for separation of the smooth and the texture regions.

This paper is organized as follows: The Curvelet transform is briefly reviewed in Section II. In Section III, we present our proposed method. Simulation results and discussions are given in Section IV and finally concluding remarks are presented in Section V.

II. Curvelet Transform

Curvelet transform is a powerful multi-scale multi-orientation image decomposition technique. It was developed to solve the problem of curve singularities. As an image analysis tool, it differs from other directional wavelet transforms in the degree of localization in orientation, which varies with scale. It provides a strong directional characterization in which elements are highly anisotropic at fine scales. With these properties, Curvelet solve the isotropic and limited directional analysis of classic wavelet transform [15].

Curvelet transform can effectively describe curve or the hyperplane singularity by direction parameter of the high dimensional signal which is anisotropic [16]. It is proposed to conduct Ridgelet transform at all possible scales and express the whole curve by local straight lines at multiple scales approximately. Curvelet can track the singularity curve of the image which is twice differentiable adaptively [17], [18].

Curvelets are band-limited complex-valued basis functions $\Psi_{\lambda\beta\varphi} : \mathbb{R}^2 \rightarrow \mathbb{C}$ parameterized in three spaces, viz. the scale $(\lambda \in \mathbb{Z}^1)$, location $(\beta \in \mathbb{Z}^2)$, and rotation $(\varphi \in \mathbb{S}^1)$. Let $I(x, y) \in L_2(\mathbb{R}^2)$ be a pixel value of an image of size $X \times Y$ at the spatial index (x, y). This square integrable function $I(x, y)$ can be represented by discrete version of the forward Curvelet transform as [19]

$$\gamma(i, j) = \sum_{\lambda \in \mathbb{Z}^1} \sum_{\beta:(x,y) \in \mathbb{Z}^2} \sum_{\varphi:(0,2\pi] \in \mathbb{S}^1} I(i - x, j - y)\Psi_{\lambda\beta\varphi} \quad (1)$$

where $\Psi_{\lambda\beta\varphi}$ is the basis function for the forward transform. In a similar fashion, the image $I(x, y)$ may be obtained from the coefficients $\gamma(i, j)$ using the inverse Curvelet transform as [19]

$$I(x, y) = \sum_{\lambda \in \mathbb{Z}^1} \sum_{\beta:(x,y) \in \mathbb{Z}^2} \sum_{\varphi:(0,2\pi] \in \mathbb{S}^1} I(i - x, j - y)\Psi_{\lambda\beta\varphi} \quad (2)$$

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where $\Psi_{\lambda\beta\varphi}$ is the basis function for the inverse transform. A further detail about the history of Curvelet transform and relationship of Curvelets to other wavelet-like transforms may be found in [20]. An implementation of Curvelet transform may be done by using the codes Curvelab version 2.1.2 available at [21].

III. PROPOSED IMAGE ENHANCEMENT METHOD

In this section, we propose an enhancement method that employs the FDCT by thresholding on the transform coefficients. The FDCT was developed from the wavelet transform for overcome the limitation of wavelet transform to remove unwanted noise from the image while preserving important information along the edges.

A. Proposed Algorithm

- Read the CBCT images.
- Apply FDCT to the images.
- The curvelet coefficients obtained from the images.
- Apply thresholding on the curvelet coefficients of 10% and 30%.
- Evaluate the curvelet coefficients to zero that they are below the threshold.
- The final enhance image is reconstructed by applying inverse curvelet transform to enhanced image.

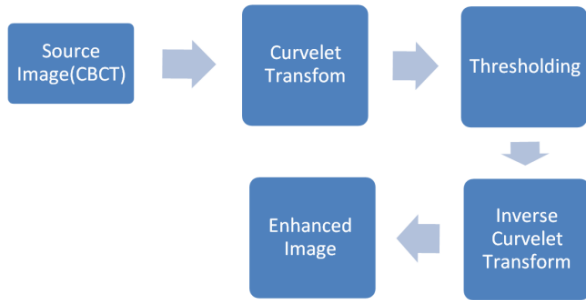Fig. 1 shows all the steps involved in enhance CBCT images.

