International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:4, No:5, 2010

Image Enhancement of Medical Images using Gabor Filter Bank on Hexagonal Sampled Grids

Veni.S [A], K.A.Narayanankutty [B]

***Abstract*—For about two decades scientists have been developing techniques for enhancing the quality of medical images using Fourier transform, DWT (Discrete wavelet transform),PDE model etc., Gabor wavelet on hexagonal sampled grid of the images is proposed in this work. This method has optimal approximation theoretic performances, for a good quality image. The computational cost is considerably low when compared to similar processing in the rectangular domain. As X-ray images contain light scattered pixels, instead of unique sigma, the parameter sigma of 0.5 to 3 is found to satisfy most of the image interpolation requirements in terms of high Peak Signal-to-Noise Ratio (PSNR) , lower Mean Squared Error (MSE) and better image quality by adopting windowing technique.

***Keywords*—Hexagonal lattices, Gabor filter, Interpolation, image processing.

I. Introduction

X- RAY image enhancement is the process of enhancing edges progressively until optimal levels of clarity are reached in the x-ray image. Basically the edge segments of the image are enhanced by making its light parts lighter and its dark parts darker along the edges, preserving interior textures at their original gray level values. An interactive system was employed in [1] which enhances a digital radiogram, giving the radiologist a refined image on which to base a diagnosis. In [2], a local adaptive image enhancement and simultaneous denoising algorithm for fulfilling the requirements of digital X-ray image enhancement is introduced. An approach to image enhancement of digital chest radiographs is described by Du-Yih TSAI and Katsuyuki KOJIMA [3]. The method is to employ various non-linear mapping functions to different scale levels at the transform domain. The mapping functions are used to project a set of discrete wavelet transform (DWT) coefficients to a new set of DWT coefficients. In [4], a new method for contrast enhancement of MR brain images was proposed using a canonical correlation based kernel independent component analysis (KICA). The method presented for enhancing medical images generated from X-rays in [5] is based on a nonlinear partial differential equation (PDE) model, Kramer's PDE model. M. Dirk Robinson [6] used a fast nonlinear deblurring algorithm, specifically address the nonstationary noise associated with multiframe reconstructed images for enhancing digital mammogram images. Thus, for about two decades scientists have been developing techniques for processing pictorial information by means of digital computers with various techniques and algorithms. All these works are based on the images on rectangular Grid. The work proposed in this paper is based on hexagonal sampling grid to process the enhancement of medical images as it has many features.

Since Golay [7], the possibility of using a hexagonal structure to represent digital images and graphics has been studied by many researchers [8-14]. Hexagonal grid of pixels can be represented on the existing rectangular screens for modeling and processing purpose, which is more suitable for computer vision modeling [15]. Manipulating data sampled on one lattice to produce data sampled on a different lattice is termed as resampling. In this approach, the original data is sampled on a square lattice while the desired image is to be sampled on a hexagonal lattice (Figure.1)

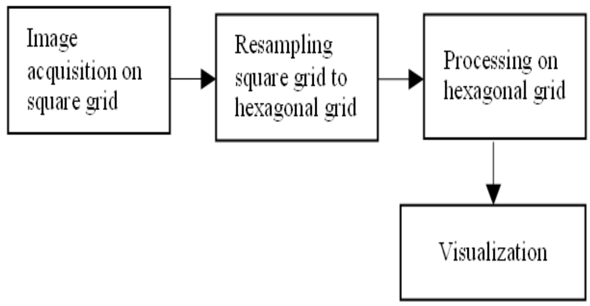


Fig. 1 Acquisition of hexagonally sampled images

The resampling method used in this paper is as follows. For each odd line, find the midpoint between two adjacent pixels by simple linear interpolation (i.e., mid = (left + right) / 2) [16]. Discard the left and right, keeping only the mid values. This gives us a hexagonal mapping from a regular square or rectangular grid. The procedure is as follows:

$$p^{new}(x,2y) = p^{old}(x,2y) \quad (1)$$

$$p^{new}(x,2y+1) = \left(p^{old}(x,2y+1) + p^{old}(x+1,2y+1)\right)/2 \quad (2)$$

During the acquisition of the images from rectangular lattice to the hexagonal lattice, it was observed that there is a considerable loss in image quality [Fig.2(a)].So, selection of suitable interpolation technique is needed before processing the image. Image reconstruction through interpolation is

Author A is with the Electronics and Communication Engineering Department, ,Amrita Vishwa Vidyapeetham , Coimbatore, Tamil Nadu,India (phone: 91-0422-2250256; e-mail: s_veni @ cb.amrita.edu).
Author B, is with the Electronics and Communication Engineering Department, Amrita Vishwa Vidyapeetham, Coimbatore, Tamil Nadu, India (e-mail: ka_narayanankutty @ cb.amrita.edu).

