Noise Reduction and Segmentation of Common Carotid Artery in Ultrasound Images and Measurement of Intima Media Thickness

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Abstract: *The study is about the assessment of use of filters for noise reduction in ultrasound images of the common carotid artery (CCA) using intima–media thickness(IMT). IMT is a risk-free technique for examining subclinical atherosclerosis and cardiovascular risk. A new combined speckle reducing anisotropic diffusion (SRAD) filter for noise reduction is then proposed. Initially samples of ultrasound images of carotid arteries were collected. The program was implemented using MATLAB software to extract consecutive images in bit map format. In addition to that, another program was implemented in MATLAB to apply the region of interest (ROI) to the thickness of the intima–media of the posterior walls of the arteries. Variety of noise reduction filters and Canny edge detection were implemented separately in the ROI. The program measured mean square error (MSE) and peak signal-to-noise ratio(PSNR). Results implied that the new combined SRAD filter with Canny edge detection generated minimum value for MSE and the maximum value for PSNR. This indicates that the results, both MSE and PSNR were better detected by the proposed SRAD filter with Canny edge detection, than it did for the other filters for speckle suppression and preservation detail in carotid arteries ultrasound images. Ultrasound images of carotid artery are one of the parts that hard to identify by inexperience doctor or radiologist because the shape is almost same like the muscle layer. Hence, the segmentation of carotid artery layer and measurement of the Intima Media Thickness (IMT) is proposed. We use Otsu's thresholding algorithm to segment the carotid artery from the background. After applying binarization technique and by performing morphological operations, the carotid artery region in the image is clearly visible, such that it is easy to measure the Intima Media Thickness (IMT).*

Keywords: *CCA, IMT, SRAD, Canny Edge Detection, ROI, MSE, PSNR, Otsu's Thresholding*

I. Introduction*:*

Precise measurement of the Intima–Media Thickness (IMT) of common carotid artery (CCA) is a major method for prediction of cardiovascular diseases. For accurate diagnosis, medical images needs to be clear, sharp, without noise and artifacts. Usually an ultrasound image predominantly contains speckle noise which affects imaging modality. Interference of energy from randomly distributed scattering results in Speckle Artifact. It reduces image resolution, contrast and blurs details. Thus, speckle noise reduces the diagnostic value of the ultrasound images. Whenever ultrasound imaging is employed it is essential to decrease the incidence of speckle noise. Speckle noise reduction techniques include the use of Lee, Kuan, Weiner, and wavelet filters. Lee and Kuan filters perform the same function, i.e both reduce the mean square error (MSE) between the estimated pixel value and the real value.

Kuar et al. used and compared various speckle reduction filters on ultrasound images which indicated that wavelet filters outperform other regular speckle filters [5]. Donoho introduced soft-thresholding wavelet-based denoising wherever an image is decomposed into the wavelet domain [6]. Takur et al. compared wavelet filters with different thresholding values for ultrasound images using Donoho's method [2]. Sudha et al. [7] used a method based on wavelet thresholding to decrease speckle noise in medical ultrasound images. Nicolae et al. [8] proposed an algorithm to differentiate speckle noise from signals. They attained structural information from the wavelet-decomposed image at resolution scale.

Vishwa and Sharma [9] used a wavelet thresholding method that estimated thresholds using the discrete wavelet transform of the image. Filtering based on anisotropic diffusion was introduced by Perona and Malik and constitutes an important tool for image enhancement [10].

Yu et al. suggested a new filtering plan based on the filter first described by Lee and Frost. They found a relation between the former and the anisotropic diffusion equations which gave rise to speckle reduction filter they called SRAD(Speckle Reducing Anisotropic Diffusion) [11]. The SRAD filter, a Hybrid model, provided better results when compared with stand-alone anisotropic diffusion and other filtering techniques, although image clarity was reduced significantly. Another study, designed hybrid models for speckle noise reduction by combining traditional linear detailed preserving anisotropic diffusion and anisotropic diffusion based on fourth-order PDE.

II. Methodology & Filters*:*

A. Despeckling Techniques:

Speckles are multiplicative in nature. Speckle noise with a random granular pattern corrupts the image and delays interpretation of the image content[4]. A speckle image is usually described as multiplicative noise in ultrasound images.

