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Technical note

Adaptive speckle reduction in ultrasound images using fuzzy logic on Coefficient of Variation

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ABSTRACT

Speckle reduction is an important pre-processing stage for ultrasound medical image processing. In this paper, an adaptive fuzzy logic approach for speckle noise reduction in ultrasound images is presented. In the proposed method, adaptiveness is incorporated at two levels. In the first level, applying fuzzy logic on the coefficients of variation computed from the noisy image, image regions are classified. The best suitable filter for the particular image region is adaptively selected by the system yielding appreciable improvement in noise suppression and preservation of image structural details. At the second level, to distinguish between edges and noise, the proposed method uses a weighted averaging filter. The structural similarity measure, which depends on the nature of image and quantity of noise present in the image, is used as the tuning parameter. Thus with two levels of adaptiveness, the proposed method has better edge preservation compared to existing methods. Experimental results of the proposed method for natural images, Field II simulated images and real ultrasound images, show that proposed denoising algorithm has better noise suppression and is able to preserve edges and image structural details compared with existing methods.

1. Introduction

Ultrasound imaging is predominantly used for diagnosis of thyroid diseases compared to X-ray, computed tomography and magnetic resonance imaging as it is non-invasive, utilises non-ionising radiation and is cost effective. However, the main disadvantage of medical ultrasonography is the poor image quality due to backscattered echo signals called speckle [1]. Therefore, it is not only difficult for the physician to analyse and diagnose the image in the presence of speckle noise but it is also difficult for feature extraction, analysis, and recognition [2]. Hence, speckle filtering is a critical pre-processing step. Researchers have proposed a number of methods for speckle reduction. Lee [3], Frost et al. [4], and Kuan et al. [5] have proposed spatial domain filters based on the local statistics of the image. These methods achieve good speckle reduction in homogeneous areas but ignore the speckle noise in areas close to the edges and lines. Perona and Malik [6] developed a method called anisotropic diffusion based on heat equation. This technique works well in homogenous areas with edge preservation for images corrupted by additive noise but the performance is poor for the multiplicative speckle noise. Yu and Acton [7] proposed a method called speckle reduction anisotropic diffusion (SRAD). In this method, a diffusion coefficient is defined based on the ratio of local standard deviation to mean using four nearest neighbour window. However, smoothening of the edges and structural content occurs in this method.

Achim et al. [8] proposed a speckle reduction based on homomorphic filtering and modelled the wavelet coefficients as a non-Gaussian model. However, this approach is computationally expensive, as it requires the extraction of distribution parameters. Yue et al. [9] developed a non-linear multiscale wavelet diffusion algorithm for speckle suppression. This technique not only preserves edges but also enhances edges by inhibiting diffusion across edges. Pizurica et al. [10] proposed a generalised likelihood (GenLik) method in which wavelet coefficients are denoised by likelihood ratio using local neighbours following non-homomorphic filtering technique. An adaptive wavelet thresholding technique was proposed in [11] based on Bayesian maximum aposteriori probability (MAP) by modelling the noise free signal coefficients as symmetric normal inverse Gaussian and noisy coefficients as Gaussian distribution. From this, an adaptive threshold is obtained to reduce the speckle noise in ultrasound images. An adaptive bilateral filtering algorithm was developed in [12] by estimating the range parameter using intensity homogeneity measurements and denoising was performed iteratively. Nonsubsampled Contourlet Transform

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(NSCT) developed by Cunha et al. [13] tested the transform on image corrupted with additive white Gaussian noise (AWGN) and applied hard thresholding. This method gives better performance than the undecimated wavelet transform in image enhancement as well as in filtering AWGN noise. Cheng et al. [14] proposed speckle reduction of synthetic aperture radar images based on fuzzy logic. This technique computes fuzzy edges for each pixel in the filter window and uses these to weight the contributions of neighbouring pixels to perform fuzzy filtering. Nevertheless, this iterative filter has the drawback that it is suitable only for images with large homogenous area. Zhang et al. [15] proposed a fuzzy sub pixel fractional partial difference method for ultrasound speckle reduction. In this, the Euler Lagrange equation is employed and filtering is done in an iterative manner by which image contrast is improved. Nevertheless, calculation of parameters for image fuzzification at every iteration is the limitation of this scheme. Kwan et al. [16,17] proposed symmetrical and asymmetrical triangle fuzzy filters based on median and average filters. However, the fuzzy based median or average filters tend to smoothen the fine details causing poor edge preservation. Binaee et al. [18] developed a fuzzy filter based on local gradient of the image and used fuzzy inference to categorise the image regions and structural information. Weights were found based on a similarity window by non-local means filtering process. Nevertheless, the method is computationally intensive as it takes much iterations to locate the similarity window. Guo et al. [19] proposed a despeckling filter based on modified non local means algorithm. This method consists of two steps, first noise free pixel has been estimated using maximum likelihood estimator and a non-local means algorithm has been applied to restore details. The noise variance parameters in maximum likelihood estimator is directly related with exponential function in non-local means algorithm; hence optimisation of this parameter is difficult and this algorithm is time consuming. Damodaran et al. [20] developed an algorithm based on discrete topological derivative. This algorithm is able to reduce speckle noise and contrast of the image has been improved at the cost of more computational time. Tsakalakis et al. [21] developed a denoising filter based on novel multi-transducer architecture. Despeckling technique has been employed by combining frequency and spatial compounding along with despeckling super resolution algorithm. The main drawback is that image registration step is required as images are captured from different sensors with different frequencies.