Fig. 1 Block Diagram of Proposed Image Enhancement Method

IV. EXPERIMENTAL RESULTS

Image enhancement using FDCT is applied to many CBCT images and the results are shown in the following figures. The figure shows the original image and the enhanced images using FDCT. And the parameters used to find the best method are calculated. The proposed method is compared with the conventional discrete wavelet transform and the results shows that the proposed method is very efficient in enhance the CBCT images.

The input images applied to the FDCT are the CBCT images which are shown in figures. These images are enhanced after undergoing decomposition and thresholding rule. The final fused image is shown in figures which are used by the radiologist for further processing.

A. Image Database

For this study, the Osirix dental scan Dataset available at [22] that consists of 300 different CT images was used, with 12 real CBCT samples collected for each transform.

B. Evaluation Parameters

1) MSE

The mean squared error (MSE) considers the quantity of the removed noise. Accordingly, the mean squared error of an estimator measures the average of the squares of the errors, that is, the difference between the estimator and what is estimated [23].

$$MSE = \frac{1}{k_1 k_2}\sum_{l=1}^{k_2}\sum_{k=1}^{k_1}[X(k,l) - Y(k,l)]^2$$

2) PSNR

PSNR is generally utilized for measuring the quality of the image and involve deviation of the enhanced image from the original image with respect to the peak value of the color level that affects the fidelity of its representation; although, it is an approximation to human sensitivity of reconstruction quality. Even though a higher PSNR generally indicates that the reconstruction is of higher quality, in some cases it may not. PSNR is most easily defined via the mean squared error (MSE) [24].

$$PSNR = 10\ log_{10}\frac{255^2}{MSE}$$

3) EME

EME is a quantitative measure of image enhancement. It is obtained by splitting the image into a number of blocks and using,

$$EME = \frac{1}{k_1 k_2}\sum_{l=1}^{k_2}\sum_{k=1}^{k_1} 20\ log\frac{I^w_{max;k;l}}{I^w_{min;k;l}}$$

where, k_1, k_2 are the number of horizontal and vertical blocks in the image, $I^w_{max;k;l}$ and $I^w_{min;k;l}$ are the maximum and minimum pixel values in a given block [25].

We select 2 real images from our real dataset and results shown in Figs. 2 and 3.

Fig. 2 shows first original real image and the results of, respectively, Curvelet by a threshold of 30%, Curvelet by a threshold of 10%, wavelet using db1 filter, wavelet using db4 filter and wavelet using sym4 filter, using the original real image. These examples present some evidence for the benefits of Curvelet enhancement.

