EFFICIENT SEM IMAGE COMPRESSION USING HYBRID DWT-DCT TRANSFORM WITH EMBEDDED ZERO-TREE CODING

Vikrant singh Thakur[a], Kavita Thakur[b*], Shubhrata Gupta[a]
[a]Department of Electrical Engineering, National Institute of Technology, Raipur, 492010, India
[b]S.O.S. in Electronics and Photonics, Pt. Ravishankar Shukla University, Raipur, 492010, India

ABSTRACT

Scanning Electron Microscopy (SEM) imaging is an important process for the proper analysis and characterization of the materials after fabrication. In a raw form, the high resolution SEM images occupy large storage space and also require higher bandwidth for the good quality transmission over the band-limited channel. Usually, all the raw SEM images are compressed in a lossy mode to reduce the higher transmission bandwidth and storage space requirements. The higher compression of SEM images significantly reduces the quality and hence highly affects the proper analysis of the materials. Hence, in this paper the authors contribute a new SEM image compression technique, which can provide high-quality compression of SEM images on higher compression rates. The proposed coder utilizes a hybrid version of two individual transforms, Discrete Wavelet Transform (DWT) and Discrete Cosine Transform (DCT) to achieve higher energy compaction of the input image followed by Embedded Zero-Tree Wavelet (EZW) coding to efficiently generate the final bit-stream. Several experiments have been performed to analyze the compression performance of the proposed SEM image coder against the popular JPEG codec and the latest JPEGXT codec. The result shows that the proposed SEM image coder provides a significant improvement in the quality of the reconstructed images in terms of the Peak Signal to Noise Ratio (PSNR) and Mean Structural Similarity Index (MSSIM) as compared to the JPEG and JPEGXT compression standard

Keywords: SEM Imagining , Material analysis and characterization, Image Compression, JPEG Standard, JPEGXT Standard, Hybrid DWT-DCT transfom, Embedded Zero-Tree Coding, PSNR, MSSIM

1. Introduction

The analysis and characterization of the fabricated material is a very important and crucial part in the material development technology. Usually this task has been performed with the help of image processing. The Scanning Image Microscopy (SEM) imaging is one of the prominent tool, which is commonly utilized for the material analysis process (Chen, Tao, & Li, 2003). The main issue related to the SEM images is their large sizes, which constrained the higher analysis time. The main issue related to SEM images is their large size, due to which analysis of material takes longer time. Further, due to large size, these images require more storage to store and require more bandwidth to transmit. To overcome this issue, all the raw SEM images are compressed in lossy mode using the existing image compression techniques. The most popular lossy compression technique for the compression of SEM images is JPEG standard (Wallace, 1991) which is based on Discrete Cosine Transform (DCT). However, there are several other image compression standards available for the compression of images, like Discrete Wavelet Transform based JPEG 2000 standard (David Taubman, Michael Marcellin, 2002), Back JPEG compatible JPEGXT standard (Mantel, Ferchiu, & Forchhammer, 2014), but JPEG standard is still popular due to its low computational complexity. The JPEG standard has the ability to offer good quality SEM Image compression over lower compression rates, but for the higher compression rates its performance decrease drastically due to the compression artifacts. As a consequence, higher compression of SEM images significantly reduces its quality and hence highly affects the proper analysis of the materials. Therefore, in this paper the authors contribute a new SEM image compression technique, which can provide high-quality compression of SEM images on higher compression rates. The proposed coder utilizes a hybrid version of two individual transforms DCT to achieve higher energy compaction of the input image with reduced computational burden followed by Embedded Zero-Tree Wavelet (EZW) Coding to efficiently generate the final bit-stream.

The remaining paper is organized as follows. The detail development process of the proposed SEM image coder is presented in section 2. The resultant compression performance of the proposed coder against the popular JPEG standard and recent JPEGXT coder is presented in section 3, which is followed by the conclusion of the present work in section 4.

1. Proposed SEM Image Coder

This section presents the detailed design process of the proposed SEM image coder. The ultimate aim is to design an image coder which can deliver good quality compression especially at the higher compression rates as compare to the available coding standards. The basic block diagram of the proposed SEM image coder is shown in fig. 1.