This paper presents a novel fuzzy based filter for speckle noise reduction based on Coefficient of Variation parameter derived from the noisy image. Using this parameter, the structural information of the images is characterised. This proposed method incorporates adaptiveness at two levels. In the first level, using fuzzy logic, image regions are classified based on Coefficient of Variation parameter and the system adaptively selects the best suitable filtering technique for the particular region of the image. By applying appropriate filters on the corrupted pixels, appreciable improvement in noise suppression and preservation of image structural details is achieved. At the second level, to distinguish between edges and noise the proposed method uses a weighted averaging filter. Using the structural similarity index for computing the tuning parameter the proposed technique adapts with the nature of image and amount of noise present in the image. Thus with two levels of adaptiveness using Coefficient of Variation and structural similarity, the proposed method has better edge preservation compared to existing methods. The performance of the proposed method is studied with natural images, Field II simulated images, real ultrasound images and compared with existing methods.

The paper is organised as follows: Section 1 describes the related works, their limitations, and the objective of the paper. Section 2 discusses the fuzzy logic model for speckle noise reduction with Coefficient of Variation, design of the adaptive weighted averaging filter and the despeckling algorithm. Section 3 describes the experimental results and Section 4 summarises the conclusions of the study.

2. Proposed method

Most of the existing denoising techniques have considered only noise suppression and failed in the preservation of important details in an image. In addition, the methods are not able to distinguish between edge information and noise, thereby suppressing the edges assuming them as noise. Therefore, there is a need for a method that not only preserves the image details but also adapts the degree of smoothing based on the noise present in the image. This paper proposes an algorithm based on the concept of fuzzy logic to classify the different noisy pixels into classes such as homogenous, details and edges using parameters derived from the noisy image itself. Based on this inference, the proposed method adaptively applies appropriate filtering methods to different regions of same image and hence is able to preserve edges and details.

2.1. Noise model

Speckle noise corrupts the information content of the ultrasound image. Speckle noise occurs due to the interaction of the ultrasound waves with objects that are comparable to its wavelength [22]. In order to derive an efficient despeckle filter, there is a need for a speckle noise model. Let $R(x, y)$ be the observed ultrasound image with size $M \times N$. The speckle noise is multiplicative in nature and hence the output of the ultrasound imaging system may be defined as:

$$R(x, y) = I(x, y) . n(x, y) + \eta(x, y) \quad (1)$$

where (x, y) denote the pixel of observed image, $I(x, y)$ represents the noise free image, $n(x, y)$ and $\eta(x, y)$ represent the multiplicative and additive noise respectively. Since the effect of additive noise is negligible compared to multiplicative noise, Eq. (1) becomes

$$R(x, y) = I(x, y) . n(x, y) \quad (2)$$

The proposed method utilises homomorphic filtering approach by which logarithmic transformation is carried out to convert the multiplicative model to an additive model. Therefore, Eq. (2) can be written as

$$R'(x, y) = \log[I(x, y)] + \log[n(x, y)] \quad (3)$$

where $R'(x, y)$ is the log-transformed image.

2.2. Adaptive fuzzy logic model

In ultrasound images, speckle noise affects the image pixels and image regions can be grouped as homogenous, detail or edge regions. Each region has its distinguished characteristic features. Based on this, each pixel can have different degree of membership. Therefore, to classify each pixel, there is a need for an appropriate reasoning method. As ultrasound images have fuzziness caused by speckle noise, fuzzy logic can be considered as a simple way to arrive at a definite output from ambiguous, imprecise, or noise input information. Hence, fuzzy logic is used to classify the noisy pixel to belong to several classes based on the membership degree. The proposed fuzzy filtering process has two stages: detection and filtering. The detection stage involves classifying the noisy pixel into various classes. The image parameter, Coefficient of Variation has been utilised to categorise each pixel for detection. In the filtering process, three filters are applied on the classified pixels to suppress noise and enhance the ultrasound image.