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Speckle reduction algorithm for optical coherence tomography based on Interval Type II Fuzzy Set

Prabakar Puvanathasan[1,2] and Kostadinka Bizheva[1]

1. *Dept. of Physics and Astronomy, University of Waterloo, Waterloo, Ontario, Canada*
2. *Dept. of Systems Design Engineering, University of Waterloo, Waterloo, Ontario, Canada*

Phone : +1 519 888 4567 x 35665; Fax: +1 519 746 8115; E-mail: ppuvanat@engmail.uwaterloo.ca

Abstract:

A novel speckle reduction technique based on soft thresholding of wavelet coefficients using interval type II fuzzy system was developed for reducing speckle noise in Optical Coherence Tomography images. The proposed algorithm is an extension of a recently published method for filtering additive noise by use of type I fuzzy system. Unlike type I, interval type II fuzzy based thresholding filter considers the uncertainty in the calculated threshold and the wavelet coefficient is adjusted based on this uncertainty. Application of this novel algorithm to optical coherence tomography images of a finger tip show reduction in speckle with little edge blurring.

Keywords: Speckle noise, Soft thresholding, Type-II Fuzzy, optical coherence tomography, biomedical optics, medical imaging

Biography:

Prabakar Puvanathasan has obtained a B.Sc. degree (Systems Design Engineering) from University of Waterloo, Canada in 2006. He is currently working towards MSc degree in Physics with Dr. Kostadinka Bizheva at University of Waterloo, Canada. His interests focus on signal and image processing and pattern recognition analysis as applied to Optical Coherence Tomography for image enhancement.

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ABSTRACT

A novel speckle reduction technique based on soft thresholding of wavelet coefficients using interval type II fuzzy system was developed for reducing speckle noise in Optical Coherence Tomography images. The proposed algorithm is an extension of a recently published method for filtering additive noise by use of type I fuzzy system Unlike type I, interval type II fuzzy based thresholding filter considers the uncertainty in the calculated threshold and the wavelet coefficient is adjusted based on this uncertainty. Application of this novel algorithm to optical coherence tomography images of a finger tip show reduction in speckle with little edge blurring.

INTRODUCTION

Optical Coherence Tomography (OCT) is a modern biomedical imaging technology that allows in vivo, non-invasive high-resolution imaging of biological tissues. OCT is based on low-coherence interferometry, which utilizes the spatial and temporal coherence properties of optical waves backscattered from biological tissue [1]. Due to use of partially coherent light in OCT,, speckle noise is an inherent component of any OCT tomogram. Presence of speckle noise i results in granular appearance of the image, which in turn can obscure small or low reflectivity features, thus degrading the image quality of OCT tomograms. Furthermore, it can impede or limit the performance of image segmentation and pattern recognition algorithms that are used to extract, analyze, and recognize diagnostically relevant features.

In the past, extensive research has been conducted both the fields of medical imaging and remote sensing for suppressing speckle noise and various algorithms. A number of speckle reduction techniques such as adaptive filters [3] and Rotating Kernel Transformation [4]have been adapted specifically for improving image quality of OCT tomograms Filtering techniques based on the rotating kernel transform can produce good contrast enhancement of image features, but they also result in significant edge blurring when strong noise reduction is required [5]. Most of the algorithms are limited in the amount of speckle that can be reduced because of their complexity.

Here we present a speckle reduction technique based on interval type II fuzzy sets (also called ultrafuzzy sets) applied to the wavelet domain. The approach is an extension to previously published work [8] that uses interval type II fuzzy sets for speckle noise reduction. This technique utilizes soft thresholding to suppress the wavelet coefficients.

METHODS

Wavelet based de-noising method consists of the following steps: i) compute the 2D-DWT of the image at various levels of decomposition ii) remove noise from the detail wavelet coefficients by soft thresholding iii) reconstruct the enhanced image using inverse 2D-DWT. A method to shrink the wavelet coefficients is introduced based on the type II fuzzy values.

In image processing, multi-resolution representation of an image allows a coarse to fine analyzes of the details present in an image. Stephane G. Mallat, in his paper [6] describes the multi-resolution representation of an image for analyzing the information content of images. Wavelet transform is a multi-resolution decomposition tool that divides the signal space into a sequence of approximation spaces by filtering and scaling the input signal. Two dimensional discrete wavelet transform (2DDWT) is applied to an image by using 4 frequency channel filter banks.

The wavelet transform has special properties like sparsity, locality and multi-resolution and as a result de-noising using wavelet transform has proven to be very effective.

Fuzzy set theory deals with the imprecision and vagueness of human understanding systems. It was first introduced by L. A. Zadeh in 1965 [7] and since then has been used extensively in image processing. In OCT images, speckle noise can be approximated as a multiplicative noise such that,

$$f(m,n) = s(m,n)n(m,n) + n_a(m,n) \qquad (1)$$

where $s(m,n)$ represents the noise free OCT image, $f(m,n)$ is the noise observation of $s(m,n)$, $n(m,n)$ and $n_a(m,n)$ are multiplicative speckle and additive noise respectively, and (m,n) is the variable of spatial locations. In eq. (1) , the additive noise component can be ignored because it is significantly small compared to the multiplicative speckle noise. For developing speckle reduction filters in the wavelet domain, multiplicative noise has to be transformed into additive noise.This can be accomplished by using the Homomorphic (logarithmic) transformation:

$$f_L(m,n) = s(m,n)_L + n_L(m,n) \qquad (2)$$

Once, the image has been transformed, the 2D-DWT can be applied:

$$f_{s,d}(m,n) = s_{s,d}(m,n)_L + n_{s,d}(m,n) \qquad (3)$$

Here $f_{s,d}$ denotes the noisy wavelet coefficient of the image in orientation d at scale s, $s_{s,d}$ is the noise-free wavelet coefficient and $n_{s,d}(m,n)$ represents the noisy wavelet coefficient of the speckle. The additive noise in the image domain remains additive in the transformed wavelet domain due to the linearity of the wavelet transformThe next step in the wavelet based de-noising algorithm is thresholding the highest frequency wavelet coefficients by a soft threshold. In soft thresholding if the magnitudes of the coefficients are below the thresholds then they are set to zero while the coefficients with the magnitudes above the threshold are scaled. This is because the coefficients that contain mostly noise should be reduced to negligible values, while the ones containing a substantial noise free component should be reduced less. In wavelet domain different types of noise are associated with small coefficients. Important image structures are contained within the magnitude of the high coefficients. The coefficients around the threshold contain both noise and signal of interest. Therefore, an optimal thresholds designed when most of the coefficients bellow it are noise and the coefficients above it represents signals of interest. Due to the ambiguity of choosing a suitable threshold, it is appropriate to apply the fuzzy set theory in such situations. Using type I fuzzy membership functions, the wavelet thresholding can be expressed as a fuzzy wavelet thresholding. However, type I fuzzy sets have limited capacity to directly model and minimize the effect of data uncertainties. This data uncertainties comes from the linguistic uncertainties that involve in saying "if a certain wavelet coefficient's and its neighbouring coefficient's magnitude are small, then this coefficient is noisy for almost sure and should be set to zero" [8]. A type II fuzzy set does not have this limitation. As a result, it is suitable for finding a good threshold.

If a certain wavelet coefficient at position (m,n) and its neighbouring coefficients around (m,n) have magnitudes that are small, then the coefficient at (m,n) is noisy for "nearly certain" and should be set to zero. Also, if the magnitudes of the neighbouring coefficients are large and the magnitude of the coefficient at (m,n) is small, then the coefficient at position (m,n) is not noise for "almost certain" because the neighbourhood coefficients should be given more importance. Using these linguistic terms, "almost certain and nearly certain" two interval type II fuzzy sets can be defined i) large wavelet coefficient at (m,n) and ii) large neighbourhood coefficients around (m,n) .Finally, using the type II fuzzy logic system (Fuzzifier, Inference, Rules, Type-Reducer, and Defuzzifier), a new coefficient can be obtained at position (m,n) which has been reduced of noise. Once, all the coefficients have been found, applying the inverse 2D-DWT will result in the de-noised image.

Experimental results using OCT images are provided in order to demonstrate the usefulness of the proposed algorithm.

RESULTS AND DISCUSSION

In order to demonstrate the usefulness of the proposed algorithm, it was applied to images acquired in-vivo from a human finger tip with a high speed, high resolution Fourier Domain OCT system (FD-OCT) operating in the

1060nm wavelength region. The FD-OCT system was powered with a superluminescent diode (Superlum, λc = 1020nm, $\Delta\lambda$ = 106nm, Pout = 10mW), which resulted in 3. 5µm (axial) and 8µm (lateral) resolution in tissue. Images of a human finger tip were acquired with 1.3mW incident power at with 97dB SNR.

Daubechies wavelet was utilized for the 2DDWT with 4 scales of decomposition. Figure1 shows the original (left) and the filtered (right) OCT images. The type II fuzzy filtered image shown on fig. 1 has clearly visible edges and much less speckle patterns.

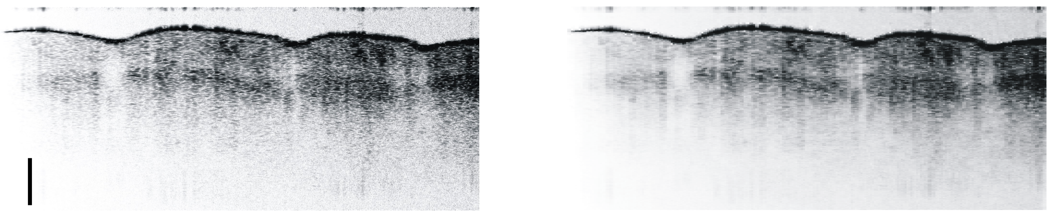

FIG. 1:Wavelet denoising of an image of a human finger tip acquired with the FD-OCT 1060nm system. The image is 1000 x 1024 (lateral x axial) pixels acquired with 3.5µm. Oringial OCT image (left) and filtered image (right) using the proposed method. The bar represents 200µm.

Our technique shows that speckle noise can be reduced using an interval type II fuzzy set based thresholding in the wavelet domain. The results from the experiment verify that interval type II fuzzy sets can reduce speckle pattern more effectively compared to standard filters.

CONCLUSION

A novel algorithm for reducing speckle noise in OCT images was presented in this paper. This algorithm is based on interval Type II fuzzy thresholding in the wavelet domain. The performance of the algorithm is comparable to pervious published algorithms on speckle reduction in OCT. It has shown to be effective in reducing speckle noise in a fingertip OCT image.

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