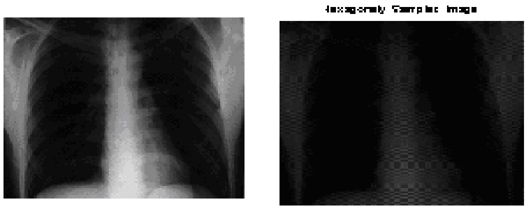


Fig. 2 (a) Original chest X-Ray image (b) Pixel representation on hexagonal grid

routine task in image processing during all transformation that is made on an image. Such transformations include scaling, rotation, registration, and edge detection. Considerable interest on hexagonal sampling is shown recently due to the interest in human vision systems , some of the image acquisition systems using hexagonally laid pixels, imaging radars and nuclear medicine. They also possess better topological and geometrical properties, resulting in a more efficient signal representation in two dimensions [17].

Images are generally constructed out of discrete sample points and if the fitted function is band limited, the signal can be reconstructed using interpolation by a Sinc-function, which is a low pass filter in the frequency domain. Ideally this interpolator should not create any artifacts on the resultant interpolation, but it introduces artifacts due to its truncation or by windowing for computational economics. This has prompted scientists to explore compactly supported interpolating functions which are approximations to obtain a perfect reconstruction. It has also a filtering effect as some noise components get suppressed during reconstruction. Much work is available for interpolation in rectangular lattices using parameterized wavelets and piecewise polynomial functions, the most important being that is using B - Splines [18]. B - Spline methods enable approximation in a simple way using the orthogonal properties of B - Splines. In hexagonal grid, three methods namely, box splines, hex-splines and generalized splines of maximal order and minimum support are proposed [19-26]. The first one exploits the six fold symmetry and the second, twelve fold symmetry. However the third one is a generalization to get best results out of an interpolation with a trade off between the interpolated result and computational complexity. This is achieved from error minimization using the spectral components with an assumption that the signal energy is concentrated over the low-frequency region. A method employing Gabor filters is proposed on the hexagonal lattice to get enhanced quality image reconstruction with some extra computational power. For analysis, windowing technique is used which yields improved results.

II. GABOR FILTERS

A. Overview of Gabor filters

Gabor filters have desirable properties for picture analysis and feature extraction: They are selective in space, spatial frequency and orientation , achieving the theoretical limit for conjoint resolution in the spatial and spatial frequency domain [27]. Therefore, they have been widely used in these fields in recent years [28-31]. Those filters were also used to describe the behavior of simple cells in area V1 of the human visual cortex, which has turned out to be very successful [32]. Hubel and Wiesel [33] found simple cells in a cat's visual cortex, which was sensitive to frequency and orientation of an image perceived. Experiments revealed that a Gabor filter takes the form of a Gaussian modulated complex sinusoid in the spatial domain. The standard definition proposed by B. S. Manjunath and W. Y. Ma [34] is used (Equation 3).A two dimensional Gabor function *g(x, y)* and its Fourier transform *G(u, v)* can be written as:

$$g(x,y)=\left(\frac{1}{2\pi\sigma_x\sigma_y}\right)\exp\left[-\frac{1}{2}\left(\frac{x^2}{\sigma_x^2}+\frac{y^2}{\sigma_y^2}\right)+2\pi jWx\right]$$

or

$$g(x,y)=\frac{1}{2\pi\sigma_g^2}\exp[-\frac{x^2+y^2}{2\sigma_g^2}]\exp(j2\pi F(x\cos\theta+y\sin\theta)) \tag{3}$$

In the frequency domain,

$$G(u,v)=\exp\left\{-\frac{1}{2}\left[\frac{(u-W)^2}{\sigma_u^2}+\frac{v^2}{\sigma_v^2}\right]\right\} \tag{4}$$