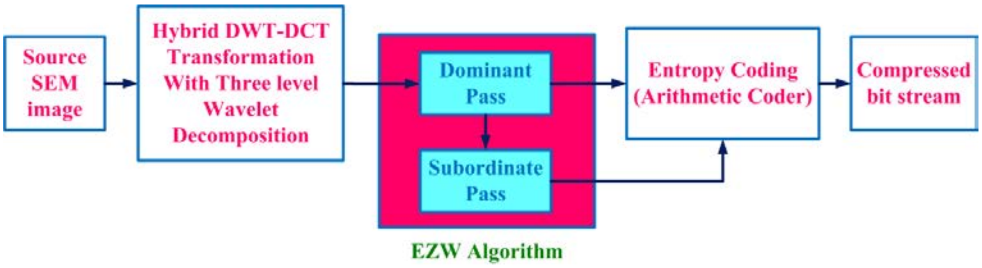


Fig. 1 - Block diagram of the proposed SEM image coder.

Generally, in a DWT based coder the input image is first decomposed into different frequency levels using low pass and high pass filter banks. The number of decomposition levels are application depended, however, higher number of levels leads to the finer details of the input signal with higher computational complexity. For the image coding field, it is always beneficial to use higher number of levels to achieve good quality compression, which comes with the cost of higher computational burden. In order to achieve an optimum tradeoff between the acquisition of finer details and computational complexity, in this work we have used a hybrid combination of two individual transforms DWT and DCT. The basic idea is to get fine details of input image at the lower decomposition levels via lower computation. Hence, in the proposed hybrid DWT-DCT transform three levels wavelet decomposition is proposed where the approximate coefficients are further refined by the DCT transform. The structure of the proposed hybrid DWT-DCT forward transform is shown in fig. 2.

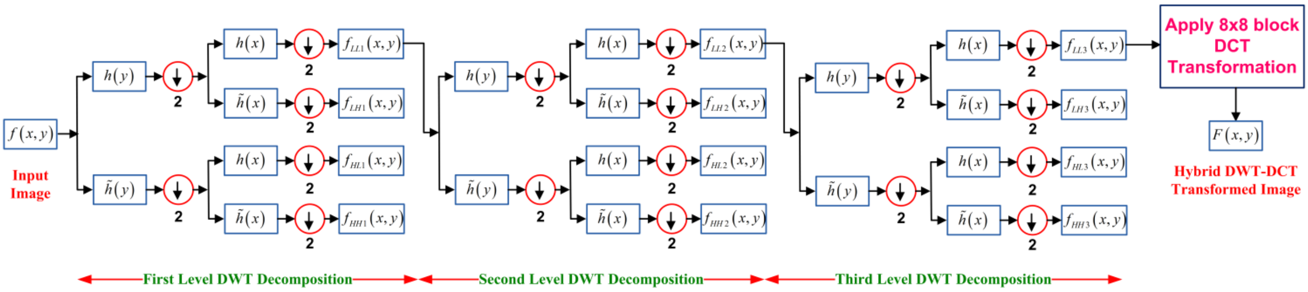


Fig. 2 - Structure of the proposed hybrid DWT-DCT forward transform.

In fig. 2, $h(x)$ and $h(y)$ are low pass and high pass filters respectively. Further, in any wavelet based coder the next task is the quantization and entropy coding of the transform coefficients. In this work, similar to the conventional EZW technique based image compression, the hybrid DWT-DCT transform coefficients are quantize and entropy coded using the EZW algorithm. The detail description of the EZW algorithm is given in following sub-section.

1.1. Embedded Zero-Tree Wavelet (EZW) Algorithm

The EZW is a very clever progressive algorithm that generates a sequence of coded symbols for the wavelet coefficients using the zero-tree concept, which intern coded by the entropy coder to generate final compressed bit stream. The general structure of a conventional EZW technique based image compression is shown in fig. 3. In this technique, first the input image is decomposed into different sub bands at multiple levels by using 2-D DWT transform (Taubman, & Marcellin, 2002; Shi, & Sun, 2007; Woods, 2012). The number of decomposition levels is calculated based on the input image size as shown in fig. 3. For instance, if the size of input image is 1024×1024 then the number of decomposition level will be 10 which is very high and hence EZW technique will offer very high computational complexity for the compression of this image. Further, after the DWT decomposition, the decomposed image forms a tree structure, because of the sub sampling offered by the DWT transformation at each level (Janaki, & Tamilarasi, 2011; Goswami, & Chan, 2011; Edwards, 1991). As a result a coefficient that lies in a lower sub band has four children descendants in the next higher sub band. Moving further, each child also has its four descendants in the next higher sub band and so on. This process makes groups of quad trees with every root having four leafs, as shown in the fig.4.