This is given by the following equation-

$$f(x,y)= z(x,y)*u(x,y) + m(x,y)\text{.............} (1)$$

where f(x,y) denotes the noisy image, z(x,y) denotes the intensiy of image without speckle, u(x,y) denotes the multiplicative noise component, m(x,y) is the additive noise component. Additive component is smaller when compared to the multiplicative component, it is discarded.

$$f(x,y)=z(x,y)*u(x,y)$$

Taking logarithm on both sides of the equation transforms it into a classic signal in additive noise form as-

$$\log f(x,y)= \log z(x,y) + \log u(x,y)\text{....................} (2)$$

or

$$f^{l}(x, y)= z^{l}(x, y) * m^{l}(x, y) ;$$

where m^L is approximated as additive white noise. Assuming that speckle pattern has a white Gaussian noise model, there are several speckle reducing filters available for this case, where some provides better noise reduction and some provides good visual interpretations. Lee, Kuan, Weiner, unsharp, wavelet, new mixture SRAD, frequency domain, are some of the best speckle-reduction filters.

1. Lee Filter: The Lee filter originated from the linear speckle noise model and its criterion is minimum MSE (MMSE). If the variance is low or constant, smoothing will not be performed unless high variance is detected [3].

The equation utilizing lee filter-

$$R=I(t)*w(t)+I(t)*[1-w(t)]$$

where the denoise image is R and the image corrupted with speckle noise is I(t) and w(t) is weighted coefficient attained as:

$$w(t) = 1- c_u^2/c_I^2(t),$$

where $c_I(t)$ are variation coefficients and σ_u, c_u, and σ_I are SDs of speckle u(t) and image I(t), respectively:

$c_u=s_u/u$,

$c_i(t)=s_I(t)/I(t)$.

2. Kuan Filter: The Kuan filter transforms the multiplicative noise model and utilizes the MMSE criterion. Statistical distribution of the pixels in the moving window is used to estimate the value of the pixel of interest. Kuan filter is based on the assumption that the mean and variance of the pixel of interest equalthe local mean and variance of all pixels within the moving window [4]. The equation utilizing kuan filter is same as that of lee filter, with W(t) different.

$$R = I(t) *w (t) + I(t)*[1 - w(t)]$$

where w(t) is, $w(t)= (1 - (c_u^2/c_I^2(t))) / (1 + c_u^2)$

3. Wavelet De-noising Filter: This filter uses thresholding of wavelet coefficients to minimize speckle noise. Wavelet

denoising is based on discrete wavelet transformation followed by coefficient thresholding. Speckle noise is multiplicative, logarithmic transformation of the original image should be performed before wavelet decomposition. Soft and hard thresholding are the thresholding methods. Hard thresholding deletes all coefficients smaller than the threshold and retains the other unchanged. Soft thresholding deletes all coefficients under the threshold, but scales the remaining coefficients. Hard thresholding creates discontinuities in the reconstructed signal and soft thresholding does not [12].

soft thresholding $X' = \begin{cases} x - x_{thr}, & \text{for } x \ge x_{thr} \\ 0, & -x_{thr} \le x \le x_{thr} \\ x + x_{thr}, & \text{for } x < -x_{thr} \end{cases}$ X_{thr} is threshold

hard thresholding $X' = \begin{cases} x, & \text{for } |x| > x_{thr} \\ 0, & \text{for } -x_{thr} \le x \le x_{thr} \end{cases}$

$$\frac{\partial u}{\partial t} = -\nabla^2 [c(|\nabla^2_u|\nabla^2_u)$$

$$E(u) = \int_V f(|\nabla^2| dx\, dy)$$

$$|\nabla_u^2| = 0 \text{ for all } (x, y) [V$$

4. SRAD Filter: SRAD stands for Speckle Reducing Anisotropic Diffusion filter. It is used to directly suppress the speckle noise in ultrasound images and radar images. SRAD is based on a PDE that includes the imaging gradient, Laplacian, and image intensity. New mixture SRADs with fourth-order PDE, anisotropic diffusion, and soft-threshold wavelets include total variation (TV) diffusivity functions to minimize blocking artifacts and develop the quality of the non-speckled image.

SRAD in this paper (combined SRAD)

$$SRAD(U) = ut + =$$

$$ut + \frac{D_t}{} \, div(g(ICOV(u))x\nabla u)$$

$$U_{ij} = \frac{1}{W^2_m} \sum_{(-w/2)}^{(w/2)} \sum_{n=(-w/2)}^{(w/2)} X_{j-m, j-n}$$

$$s^2_{i,j} = \frac{1}{} \sum_{m=(-w/2)}^{(w/2)} \sum_{n=(-w/2)}^{(w/2)}$$

SRAD with non-linear fourth-order PDEs are used effectively in noise reduction.