Where

$$\sigma u=\frac{1}{2\pi\sigma x}\quad and\quad \sigma v=\frac{1}{2\pi\sigma y}$$

While σx and σy are the standard deviations of the elliptical Gaussian along x and y axes. The DC values of 2D Gabor filters were removed in order to eliminate high response to absolute intensity values. Filter parameters were obtained using the following Formulas:

$$a=\left(\frac{U_h}{U_l}\right)^{-\frac{1}{s-1}}$$

$$U_0=\frac{U_h}{a(s-m)}$$

$$\sigma_u=\frac{(a-1)U_0}{(a+1)\sqrt{2\ln 2}}$$

$$\sigma_V=\tan\left(\frac{\pi}{2k}\right)\left[U_h-2\ln\left(\frac{\sigma_u^2}{U_h}\right)\right]\left[2\ln 2-\frac{(2\ln 2)^2\sigma_u^2}{U_h^2}\right]^{-\frac{1}{2}} \tag{5}$$

Where S is the total number of stages and $m = 0,1,$ ___S-1. The DC values of 2D Gabor filters were removed in order to eliminate high response to absolute intensity values.

International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:4, No:5, 2010

B.Importance of windowing

Usually, it is not possible to process all the samples of a signal simultaneously. The signal is processed in reduced segments, chosen with an analysis window. By choosing a size of an adopted window, we can generally observe that the signal is stationary during the duration of the analysis period. Apodization windows are often used in signal processing to reduce the ill effects of finite processing windows. The windowed signal Xw (k) is thus represented as the product of the signal and of the weighted window:

$$Xw(k) = x(k).w(k)$$

Where x (k) is the signal to be analyzed and w(k) the weighting or temporal window of null value outside the observation interval. This temporal product is transformed in the frequency domain by a convolution product of the Fourier transforms of the sequence and window. A window is needed which does not suddenly cut off the signal at its edges, but rather one which smooths the signal gradually down to zero at its edges. One candidate for this is selected as the *Hanning window* [35]. This is defined by

$$h_k = 0.54 - 0.46\cos\left(\frac{2\pi k}{N-1}\right), \qquad 0 \le k \le N \qquad (6)$$

Effect of the Gabor filter with Hanning window on the texture image with hexagonal sampling is discussed in the section IV.

III Computational Results

A.Gabor Filter Bank

The filter bank was carried out with six orientations as 0º, 30º, 60º, 90º, 120º and 150º and three radial frequency values: *F* = (0.3536, 0.1768 and 0.0884). This leaves us with a total of 18 filters that cover the frequency domain. Different standard deviation values of the Gaussian curve were tested, those being the three values used in the study σ_g = (2.91, 5.82 and 11.64) [Equation (3)].

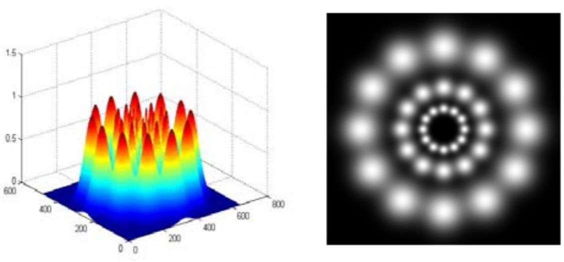


Fig. 3 (a) Gabor kernel and (b) Gabor filter bank with σ_g =11.64; F=0.0884

B.Gabor filter bank for hexagonal sampled Image

Next the filter bank was carried out with three orientations 0^0, 60^0 and 120^0. The filter bank was applied to the hexagonal sampled images e.g chestxray.tif - Figure 2(b) which is of poor quality obtained for the input image shown in Figure 2(a).Half pixel shift method for the acquisition of hexagonal lattice from rectangular lattice is used as reported in our earlier paper [36-37].

