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A Review of: Filter Performance Evaluation for Noise Reduction in Bio Images

Satyawan Patil[1]
Department of Computer Engineering
Dr. D. Y. Patil SOET
Lohegaon, Pune.

Sathish Kumar Penchala[2]
Assistant Professor Department of Computer Engineering
Dr. D. Y. Patil SOET
Lohegaon, Pune.

Abstract: Noise suppression of echocardiography images is a challenging issue for accurate and effective human interpretation and computer-assisted analysis. In spite of comprehensive speckle reduction methods, until now there have been few studies of denoising echocardiography sequences based on temporal information. In this paper, a fast and accurate filter based on temporal information has been proposed that enables the reduction of noise in echocardiography images. The proposed method consists of smoothing intensity variation time curves (IVTC) assessed in each pixel. By filtering high-frequency components of each temporal signal and then replacing the smooth signals in their positions, all pixels of all frames can be reconstructed in a parallel manner. The performance of the proposed method is evaluated and compared with seven other speckle-reduction filters. Comparison of the filters is based on a series of computer-simulated and real clinical images, and also on visual assessment by experts. The experimental results show that the proposed algorithm is fast, less computationally demanding than other filters, and accurate, in addition to preserving the edges of the images.

Keywords: Noise suppression, echocardiography, filters, ultrasound machine.

I. INTRODUCTION

The use of ultrasound imaging as a diagnostic tool is well established because it is cheap, non-invasive, real-time, and safe in nature. However, accurate human interpretation and computer-assisted analysis are usually affected by a form of locally correlated noise [1], [2]. Two prominent phenomena in medical ultrasound imaging are scattering and reflection, which are two closely related concepts. When particles are larger than the wavelength, this is called reflection. However, scattering occurs when the scatterers are smaller than the sound's wavelength. The back-scattered acoustic pulses received by the transducer may be in phase or out of phase. This phenomenon leads to both constructive and destructive interference and appears as a granular pattern called speckle noise [1], [2].

In an ultrasound imaging system, if the envelope signal is captured before logarithmic compression, the speckle noise model may be approximated as multiplicative noise. After logarithmic compression, the speckle noise becomes noise transforms into the classical signal in the additive noise model [3]. Because the speckle texture often contains information about the tissue texture, speckle is not truly a noise [3]. Unfortunately, however, the presence of speckle limits contrast resolution in diagnostic ultrasound imaging and also adversely affects the application of image processing algorithms such as edge detection, segmentation, tracking, and registration [4], [5].Similarly, the variations caused by speckle are present in all cross-sectional views of echocardiographic images.

Speckle is prominent and more significant than additive noise. Speckle must be suppressed to positively affect subjective image quality and improve other image processing applications [6], [7].

A considerable amount of research attempts to reduce or eliminate speckle. Current approaches fall into two categories. The first category is based on using the phased data of RF signals; the second category comprises postprocessing approaches. Most post-processing techniques are well developed and include local statistical filters [8]– [14], geometric filters [15], wavelet filters [16], and anisotropic diffusion filters .

II. LITERATURE REVIEW

The theory, design, and application on generation, transmission, and detection of bulk and surface mechanical waves; fundamental studies in physical acoustics; design of sonic and ultrasonic devices and their applications in industry, biomedicine,and signal processing.[1]

One of the drawbacks to post-process and to interpret ultrasound medical images is speckle noise. In this paper we used fourth-order partial differential equation method proposed by Lysaker et al. for speckle reduction of ultrasound images.[3]

Speckle reducing anisotropic diffusion (SAR) is a partial differential equation-based method developed for this purpose. Toward its improved performance for point/linear features, we introduced a novel regulator called energy condensation integral and developed a regularized SRAD (Reg-SRAD) via minimization. The Reg-SRAD generates outputs with increased resolution for point and linear features while retaining the characteristics the SRAD–filtering speckle with regional features enhanced. The performance of the method has been illustrated using synthetic and real ultrasound data, and radar imagery as well.[5]