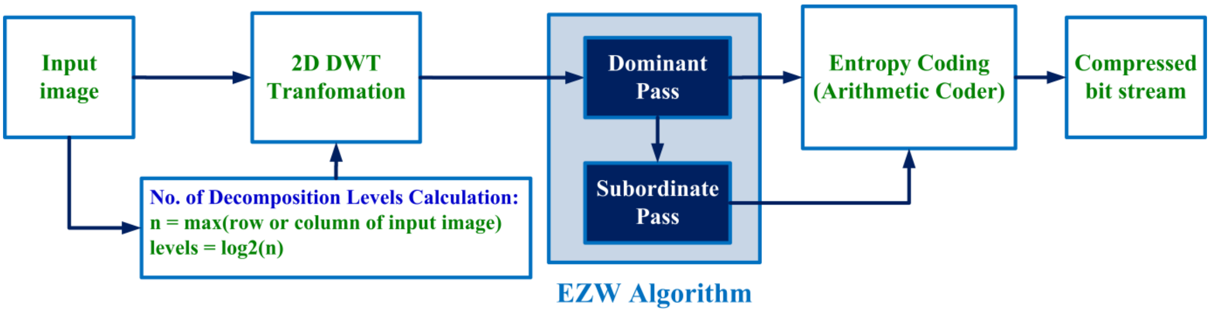


Fig. 3 - Block diagram representation of EZW technique based image encoder.

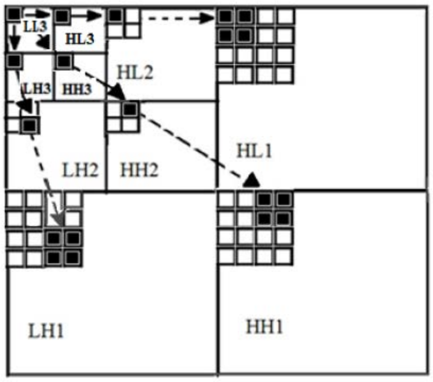


Fig. 4 - Structure of Zero-tree and Parent-Child Relationship.

In EZW algorithm, for each scan there are two passes namely dominant pass and refinement pass. Dominant pass generates any one of the four possible combinations like Significant Positive (SP), Significant Negative (SN), Zero-Tree Root (ZTR) and Isolated Zero (IZ), as shown in fig.5. For a given threshold T, if a coefficient has a magnitude less than T, it is called as significant coefficient at level T. If the magnitude of the coefficient is less than T, and its all descendants also have magnitude less than T then the coefficient is called as Zero-Tree Root. However, if the coefficient value is less than T but some of its descendants have a value greater than T then such coefficient is called as Isolated Zero (Jayaraman, Esakkirajan, & Veerakumar 2009).

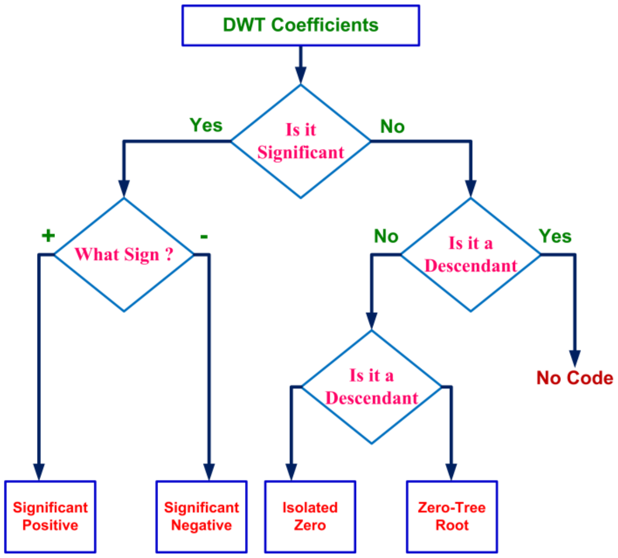


Fig. 5- Flow chart for the encoding of DWT coefficients in dominant pass coding.

A simplified version of complete EZW algorithm can be given as follows (Jayaraman, Esakkirajan, & Veerakumar 2009):

Step 1: Set the initial threshold T_0 such that $T_0 = 2^{\lfloor log_2 C_{max} \rfloor}$. where C_{max} is the maximum value of DWT coefficient.