Fig. 3 shows second original real image and the results of, respectively, Curvelet by a threshold of 30%, Curvelet by a threshold of 10%, wavelet using db1 filter, wavelet using db4 filter and wavelet using sym4 filter, using the original real image. These examples present some evidence for the benefits of Curvelet enhancement.
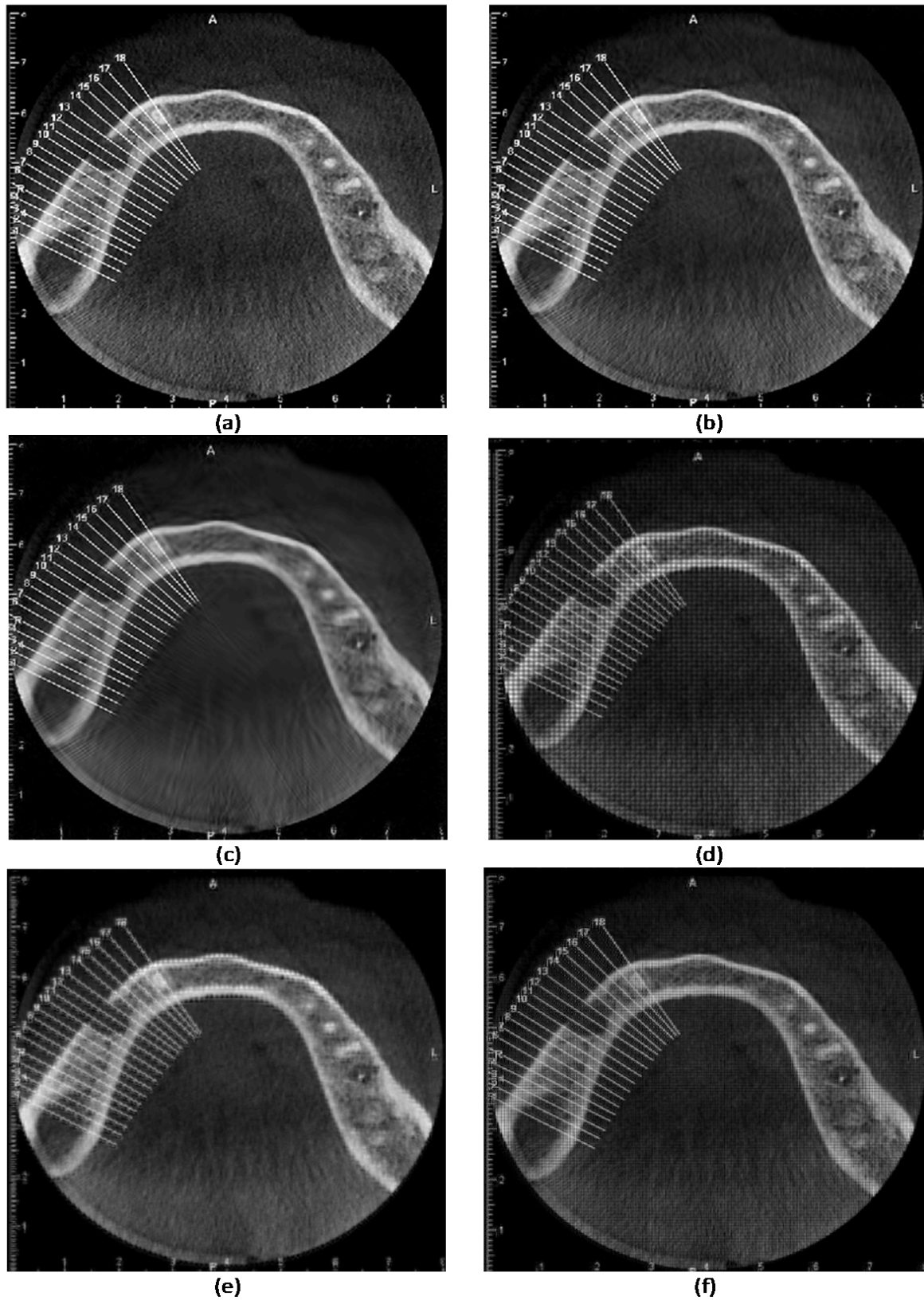
Fig. 2 (a) Original image, (b) Curvelet transform with *30% thresholding*, (c) Curvelet