The l2-curvature gradient flow is $\partial_t u$ and diffusivity function is TV diffusivity and energy function is E(u). t is the diffusion time index and t is the time step responsible for the convergence rate of the diffusion process (normally in the range 0.05–0.25) and g(.) is the diffusion function and is given by below equations:

$$g(ICOV(u)) = e - (p)$$

$$p = \frac{ICOV(u)(q^{t})^2 - 1}{1 + (q^{t})^2}$$

where q is the measure of speckle coefficient of variation in a homogenous region of the image. Moreover, in soft wavelet x (i, j) is the pixel at the location (i, j). W is the moving window. Our SRAD filter combined with fourth-order PDE and soft wavelet denoising model

The PDE attempts to remove noise and preserve edges**.**

Fig. 1 shows conversion of signal i input to signal I output using a new mixture SRAD model.

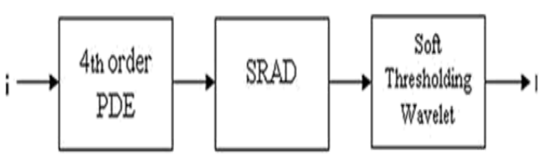


Fig. 1 Combined SRAD schema

B. Edge Detection: Edge detection algorithms can be sub-categorized into two groups. A gradient-based detector in which classic edge operators such as Sobel,Canny,Prewitt and Roberts are used. The zero-crossing based edge detectors are those such as the Laplacian, of the Gaussian method [13]. Canny edge detection was used in this paper.

1. Canny Edge Detection: This method utilizes a multistage algorithm to detect the edges of an image. This detector searches for the local maximum of gradient of the image function (f(x, y)),to find the edges. The derivative of a Gaussian filter is used to calculate the gradient. Two thresholds are used to detect strong and weak edges [14]. For edge detection, the weak edges are connected to the strong edges.

***C. Thresholding & Otsu's Thresholding*:** Thresholding is the simplest method of image segmentation. From a grayscale image, thresholding can be used to create binary images. To determine the thresholding level, Otsu's thresholding method is used. Otsu's thresholding method involves iterating through all the possible threshold values and calculating a measure of spread for the pixel levels each side of the threshold, i.e. the pixels that either falls in foreground or background. The aim is to find the threshold value where the sum of foreground and background spreads is at its minimum.

Otsu's Thresholding:

- separate the pixels into two clusters according to the threshold
- find the mean of each cluster0
- square the difference between the means
- multiply by the number of pixels in one cluster times the number in the other
- compute histogram and probabilities of each intensity level
- set up initial $q_i(0)$ and $\mu_i(0)$
- step through all possible threshold maximum intensity
- update q_i and μ_i
- compute $\sigma_b^2(t)$
- desired threshold corresponds to the maximum.

III. Work-Flow Chart:

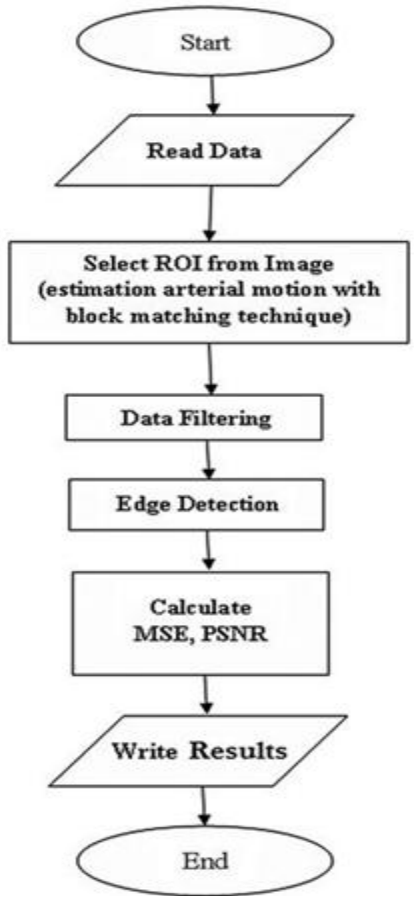


Fig 3.1: Flowchart of image processing algorithm

We start off by obtaining the appropriate image from the database, followed by selection of the ROI. The cropped image is passed through a series of filters(Lee, Kuan, Wavelet-Denoising, SRAD) with Canny-Edge Detection.MSE & PSNR values are calculated respectively and the filters are compared accordingly.