Step 2: Set $k = 0$.

Step 3: Conduct a dominant pass by scanning through the data. The output of the dominant pass is any one of the four combinations like Significant Positive (SP), Significant Negative (SN), Zero-Tree Root (ZTR) and Isolated Zero (IZ), as shown in fig.5..

Step 4: Conduct a refinement pass by scanning through the data to refine the pixels already known to be significant in the current bit plane.

Step 5: Set $k = k + 1$ and calculate the new threshold $T_k = T_{k-1}/2$.

Step 6: Stop if the stopping criterion is met or go to Step 3.

Finally, at the end of the encoding process, all the symbols which are obtained from the Dominant pass and the refinement pass will be entropy coded using arithmetic coder to generate the final bit stream.

2. Experimental Results and Conclusions

This section present the results obtained after compression and decompression of the three different SEM images each of size 512×512 with 8-bit precision as shown in fig.6, for the different compression rates using proposed SEM image coder against the popular JPEG standard and recent JPEGXT standard. Particularly, for the testing of JPEGXT coder, profile *c* has been used because profile *a* and *b* does not support the compression of integer images. Further, in order to properly evaluate the compression performance of the proposed coder against the JPEG and JPEGXT coders on various compression rates two important image quality indexes PSNR (Jayaraman, Esakkirajan, & Veerakumar 2009) and MSSIM (Wang, et al., 2004) have been used. The final PSNR and MSSIM characteristics obtained after testing for the three different SEM images are shown from fig. 7.

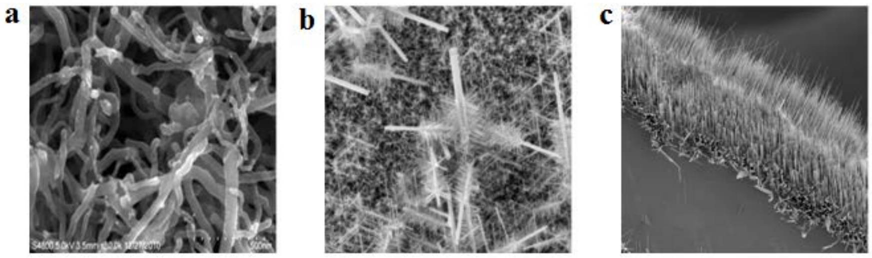


Fig. 6- Test SEM images of (a) Carbon Nanotubes (CNT.jpg), (b) Nano Tree (NT.jpg), (c) ZnO (ZnO.jpg).

Table 1 - PSNR values obtained for test image CNT.jpg.

Compression Rate	PSNR in dB		
	JPEG	JPEGXT	Proposed SEM image coder
0.250	25.159	16.778	30.010
0.350	28.201	23.756	32.209
0.500	31.406	28.692	34.909
0.750	35.074	32.964	37.989
1.000	37.750	36.454	40.260
1.250	39.807	37.033	42.590

Table 2 - MSSIM values obtained for test image CNT.jpg.

Compression Rate	MSSIM Index		
	JPEG	JPEGXT	Proposed SEM image coder
0.250	0.663	0.358	0.852
0.350	0.787	0.641	0.897
0.500	0.885	0.822	0.940
0.750	0.947	0.920	0.967
1.000	0.970	0.961	0.978
1.250	0.981	0.967	0.986

Table 3 - PSNR values obtained for test image NT.jpg.

Compression Rate	PSNR in dB		
	JPEG	JPEGXT	Proposed SEM image coder
0.250	23.441	17.959	27.364
0.350	25.507	22.553	29.021
0.500	28.233	26.705	30.667
0.750	30.816	30.056	32.761
1.000	32.679	31.648	34.448
1.250	34.119	33.873	36.149
1.500	35.291	34.232	37.605

Table 4 - MSSIM values obtained for test image NT.jpg.

