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Coupled PDE for Ultrasound Despeckling using ENI Classification

R. Soorajkumar[a], P. Krishnakumar[a], D. Girish[b,*] and Jeny Rajan[a]

[a] *National Institute of Technology, Surathkal Mangalore 575 025, Karnataka, India*
[b] *Devi Scan Centre Kothamangalam, Cochin, Kerala 686 691, India*

Abstract

Speckle is a type of noise which is often present in ultrasound images. Speckle is formed due to constructive or destructive interference of ultrasound waves. Due to the granular pattern of speckle noise, it hides important details in ultrasound images. Many despeckling techniques are proposed in the literature, but most of them fail to reach a balance between the removal of speckle noise and preservation of the fine details in the image. In this work, an improved coupled PDE model is proposed which combines second order selective degenerate diffusion (SDD) model and fourth order PDE model based on the assumption that speckle in ultrasound image follows Gamma distribution. An edge noise interior (ENI) method is used to control the diffusion. With the help of ENI controlling function, the diffusion at edge pixels and noisy pixels are selectively accomplished with varying speed. Thus, the proposed model preserves the edges and fine texture details in the image. The model is tested on simulated images after corrupting the images with various levels of Gamma noise. Further, we have tested it on real ultrasound images also. The performance of the proposed model is compared with other similar techniques and the proposed method outperforms other state-of-the-art methods, both in terms of qualitative and quantitative measures.

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Keywords: Coupled PDE; ENI; Gamma Noise; Speckle; Ultrasound.

1. Introduction

Ultrasound (US) imaging is a popularly known method in medical imaging modalities because of its versatility, non-invasiveness, portability, non-ionizing and low cost nature. However, granular pattern which exists in US image called 'speckle', degrades the performance of post-processing tasks applied to US images such as image segmentation and registration and also influences the visual analysis. Hence, there is a need for designing a filter which suppresses speckle noise without losing relevant image features.

In the past two decades, various methods have been proposed to despeckle the US images. These techniques include linear filtering, non-linear filtering, wavelet filtering, stochastic based filtering and anisotropic diffusion filters. Linear filters like Lee[1], Kuan[2] and Frost[3] filters replaces the center pixel by the weighted average of all the pixels around the neighbourhood pixels within the kernel window. These filters depends on the coefficient of variation (COV), which maintains a balance between the edge and texture features in non-homogeneous and homogeneous regions. Coupe *et al.*[4] introduced a non-local means (NLM) based approach (OBNLM) for speckle reduction, which exploits the

*Corresponding author. Tel.: +91-984-5848743.
E-mail address: soorajkumarbhat@gmail.com

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data redundancy in the image. Partial differential equation (PDE) based methods have been employed in the past for denoising and enhancing the images. The essential thought of PDE based methods is to warp the pattern of a broken image with a PDE model and get the desired results as the solution of this PDE with the noisy image as input[5]. Witkin[6] proposed a PDE model which follows heat equations. Even though this model diffuses in all directions to remove noise, the edges are not well preserved. To overcome this limitation, later researchers viewed this problem in a different perspective by taking three factor[5] into account (i) controlling the speed of diffusion (ii) controlling direction of diffusion (iii) or combination of both[5].

There exist many PDE-based methods which were used to remove noise from images. Perona and Malik (PM)[7] proposed a second order PDE model, in which the authors introduced the controlling function depending upon image gradient. Catte *et al.*[8] proposed a selective smoothing model by improving the controlling function of PM equation. Further, Alvarez *et al.*[9] improved the controlling function of PM model and added a diffusion direction term to it and named it as selective degenerated diffusion (SDD) model. Here, diffusion takes place with respect to the direction as well as speed. Yu and Acton[10] proposed a speckle reducing anisotropic diffusion (SRAD) method to suppress the speckle noise by preserving the edges. Aja-Fernández *et al.*[11] proposed a detail preserving anisotropic diffusion (DPAD) which uses a diffusion function based on Kuan filter. Both SRAD and DPAD use instantaneous coefficient to preserve the edges.

Most of the second order PDE models proposed so far are trying to achieve a trade off between removing noise and preserving edges. However, second order models usually suffer from blocky staircase effects due to piecewise constant approximation which add an unnatural look to the image. You and Kaveh[12] proposed a fourth order PDE to remove speckle noise, where they used a diffusion controlling function which is based on Laplacian of an image. By using piecewise planar approximation, the blocky stair case effects get reduced, resulting in a more natural looking image. However, fourth order PDE methods require more number of iterations to converge.

A coupled PDE model is presented which is a combination of second order SDD[9] model and a fourth order[12] PDE model. Our diffusion controlling function is based on edge-noise-interior (ENI) computation. In this way, diffusion at edge and noisy pixels are selectively accomplished with various speeds. Since we made the assumption that the speckle in the US image follows the Gamma distribution[13], it become essential to remove the bias introduced after denoising. For this purpose, we have estimated shape and scale parameters of the Gamma distribution using maximum likelihood (ML) approach[14].

We organised the paper as follows: Speckle noise characteristics are discussed in Section 2. The coupled PDE model is explained in Section 3. In Section 4, results obtained through experiments are discussed and we conclude the paper in Section 5.

2. Speckle Noise Characteristics

Speckle noise exists in US image which degrades its quality. To effectively remove speckle noise, it is essential to know the statistical distribution of noise. Speckle is formed due to overlapping of two or more backscattered US waves. Depending upon the scatter number density (SND) and presence/absence of deterministic components speckle is classified into four types. When SND is large with the absence of the deterministic components, the speckle is categorized as fully developed speckle noise and it follows Rayleigh distribution[15]. When SND is large with the presence of the deterministic components, the speckle is categorized as fully resolved speckle noise and it follows Rician distribution[15]. When SND is small with the absence of the deterministic components, the speckle is categorized as a partially developed speckle noise and it follows K-distribution[16]. When SND is small with the presence of deterministic components, the speckle is categorized as partially resolved speckle and it follows homodyned K-distribution[16]. Although in practice, the number of scatters are high, the distribution doesn't follow exactly Rayleigh distribution instead it follows the weighted sum of Rayleigh variables which can be approximated with a Gamma distribution[13].

3. Proposed Model

3.1 Speckle noise model

In this study, we assume speckle noise in US image follows Gamma distribution which can be modelled as:

$$I = I_0 + n \tag{1}$$