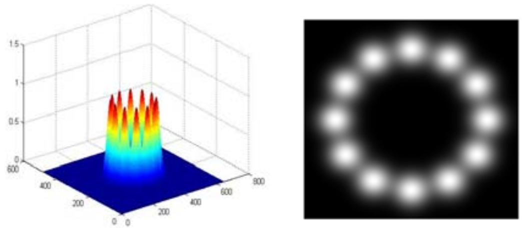


Fig. 4 (a) Gabor kernel and (b) Gabor filter bank with σ_g =5.82 ;F = 0.1786

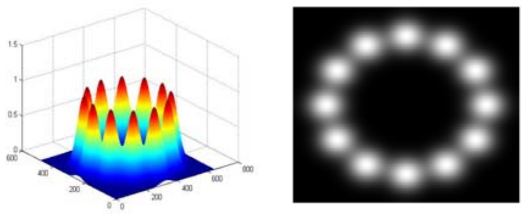
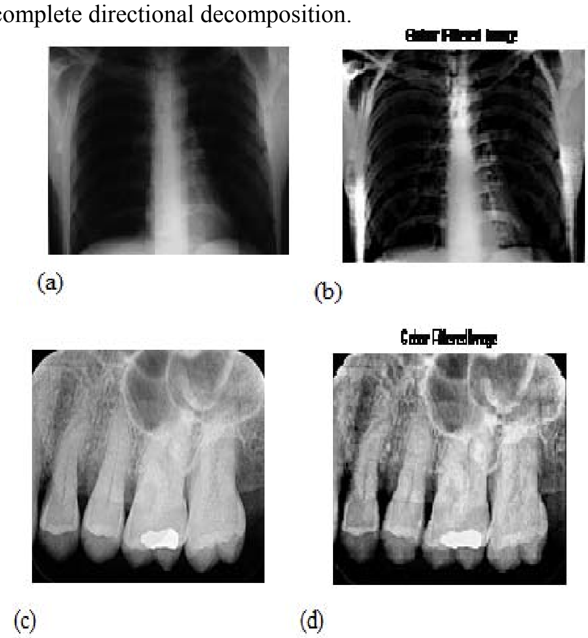


Fig. 5 (a) Gabor kernel and (b) Gabor filter bank with σ_g = 2.91 ;F = 0.3536

The image resulting from the filtering process is shown in Figure 6(b) with clarity in the image. The results show that that the proposed methodology works effectively with any complete directional decomposition.



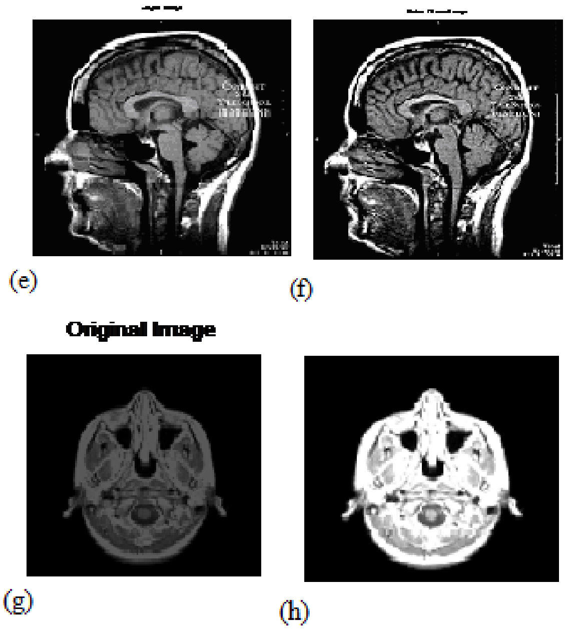


Fig. 6 (a),(c),(e),(g) Original images of Chestxray. tif,thumb.jpg, brain.jpg and mri.tif respectively (b) ,(d),(f) and (h) Gabor filtered image with the effect of filter bank corresponding to the original images

C. Gabor kernel with windowing technique

Fig. 7 shows the Gabor kernel with Hanning window discussed in section II-B. Figure .8 shows the response of image obtained by convolving the kernel of Figure.7 . With the effect of window, image is free from spurious shading and features of the image is very clear compared with the original image. The results show that the obtained image quality is better, smoothed and the orientations/edges are very clear (Figure. 9). Performance measures in terms of Peak Signal-to-Noise ratio (PSNR) and Mean Squared Error (MSE) were analysed and listed in Table.1 which shows marginal improvement with hexagonal lattice than the rectangular lattice when operating the Gabor filter on the image. For sigma value between 0.5 to 3 better results are obtained in terms of high PSNR and lower MSE values. Generally σ = 0.75, σ = 1.5, σ = 3 for simple, medium and large simple cell width respectively [39].