transform with *10% thresholding*, (d) wavelet transform with *db1* filter, (e) wavelet transform with *db4* filter, (f) wavelet transform with *sym4* filter
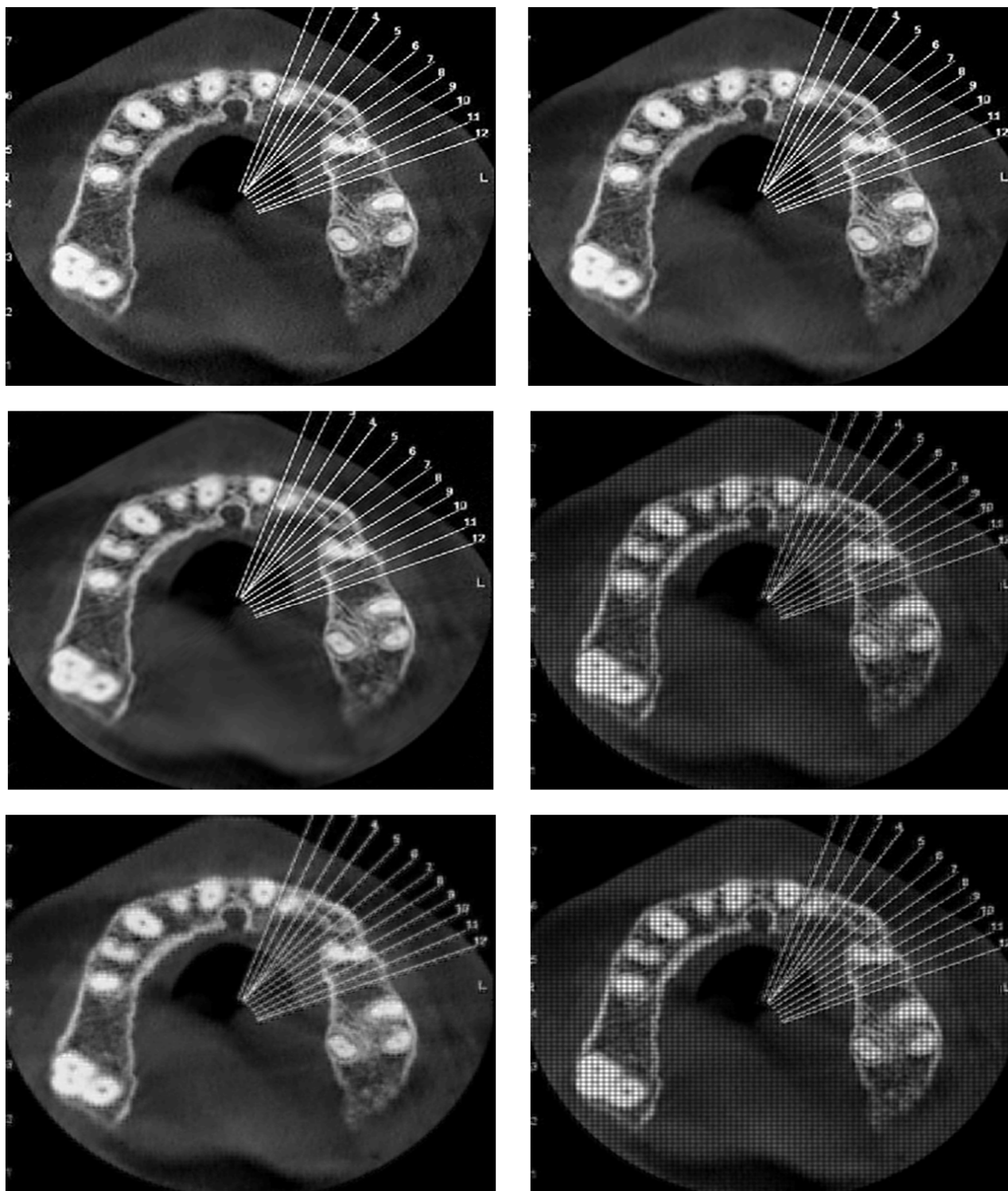
Fig. 3 (a) Original image, (b) Curvelet transform with *30% thresholding*, (c) Curvelet transform with *10% thresholding*, (d) wavelet transform with *db1* filter, (e) wavelet transform with *db4* filter, (f) wavelet transform with *sym4* filter