*A. Comparison of various filters and performance analysis***:**

The input RGB image acquired from data base is converted into gray and then cropped. The cropped image is now passed through various filters(Lee, Kuan, Wavelet-Denoising, SRAD) after despeckling. Then performance analysis i.e MSE and PSNR calculations for various filters can be done.

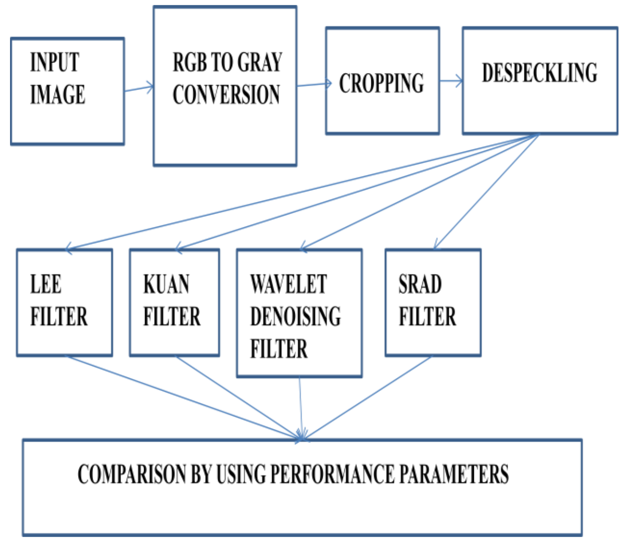


Fig 3.2: Block Diagram for comparison of various filters and performance analysis

B. Block Diagram for image segmentation and IMT measurement:

After performance calculations the filter having minimum MSE and maximum PSNR is selected for Image segmentation which involves Otsu's thresholding, Binarization, Morphological Operations. IMT is measured from the segmented carotid artery.

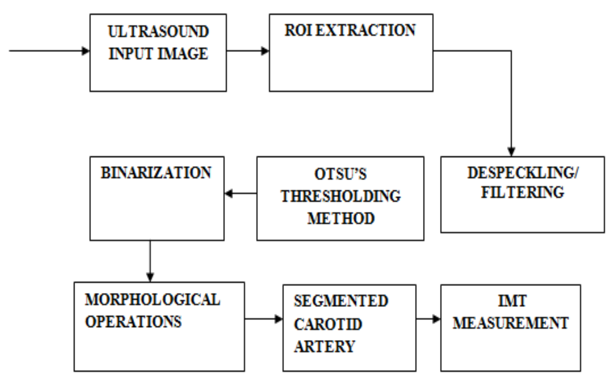
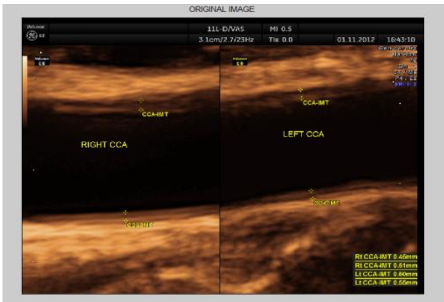


Fig 3.3: Block Diagram of how the operations are taking place.

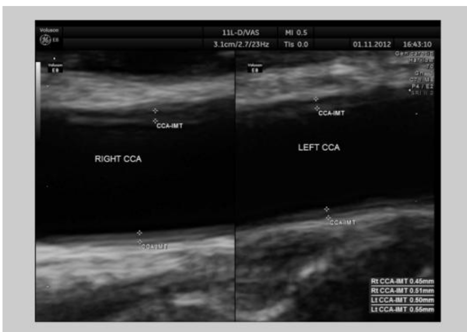
IV. Simulation & Results:

The results from the denoising filters and Canny edge detection are summarised below:

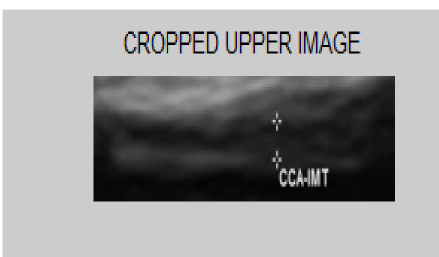
Input Ultrasound RGB Image:



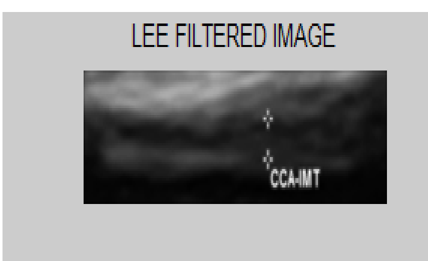
Gray Scale Image:



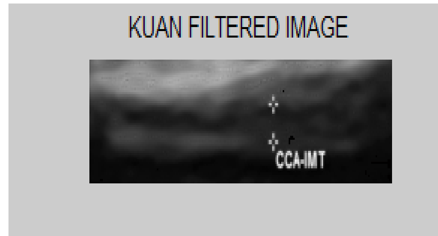
Cropped Upper Image:



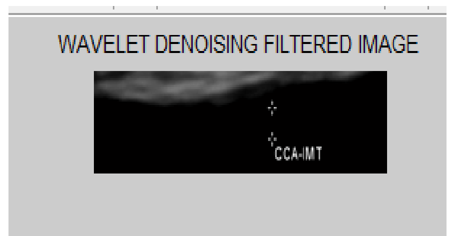
Lee Filtered Image:



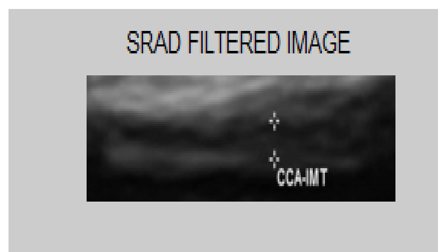
Kuan Filtered Image:



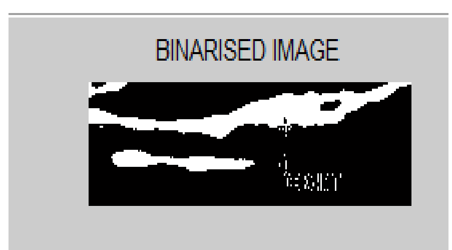
Wavelet Filtered Image:



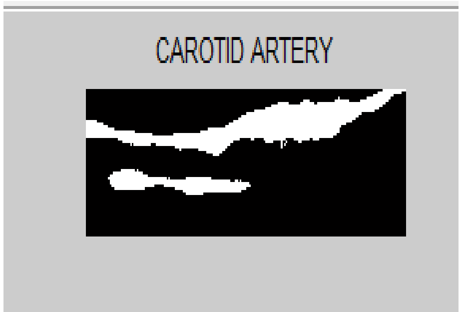
SRAD Filtered Image:



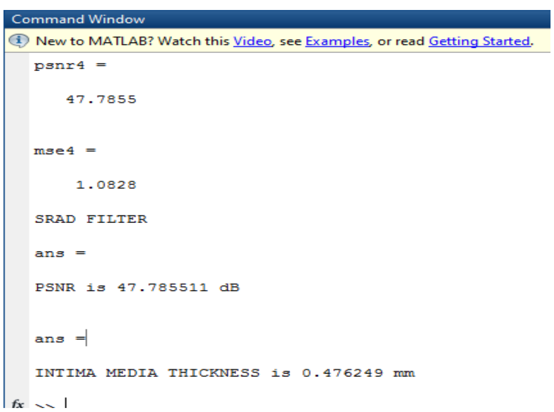
Binarized Image:



Carotid Artery Image:



There was a significant difference between the new SRAD filter combined with Canny detection and other filters with Canny edge detection ($p < 0.05$). The results of PSNR indicate a significant difference between the proposed SRAD filter with Canny edge detection and other filters with Canny edge detection.



V. Discussion:

Measurement of the IMT in the CCA using ultra-sonography is a safe, low cost, and non-invasive technique for evaluating atherosclerosis and determining cardiovascular risk [1].Speckle noise is common in ultrasound imaging. This results from random intervention between coherent returns issued from scatters present on the surface [2]. Speckles are low contrast and reduce the ability of observers to obtain real information. The presence of speckles in CCA ultrasound images hinders their enhancement. It also complicates image segmentation and edge detection. It is very important to suppress speckle noise to enhance the image before image analysis [2].