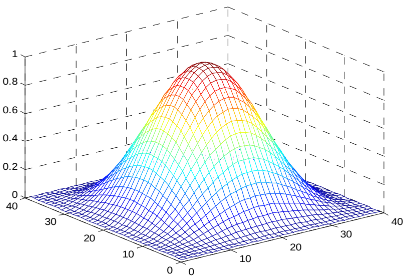


Fig.7 Gabor kernel with hanning window

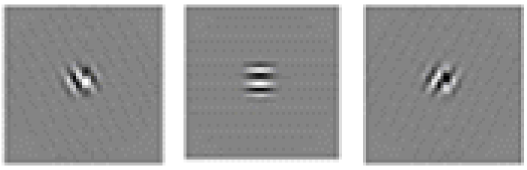


Fig. 8 Gabor filter response for $\theta = 0^0$, 60^0 and 120^0 for the hexagonal sampled image shown in Figure.2(b)

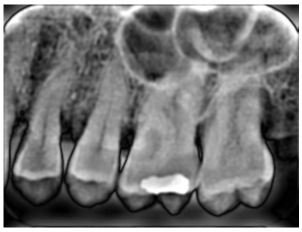


Fig. 9 Effect of Gabor kernel with Hanning window on hexagonal sampled image

From the analysis, it was found that the processed images are of better quality with these sigma values and the results are plotted for σ = 1.5 in Table .1 and Table.2.Table.1 shows the performance comparison of the Gabor filter response of the images on rectangular and hexagonal lattices.Table.2 shows the performance comparison of the Gabor filter response of the images with and without windowing technique on hexagonal lattice .

TABLE I PERFORMANCE COMPARISON OF THE GABOR FILTER RESPONSE OF THE IMAGES ON RECTANGULAR AND HEXAGONAL LATTICES (Σ = 1.5)

	Gabor filter response on rectangular lattice		Gabor filter response on hexagonal lattice With hanning window	
	PSNR	MSE	PSNR	MSE
Mri.tif	55.76	0.172	66.57	0.0143
Chest xray.tif	55.129	0.298	60.38	0.0595
Thumb.jpg	55.804	0.173	59.45	0.0737
Brain.jpg	54.827	0.214	59.84	0.0310

TABLE II PERFORMANCE COMPARISON OF THE GABOR FILTER RESPONSE OF THE IMAGES WITH AND WITHOUT WINDOWING TECHNIQUE ON HEXAGONAL LATTICE (Σ = 1.5)

	Gabor filter response With out window		Gabor filter response With hanning window	
	PSNR	MSE	PSNR	MSE
Mri.tif	63.403	0.029	65.506	0.0183

Chest xray.tif	57.412	0.118	64.296	0.0242
Thumb.jpg	52.601	0.357	59.45	0.0737
Brain.jpg	56.8244	0.1351	63.2220	0.0310

IV. CONCLUSIONS

We have proposed an implementation of Gabor filters on the hexagonal lattice for resampling and interpolation. In an earlier paper [37, 38], the benefits of hex Gabor filters were reported for the purpose of filtering, edge detection and registration. In this paper the parameter sigma` from 0.5 to 3 is found to satisfy most of the image interpolation requirements as per the results obtained in previous section. For reflected images, we can get enhancement with a unique value of sigma. The X-ray image analysis shows that this is not true for images that contain light scattered pixels.

Interpolation methods using hexsplines and other interpolating functions have a smoothing effect on the image, whereas Gabor three orientation windowed filter show that the edges are better preserved, while keeping the low frequency information intact. It gives best results for the texture images. Therefore this method is ideal for generation of medical atlas from MRI images and for high definition TV.

The image quality obtained with Gabor filter has superior visual quality over their spline counterparts over the hexagonal lattice, leading to high-quality visualization of images (see Figure 6, 9). Notice that the hazy edges are modified to very sharp boundaries.

REFERENCES

[1] R. S, L. S. Rotolo, C. M. Park, T. J. Golab,“ X-RAY Image Enhancement” , IEEE,1980.