Fig. 4 shows an original selected image from the dataset and the results of, respectively, Curvelet by a threshold of 30%, Curvelet by a threshold of 10%, wavelet using db1 filter, wavelet using db4 and wavelet using sym4 filter, using the selected image from the dataset. These examples again present some evidence for the benefits of Curvelet enhancement.
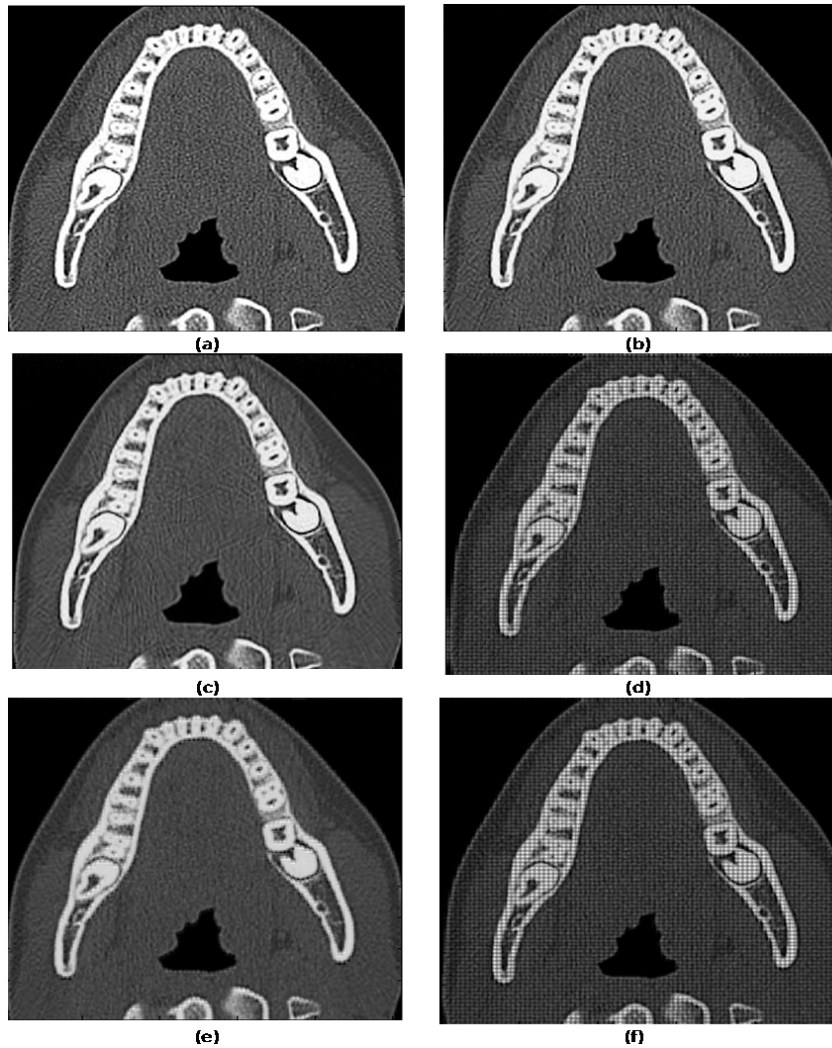
Fig. 4 (a) Original image, (b) Curvelet transform with *30% thresholding*, (c) Curvelet transform with *10% thresholding*, (d) wavelet transform with *db1* filter, (e) wavelet transform with *db4* filter, (f) wavelet transform with *sym4* filter.