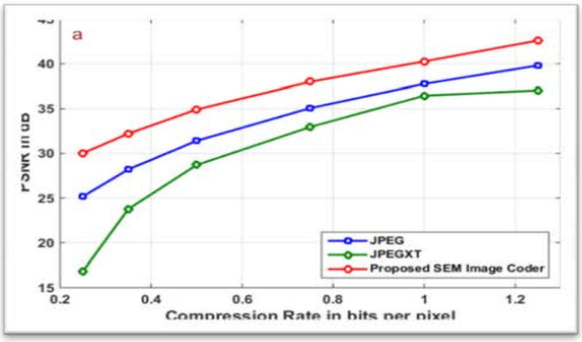
Compression Rate	MSSIM Index		
	JPEG	JPEGXT	Proposed SEM image coder
0.250	0.583	0.315	0.791
0.350	0.700	0.575	0.854
0.500	0.841	0.785	0.901
0.750	0.907	0.890	0.935
1.000	0.937	0.927	0.955
1.250	0.954	0.953	0.970
1.500	0.964	0.962	0.978

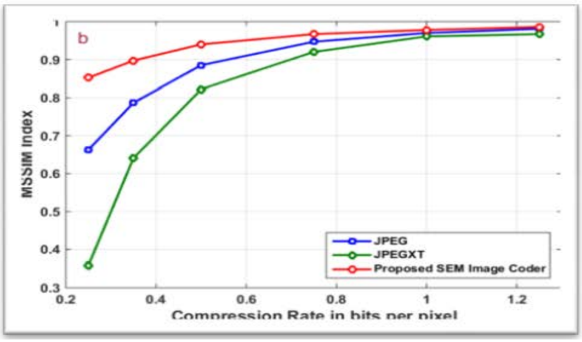
Table 5 - PSNR values obtained for test image ZnO.jpg.

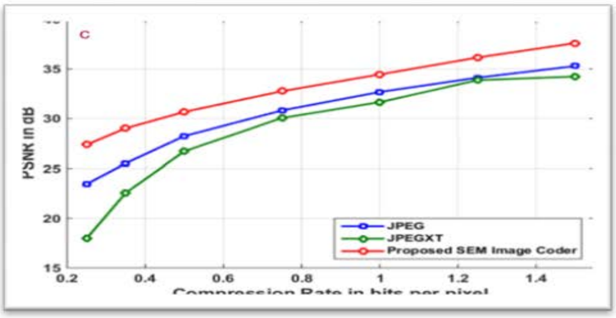
Compression Rate	PSNR in dB		
	JPEG	JPEGXT	Proposed SEM image coder
0.250	23.400	18.867	26.246
0.350	25.372	23.504	27.839
0.500	27.364	25.947	29.838
0.750	29.810	28.208	32.962
1.000	31.801	30.736	35.508
1.250	33.609	30.688	38.037

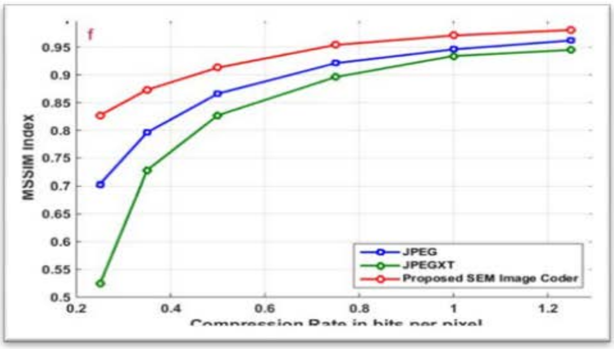
Table 6 - MSSIM values obtained for test image ZnO.jpg.

Compression Rate	MSSIM Index		
	JPEG	JPEGXT	Proposed SEM image coder
0.250	0.703	0.524	0.827
0.350	0.796	0.728	0.873
0.500	0.866	0.827	0.913
0.750	0.921	0.896	0.954
1.000	0.946	0.934	0.971
1.250	0.962	0.945	0.981