[2] Hakan O¨ ktem, Karen Egiazarian, Jarkko Niittylahti Juha Lemmetti,“ An approach to adaptive Enhancement of Diagnostic X-Ray Images ,” EURASIP Journal on Applied Signal Processing 2003:5, 430–436.

[3] Du-Yih TSAI and Katsuyuki KOJIMA,“Wavelet coefficient mapping for enhancement of chest x-ray images, ” Proceedings, XVII IMEKO World Congress, June 22 – 27, 2003, Dubrovnik, Croatia.

[4] Tomoko Tateyama, Zensho Nakao, Xianhua Han and Yen-Wei Chen,“ Contrast enhancement of MR brain images by Canonical correlations based Kernel independent component analysis,” International Journal of Innovative Computing, Information and Control, Vol.5, No.7, July 2009.

[5] Yan-Fei Zhao, Qing- Wei Gao, De-Xiang Zhang, and Yi-Xiang Lu,“ Medical X-Ray Image Enhancement Based on Kramer’s PDE Model,” Journal of Electronic Science and Technology of China, Vol. 5, No. 2, June 2007.

[6] M. Dirk Robinson , Sina Farsiu, Joseph Y. Lo and Cynthia A. Toth ,“ Efficient Restoration and Enhancement of Super-resolved X-ray Images,” ICIP , IEEE , 2008.

[7] M.Golay, "Hexagonal parallel pattern transformation", IEEE Transactions on computers, Vol. 18, No.8, pp.733- 740, 1969.

[8] R.M.Mersereau., "The process of hexagonally sampled Two – dimensional signals", Proceedings of the IEEE, Vol 67, pp.930-949, 1979.

[9] B.Kamgar-Parsi and W.A. Sander, III, "Quantization error in spatial sampling: comparison between square and hexagonal pixels", Computer Vision and Pattern Recognition, Proceedings CVPR ‘89’ pp. 604 – 611, 1989.

[10] B.Kamgar-Parsi, "Quantization error in hexagonal sensory configurations", IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol.14, No.6, pp. 665-671, 1992.

[11] J.P.Mylopoulos and T.Pavlidis, "On the topological properties of quantized spaces, I. the notion of dimension", Journal of the ACM (JACM), Vol.18, No.2, pp. 239-246, 1971.

[12] J.P.Mylopoulos and T.Pavlidis, "On the topological properties of quantized spaces, II. connectivity and order of connectivity", Journal of the ACM (JACM), Vol 18,No 2, pp.247- 254,1971.

[13] R.Vitulli, et al., "Aliasing effects mitigation by optimized sampling grids and impact on image acquisition chains", Geoscience and Remote Sensing Symposium, IGARSS '02, pp. 979-981, 2002.

[14] Eric Anterrieu, Philippe Waldteufel and André Lannes, “Apodization Functions for 2-D Hexagonally Sampled Synthetic Aperture Imaging Radiometers”, IEEE Transactions On Geoscience And Remote Sensing, Vol. 40, No. 12, pp. 2531-2542, December 2002.

[15] Lee Middleton and Jayanthi Sivaswamy , “Hexagonal Image Processing – A Practical approach”, Springer-Verlag London Limited, 2005.

[16] Senthil Periaswamy, “Detection of Micro calcifications in Mammograms Using Hexagonal Wavelets”, Thesis work, University of South Carolina, 1996.

[17] L. Condat, D. Van De Ville, and T. Blu, “Hexagonal versus orthogonal lattices: A new comparison using approximation theory,” in *Proceedings of IEEE, ICIP*,Vol. 3, Sept. 2005.

[18] M. Unser, “Splines: A perfect fit for signal and image processing,” IEEE Signal Processing Magazine., Vol. 16, No. 6, pp. 22–38, Nov. 1999.

[19] D. Van De Ville, W. Philips, and I. Lemahieu, “Least-squares spline resampling to a hexagonal lattice,” Signal Processing: Image Communication, Vol. 17, No. 5, pp. 393–408, May 2002.

[20] L. Condat and D. Van De Ville , “Quasi-interpolating spline models for hexagonally sampled data,” *IEEE Transactions on Image Processing*, Vol. 16, No. 5, May 2007, pp.1195-1206.