TABLE I
ENHANCEMENT PERFORMANCE OF PROPOSED METHOD WITH WAVELET TRANSFORMS

Image	Fig. 2			Fig. 3			Fig. 4		
	PSNR	*EME(5*5)*	*EME(8*8)*	*PSNR*	*EME(5*5)*	*EME(8*8)*	*PSNR*	*EME(5*5)*	*EME(8*8)*
A	/ / /	12.386016	15.851909	/ / /	8.163205	10.379462	/ / /	11.140845	14.837895
B	23.279325	22.973671	31.792649	23.435445	21.350756	28.563906	17.163071	18.640671	25.830038
C	23.459090	18.778717	26.327491	23.525942	19.350101	26.651165	17.266884	15.680923	22.189021
D	16.278802	18.704446	20.108448	16.321808	17.892887	19.619070	9.944191	19.631828	23.216279
E	9.173431	11.403758	14.366804	9.059696	10.406529	12.766494	2.477280	10.048683	13.855481
F	16.376346	18.240431	20.360717	16.339336	16.905027	18.356056	9.893298	18.801317	22.492650

	Original	Curvelet 30%	Curvelet 10%	db1	db4	sym4
EME(5*5) Fig.2	12,386016	22,973671	18,778717	18,704446	11,403758	18,240431
EME(5*5) Fig.3	8,163205	21,350756	19,350101	17,892887	10,406529	16,905027
EME(5*5) Fig.4	11,140845	18,640671	15,680923	19,631828	10,048683	18,801317

Fig. 5 EME (5*5) comparision of wavelet and proposed method

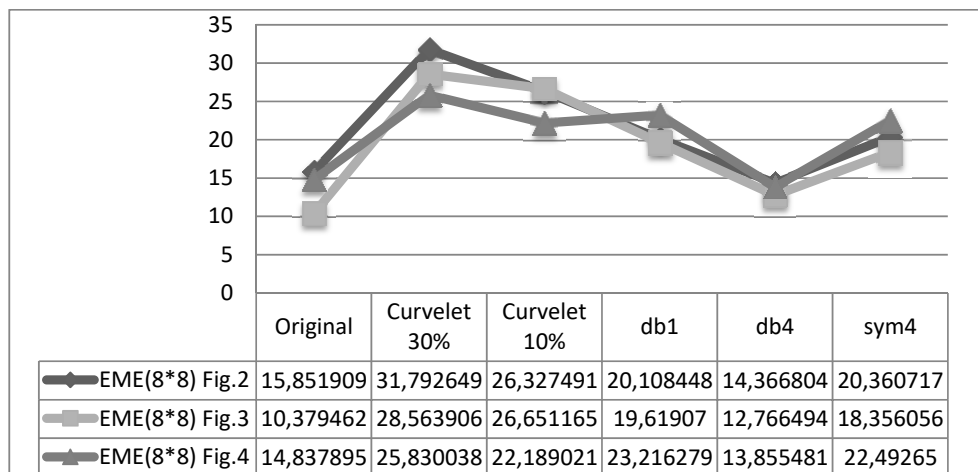|	Original	Curvelet 30%	Curvelet 10%	db1	db4	sym4
EME(8*8) Fig.2	15,851909	31,792649	26,327491	20,108448	14,366804	20,360717
EME(8*8) Fig.3	10,379462	28,563906	26,651165	19,61907	12,766494	18,356056
EME(8*8) Fig.4	14,837895	25,830038	22,189021	23,216279	13,855481	22,49265

Fig. 6 EME (8*8) comparision of wavelet and proposed method

In Table I, we could not put value in the first row for PSNR parameter cause there is no denoised image to compare. From Table I, it is again clear that the proposed method produces enhanced image than the existing methods. This is evident from the high EME values in 5*5 blocks and 8*8 blocks obtained. According to the results, the proposed method is best suited for CBCT images as it produces a high EME (8*8) of 31.792649Db in the first real sample and a high EME (8*8) of 28.563906Db in the second real sample, as well a high EME (5*5) of 22.973671Db in the first real sample and a high EME (5*5) of 21.350756Db in the second real sample.

V. CONCLUSION

Image enhancement is one of the main contents of image processing, improving the intelligibility of the image, which is highlighting some features of the image selectively, making it more applicable to specific areas is the main objective of image enhancement. This paper presented the CBCT image enhancement method which based on FDCT to produce an enhanced image. The input image is decomposed using FDCT. Curvelet coefficients of the input image are obtained by applying Curvelet Transform moreover apply thresholding on the Curvelet coefficients, then using the inverse transform to gain enhanced image. The results reveal that the Curvelet method works better than the wavelet method. It can be observed from the enhancement results that for almost all images with various noise levels, significant improvement in the values of EME is obtained as it produces a high EME (8*8) of 31.792649dB in first real sample and an improvement of approximately 15.94074dB in EME (8*8) value is obtained when the image is enhanced using FDCT notwithstanding using of the wavelet transform. This is found useful in extracting all the information present in the CBCT images which in the future is used to diagnose the disease.

ETHICAL STANDARDS

The authors declare that the experiments comply with the current laws of the country in which we were performed.

CONFLICT OF INTEREST

The authors have no actual or potential conflict of interest including any financial, personal, or other relationships with other people or organizations to disclose.

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