A diffusion method tailored to ultrasonic and radar imaging applications. SRAD is the edge-sensitive diffusion for speckled images, in the same way that conventional anisotropic diffusion is the edge-sensitive diffusion for images corrupted with additive noise. We first show that the Lee and Frost filters can be cast as partial differential equations, and then we derive SRAD by allowing edge-sensitive nisotropic diffusion within this context. Just as the Lee and Frost filters utilize the coefficient of variation in adaptive filtering, SRAD exploits the instantaneous coefficient of variation, which is shown to be a function of the local gradient magnitude and Laplacian operators. [5]

A fast and accurate filter based on temporal information has been proposed that enables the reduction of noise in echocardiography images. The proposed method consists of smoothing intensity variation time curves (IVTC) assessed in each pixel. By filtering high-frequency components of each temporal signal and then replacing the smooth signals in their positions, all pixels of all frames can be reconstructed in a parallel manner. [22]

ULTRASOUND speckle is the result of the diffuse scattering, which occurs when an ultrasound pulse randomly interferes with the small particles or objects on a scale comparable to the sound wavelength. Speckle is an inherent property of an ultrasound image, and is modeled as spatial correlated multiplicative noise. In most cases, it is considered a contaminating factor that severely degrades image quality. To improve clinical diagnosis, speckle reduction is generally used for two applications: visualization enhancement and auto-segmentation improvement .[8]

The most important tool is satellite-based synthetic aperture radar (SAR) systems. As an important aspect of measurement, monitoring and understanding of sea ice evolution during the seasons, the generation of ice maps is a fundamental step in interpretation of these data. The Canadian IceService(CIS) is a government agency that generates daily maps for monitoring ice-infested regions. Currently, all of the ice map generation is performed manually using digital techniques. An example of an ice map complete during the World Meteorological Organization (WMO) standard is found in [19]. A primary source of digital imagery in support of CIS operations is RADARSAT, a Canadian SAR satellite.

Speckle reducing anisotropic diffusion (SRAD) [20] has been emerged as a tool for reducing speckle with regional feature neatly enhanced. The method relies on the *instantaneous coefficient of variation* (ICOV) edge detector [20,,21] as a controller of diffusion rate near edges of regional structures. In SAR imagery, man-made targets usually show as dominant point scatterers and it is necessary for object detection and recognition methods attempt to extract the locations of them. In ultrasound images of artery, linear features are important. For thin linear features and point features, SRAD for regional feature characterization, the broadening is trivial; for linear feature characterization, it needs to be corrected. There exists a need to improve SRAD for applications where point and linear feature are critical.[20,21]

III. Paper Layout

The rest of the paper is organized as follows: first we go with proposed work in section IV and then filter performance evaluation in Section V. It highlights the key challenge in achieving our goal, and presents the LI ET AL.: NOISE REDUCTION OF ECHOCARDIOGRAPHIC IMAGES BASED ON TEMPORAL INFORMATION.

IV. Proposed Work

The proposed method consists of smoothing IVTCs assessed in each pixel. The IVTC signal can be explained by $p(x, y, t)$ for the pixel in coordinate (x, y) at the frame of t. The proposed method is not limited to one cycle and can have any desired number of required frames. Hence, the parameter t is in the range from 1 to T, in which T is the total number of frames which will be denoised. It shows a sample IVTC signal from a fixed coordinate (x, y) of 128 consecutive frames. The signal variations are based on the intensity variations of each pixel in the time. Three different points, which have different cardiac textures, are white arrows. These points are on the cardiac muscle, the ventricle border, and in the atrial cavity. Also shows the temporal signals from these different coordinates of (x, y) for t in the range of 1 to 250 of a real echocardiography sequence.

Because the atrial cavity is darker than the cardiac muscle and ventricle border, the mean intensity of atrial cavity is smaller than the two other positions. As mentioned previously, when the backscattered acoustic pulses are received by the transducer they may be in or out of phase. Hence, the granular patterns of speckle noise are the lighter and darker pixels on the image texture. These patterns correspond to high-frequency variations in the temporal signals.

To understand how the strength of a signal is distributed in the frequency domain, spectral analysis of the temporal signals was accomplished. To observe the frequency components, a single-sided amplitude spectrum was implemented. In a single-sided amplitude spectrum, the fast Fourier transform finds the frequency components of a signal. Also illustrates the corresponding Fourier transform of the original temporal signal. As expected, by filtering the high-frequency components of each temporal signal and then replacing the smoothed signals in their positions, all pixels of all frames can be reconstructed in a parallel manner.