[21] P. Th´evenaz, T. Blu, and M. Unser, “Interpolation revisited,” *IEEE Transactions on Medical Imaging* , Vol. 19, No.7, pp. 739–758, July 2000.

[22] D. E. Dudgeon and M. E. Mersereau, Multidimensional Signal Processing. Englewood Cliffs, NJ: Prentice-Hall, 1984.

[23] D. Van De Ville, T. Blu,M. Unser,W. Philips and I. Lemahieu, “Hex-spline: A novel family for hexagonal lattices,” *IEEE Transactions on Image Processing*, Vol. 13, No. 6, June 2004, pp.758–772.

[24] Laurent Condat and Dimitri Van De Ville,“Three-directional box-splines: Characterization and efficient evaluation,” *IEEE Signal Processing Letters*., Vol. 13, No. 7, July 2006 , pp. 417–420.

[25] C. de Boor, K. Hollig, and S. Riemenschneider, “Box Splines”: Springer-Verlag, 1993, Applied Mathematical Sciences,Vol. 98.

[26] H. Prautzsch and W. Boehm, “Box splines,” in Handbook of Computer Aided Geometric Design. Berlin: Springer, 2001.

[27] Lee, T.S, “Image Representation Using 2D Gabor Wavelets, *IEEE Transactions on Pattern Analysis and Machine Intelligence,* ” Vol. 18, Issue 10, 1996, pp. 951-979.

[28] D. J. Gabor, “Theory of communication,” IEE, Vol. 93, No. 26, pp. 429–457, 1946.

[29] Xu, Y., Zhang, X ,“ Gabor Filter bank and its Application in the Fingerprint Texture Analysis,” PDCAT 2005, pp. 829-831.

[30] Huang, L., Shimizu, A., Kobatake, H , “Classification-Based Face Detection Using Gabor Filter Features,” *Proceedings of the IEEE International Conference on Automatic Face and Gesture Recognition*, 2004, pp. 397-402.

[31] Jain, A.K., Prabhakar, S., Hong, L., Pankanti, S,“Filter bank-Based Fingerprint Matching,” *IEEE Transactions on Image Processing*, Vol. 9, Issue 5, 2000, pp. 846-859.

[32] Jones, J.P., Palmer, L.A, “An Evaluation of the Two-Dimensional Gabor Filter Model of Simple Receptive Fields in Cat Striate Cortex, “ Journal of Neurophysiology, Vol. 58, Issue 6, 1987, pp. 1233-1258.

[33] D.Hubel and T.Weisel ,“ Receptive fields and functional architecture of monkey striate cortex,” *Journal of Physiology* ,Vol..195, pp.215-243,1968.

[34] B. S. Manjunath and W. Y. Ma, “Texture features for browsing and retrieval of image data,” *IEEE Transactions on Pattern Analysis and Machine Intelligence.*, Vol. 18, No 8, August 1996, pp. 837–842.

[35] Mohamed Najim ,“Digital Filters Design for Signal and Image Processing,” ISTE Ltd, USA.

[36] Veni. S, K.A. Narayanankutty, Satyapal Reddy.L, Vidya.P ,“ Wavelet based Edge detection and Multiresolution analysis on Hexagonal Sampled Grid Using Interpolation,” proceedings ICSIP - 2009 , August 12-14 2009 , Excel publications, ISBN:978-93-80043-26-5,pp.186-200.

[37] Veni.S, K.A.Narayanankutty , Vidya.P ,“ Performance analysis of Edge Detection methods on hexagonal sampling Grid,” *International Journal*

of Electronics Engineering and Research (IJEER), Research India publications Vol.1, No. 4 (2009) ,pp. 313–328.

S.Veni received the Master of Engineering degree (Applied Electronics) from the Bharathiar University and AMIE (Electronics and communication Engineering) from the Institution of Engineers (Calcutta), India in 1997 and 1994 respectively .She is now Assistant Professor at Amrita School of Engineering, Amrita Vishwa Vidya Peetham, Coimbatore, Tamil Nadu, India.

K.A Narayanankutty received the Master of Engineering degree (Electrical Engineering) and Ph.D from the Indian Institute of Science, Bangalore, India in 1974 and 1980 respectively .He is now Professor at Amrita School of Engineering, Amrita Vishwa Vidya Peetham, Coimbatore, Tamil Nadu, India.