The present paper demonstrated that the SRAD filter combined with Canny edge detection outperformed other filters for noise reduction in MSE and PSNR. This could result from problems in these filters for noise reduction. The Lee, Kuan filters are sensitive to the size and form of the filter window. They are not directional and cannot reduce noise close to an edge [15]. SRAD is better than other common filters for speckle reduction [8]. The results of the present paper were better than those from previous studies in PSNR terms. This may result from the use of fourth-order instead of second-order PDE in the proposed filter. One advantage of fourth-order PDE is that it dampens oscillations at high frequencies (i.e. noise) much faster than second-order diffusion. It is also possible to develop schemes that include the effects of curvature (i.e. second derivatives of the image) in the dynamics to create a richer set of functional behaviors[16]. Experimental results prove that the proposed SRAD combined with Canny edge detection efficiently produced quality denoised ultrasound images of the CCA. The addition of Image segmentation using Otsu's Thresholding Technique produced a better denoised image than the previous case and ergo, will have significant role in further diagnosis.

VI. Conclusion:

Ultrasound images of carotid artery are one of the parts that are hard to identify by the doctors or radiologists because the shape is almost same like the muscle layer. Hence, a carotid artery automatic detection method is proposed for the segmentation and the measurement of the Intima Media Thickness (IMT) is also proposed in this study. The overall method of segmenting the carotid artery has been successfully developed using MATLAB to automatically detect the carotid artery from ultrasound images. The results will help the doctors and radiologist for further diagnosis. Besides that, the patient can get the correct earlier treatment and the chance of recovery is increased.

References:

1. Rafati, M., Arabfard, M., Rafati Rahimzadeh, M.: 'Comparison of different edge detections and noise reduction on ultrasound images of carotid and brachial arteries using a speckle reducing anisotropic diffusion filter', Iran. Red Crescent Med. J., 2014, 16, (9),
2. Hafizah, W.M., Supriyanto, E.: 'Comparative evaluation of ultrasound kidney image enhancement techniques', Int. J. Comput. Technol. Appl., 2011, 21,

3. Benes, R., Riha, K.: 'Medical image denoising by improved Kuan filter', Adv. Electr. Electron. Eng., 2012, 10..
4. Kaur, J., Kaur, J., Kaur, M.: 'Survey of despeckling techniques for medical ultrasound images', Int. J. Comput. Technol. Appl., 2011, 2, pp. 1003–1007.
5. Kaur, J., Kaur, J., Kaur, M.: 'Survey of despeckling techniques for medical ultrasound images', Int. J. Comput. Technol. Appl., 2011, 2, pp. 1003–1007
6. Om, H., Biswas, M.: 'A new image denoising scheme using soft-thresholding', J. Signal Inf. Process., 2012, 3, pp. 360–363
7. Sudha, S., Suresh, G.R., Sukanesh, R.: 'Speckle noise reduction in ultrasound images by wavelet thresholding based on weighted variance', Int. J. Comput. Theory Eng., 2009, 1, pp. 7–12
8. Nicolae, M.C., Moraru, L., Onose, L.: 'Comparative approach for speckle reduction in medical ultrasound images', Rom. J. Biophys., 2009, 1, pp. 13–21
9. Vishwa, A., Sharma, S.: 'Speckle noise reduction in ultrasound images by wavelet thresholding', Int. J. Adv. Res. Comput. Sci. Softw. Eng., 2012, 2, pp. 25–30
10. Yu, J., Wang, Y., Shen, Y.: 'Noise reduction and edge detection via kernel anisotropic diffusion', Pattern Recognit. Lett., 2008, 29, pp. 1496–1503
11. Geethalkshmi, S.N., Suguna, J.: 'Hybrid models for denoising ultrasonic images', J. Glob. Res. Comput. Sci., 2010, 1, pp. 38–45
12. Shruthi, G., Usha, B.S., Sandya, S.: 'A novel approach for speckle reduction and enhancement of ultrasound images', Int. J. Comput. Appl., 2012, 45, pp. 14–20
13. Acharjya, P.P., Das, R., Ghoshal, D.: 'Study and comparison of different edge detectors for image segmentation', Glob. J. Comput. Sci. Technol. Graph. Vis., 2012, 12, pp. 29–32
14. Preetha, J., Selvarajan, S., Suresh, P.: 'Comparative analysis of various image edge detection techniques for two dimensional CT scan neck disc image', Int. J. Comput. Sci. Commun., 2012, 3, pp. 57–61
15. Singh, R., Kaur, A.: 'Comparative analysis of speckle noise reduction techniques and their affect on image edge localization', Int. J. Comput. Sci. Technol., 2011, 2, pp. 78–82
16. Hajiaboli, M.N.: 'An anisotropic fourth-order diffusion filter for image noise removal', Int. J. Comput. Vis., 2011, 92, pp. 177–191.