To suppress high-frequency components, different low-pass filters can be selected. For simplicity, low complexity, and proper accuracy, we chose a second-order Butterworth filter with a normalized cut off frequency of 0.25.

V. Filter Performance Evaluation

To evaluate the performance of the proposed speckle reduction filter, two groups of simulated and clinical echocardiography images were analysed while considering that the clinical and simulated images determine the outcomes of filtering in different ways. In other words, because of the lack of a noise-free reference in clinical tests, the performances of these images are measured relative to the original speckled input but the simulated images are measured according to a noise-free reference.

a) *Simulated Images*

A short-axis view of a left ventricle was simulated as a tube which shrinks and expands. This was achieved using Autodesk 3ds Max software (Autodesk Inc., San Rafael, CA). Each cardiac cycle included 240 frames. These images are noise-free references. The simulated noisy images were generated by adding speckle noise in a Matlab 7 environment (The MathWorks Inc., Natick, MA).

b) *Clinical Images*

The speckle reduction techniques were applied on grayscale four-chamber and two-chamber view sequences of a set of healthy volunteers and volunteers with cardiac dysfunction. 1 The echocardiographies were recorded using a GE Vivid 3 ultrasound machine (General Electric Healthcare, Waukesha, WI) with a 2.0 MHz probe and stored in AVI format. The resolution of each image was 220 × 320 pixels. There was no built-in temporal and spatial noise reduction in these films.

Denoising Techniques Besides the benefits of the proposed method that have already been stated, one prominent advantage of this filter is its very low computational cost and, hence, fast execution. This property is suitable for denoising of high-framerate imaging systems which have large numbers of frames in each cardiac cycle. For a signal with t samples, second-order Butterworth filter implementation just required $2 \times t$ multiplications and $2 \times t$ addition operations to produce each output sample. Hence, to filter all pixels of all consecutive frames the computational requirements are $N \times 2 \times t$ multiplications and $N \times 2 \times t$ additions, where N is the number of pixels in each image and t is the number of frames. According to the computational requirements comparison between 15 different despeckling filters in [43], the proposed filter has the fewest multiplication/division and addition/subtraction requirements. Result shows the time consumed for denoising each frame of two cycles of a heartbeat. The implementation was done via an Intel core 2 Duo (Intel Corp., Santa Clara, CA) with a 2.00-GHz CPU and 2.00-GHz RAM. It is obvious that, after median filtering, the proposed filter is the fastest filter. The Frost, Kuan, and SRAD filters are the slowest filters.

VI. YHTRI

The objective of this work was to denoise echocardiographic images based on temporal information. In the pro-posed algorithm, the filtering was done on video frames which had been through attenuation correction and a nonlinear transform (close to the logarithmic transform) of the intensity value record by a transducer. Accordingly,the noise model can be assumed to be an additive noise model and the common LTI low-pass filters can suppress the high-frequency noise components. In this paper, we implemented a second-order low-pass Butterworth filter to reduce the noise in long-term temporal signals obtained from fixed coordinates of consecutive frames. In fact, we tested and chose the Butterworth filter from among other low-pass filters. The tested filters were the second-order Bessel filter and hard thresholding of FFT coefficients. We obtained the best result from the Butterworth filter in terms of both quantitative metrics and computational cost.

A comparative evaluation of the proposed method with other despeckle filtering techniques was accomplished. We chose Lee, Frost, Wiener, Kuan, and median filters because they are popular in noise reduction for echocardiography images and also have low computational costs. The comprehensive results assessment shows that the proposed filter suppresses speckle noise, successfully preserves edge details, and causes no significant blurring.

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AUTHOR(S) PROFILE

Satyawan Patil received the B.E. Degree in Computer Science & Engineering in 2012, From Adarsh Institute of Engineering and Technology, Vita. Now, Pursuing M.E. Degree in Computer Networks from Dr. D. Y. Patil School of Engineering and Technology in current academic year 2014-15. His current research focus is on Image Processing domain.

Prof.Sathish kumar Penchala received the Masters Degree in Computer Science, From Pondicherry University. Now, Assistant Professor in Department of Computer Engineering, Dr. D. Y. Patil School of Engineering and Technology Lohegaon, Pune.