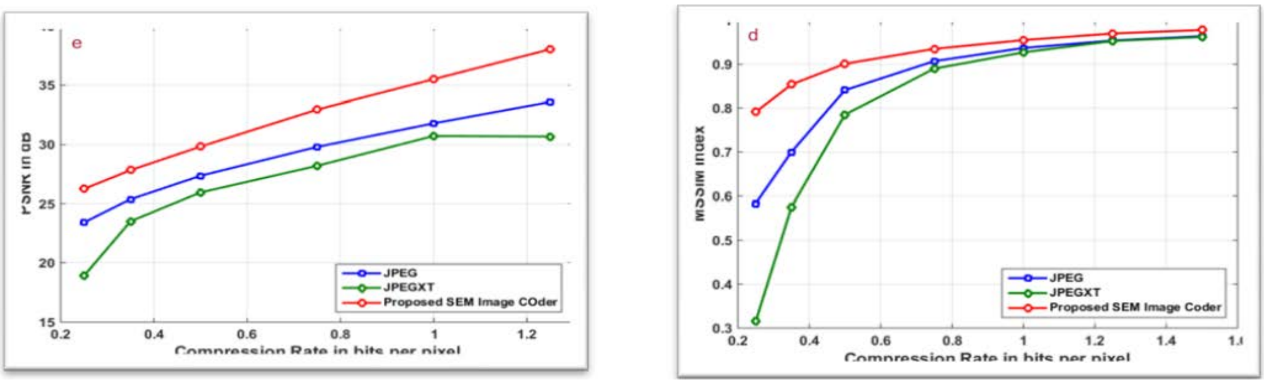


Fig. 7- Resultant PSNR and MSSIM characteristics (a) PSNR and (b) MSSIM curve for test image CNT.jpg, (c) PSNR and (d) MSSIM curve for test image NT.jpg, (e) PSNR and (f) MSSIM curve for test image ZnO.jpg.

The resultant PSNR and MSSIM values tabulated from Table 1 to Table 6 and also plotted in fig. 7 clearly reflects that the proposed SEM image coder outperforms and offers better quality compression and reconstruction for all the three test images as compared the existing JPEG and JPEGXT standards. Meanwhile, it is also observable that the proposed coder provides significant improvement on both the image quality parameters PSNR and MSSIM index. The proposed coder offers an average PSNR gain of about 2.7 dB from JPEG coder and 5 dB form the JPEGXT coder. Whereas, it provides average gains in MSSIM index of about 0.1 unit from JPEG coder and 0.15 unit from the JPEGXT coder. Hence, by using the proposed image coder we can compress the SEM images on higher compression rates without much degradation in the reconstruction quality.

4. Conclusions

In this paper, an efficient SEM image coder has been developed using hybrid DWT-DCT transform and Embedded Zero-Tree Wavelet (EZW) coding technique. The EZW technique based image compression is already an established technique but restricted for the real time applications due to its high computational complexity. In the proposed image coder we have utilized hybrid DWT-DCT transform with only three level wavelet decomposition to compensate the computational burden of EZW technique, and to achieve higher energy compaction as compared to the individual transforms. The proposed image coder has been extensively tested on different compression rates for the three test images. It is finally reported that the proposed image coder provides higher quality compression of SEM images as compared to the existing JPEG and JPEGXT compression standards.

REFERENCES

1. Chen, J., Tao, Z. L., and Li, S. L.(2003). Lithium Intercalation in Open-Ended TiS2 Nanotubes. *Angewandte Chemie*, 115, 2197–2201.
2. Wallace G. K. (1991). The JPEG still picture compression standard. *Commun. ACM*, 34 (4), 30–44.
3. David Taubman, Michael Marcellin (2002). JPEG2000: standard for interactive imaging. *Proceedings of the IEEE*, 90 (8), 1336 - 1357.
4. Mantel, C., Ferchiu, S., Forchhammer, S. (2014). Comparing subjective and objective quality assessment of HDR images compressed with JPEG XT. *IEEE MMSP*, 1–6.
5. Taubman, D., and Marcellin, M. (2002). JPEG2000 Image Compression Fundamentals, Standards and Practice. *Kluwer Academic Publishers*, 5-306.
6. Shi, Y. & Sun, H. (2007). Image and Video Compression for Multimedia Engineering, Fundamentals, Algorithms and Standards, *CRC press (2nd ed.)*, 216 -228.
7. Woods, J. (2012). Multidimensional Signal, Image, and Video Processing and Coding Second Edition, *Elsevier*, 363, 364.
8. Janaki, R. and Tamilarasi, A. (2011) Still Image Compression by Combining EZW Encoding with Huffman Encode.

International Journal of Computer Applications, 13(7), 2011.

9. Goswami, J. and Chan, A. (2011). Fundamentals of Wavelets, Theory, Algorithm and Applications. *Wiley (2nd ed.)*, 41 - 69, 153, 273 - 294.
10. Edwards, T. (1991). Discrete wavelet Transforms, Theory & Implementation, Stanford University, September 1991, Draft #2, June 4, 1992.
11. Jayaraman, S., Esakkirajan, S., and Veerakumar T. (2009). Digital Image Processing, *Tata McGraw Hill Edu.(1st ed.*).
12. Wang, Z., et al. (2004). Image quality assessment: From error visibility to structural similarity. *IEEE Transactions on Image Processing*, 13(4), 600-612.