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위상필터를 사용한 초음파 영상에서의 반점 제거

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Suppression of Speckle in ultrasonic image by Phase Filtering

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ABSTRACT

The object detection capabilities of ultrasonic imaging systems are limited by the ability of the detection process to distinguish the resolved object signals from backscattered speckle noise. It has been shown that the phase component of the Fourier transform of the speckle noise is random. Based on this property, we propose a new algorithm for distinguishing between speckle and specular targets. The proposed algorithm is implemented by taking the Fourier transform of the received signal , low-pass filtering the phase, and taking the inverse Fourier transform of the filtered phase to enhance specular reflectors and reduce speckle in the image. Simulations and experiments using phantoms confirm the algorithm yielding significant reduction of speckle noise.

1. INTRODUCTION

The texture pattern of ultrasound pulse-echo images caused by random interference between scattering regions has been called speckle. Speckle has a mottled or granular appearance in ultrasound pulse-echo images. This is equivalent to grain noise in nondestructive material evaluation and clutter noise in radar detection. The presence of such noise masks targets reducing their detectability.

Many algorithms have been developed to reduce the effect of such noise. Frequency and spatial compounding techniques [1,2] reduce speckle noise by shifting the transmitted frequency or the transducer position. SSP (Split-Spectrum Processing) methods [3,4] can acquire a set of decorrelated singnals without having to scan the object several times. The implementation of SSP involves taking the FFT (Fast Fourier Transform) of the received wideband signal and separating the resulting spectrum into window segments. The time domain representation is then obtained by the combination of the magnitude of the inverse FFT on each of the windowed frequency bins. Bamber et al. have developed an adaptive filter which uses local features of image texture to recognize speckled parts of the image [5]. O'Donnell [6] has proposed a phase insensitive detection scheme to minimize the speckle noise due to phase cancellation. Li et al. [7] have presented a new method for determining the optimal spectral region of the band-pass filter to reduce speckle noise based on the concept of group delay statistics. The group delay is the negative of the first derivative of the phase with respect to frequency [7].

Although speckle noise is of random character, it is not random in the same sense as electrical noise. If an object is imaged many times under exactly the same conditions, then identical speckle noise are obtained. It is shown in [7] that high SNR (sinal-to-noise ratio) in the frequency domain results in a constant group delay, while low SNR in the frequency results in a random group delay. Using this characterristic of the phase, we propose a new method to reduce speckle noise with phase filtering. The new PF (phase filtering) algorithm reported in this paper is implemented by taking the FFT of the received signal, low-pass filtering the unwrapped phase to remove quickly shifting phase components, and taking the inverse FFT to get the original domain representation. Since the new method uses the filtered phase, the reconstructed signal shape is completely different from the received signal. However, peaks representing "resolved" signals appear at the correct positions. Experimental images of a graphite and gelatin phantom with known reflectors, and of a tissue mimicking ecobloc show that the new algorithm can dramatically reduce speckle noise while enhancing the appearance of resolved scatterers. Simulation results with computer-generated speckle and a reflector also show the reduction of speckle under the condition of low SNR. The method presented in this paper can be extended to other applications such as radar, sonar, and nondestructive material evaluation.

2. PHASE CHARACTERISTICS OF THE RECEIVED SIGNAL

The phenomenon of speckle results from the use of coherent radiation for imaging. It occurs when small structures compared to the wavelength of the ultrasound signal cause interference between different parts of the wave received from the object.

The ultrasound signal echoing from an object larger than the ultrasound wavelength will result in a single "resolved" pulse [7]

$$S(t) = af(t-T_o), \qquad (1)$$

where A and T_o are constants, depending on the object position and reflectivity, respectively. The echo signal f(t) can be assumed to be an even function with low-pass frequency response [8].

In general, high concentrations of scatterers smaller than the ultrasonic wavelength produce speckle which has a Rayleigh amplitude distribution [7]. Speckle noise for an object consisting of N scatterers can be modeled as [7].

$$n(t) = \sum_{i=1}^{N} a_i \delta(t-\tau_i) * f(t), \qquad (2)$$

where a_i and τ_i are assumed to be uncorrelated random variables depending on the position and property of the scatterer. Li et al. [9] show that magnitude spectrum of n(t) in (2) exhibits periodic peaks in frequency.

The received signal x(t) is a sum of the echo signal from the object whose size is larger than the ultrasound wavelength and echoes from N scatterers represented in (2). It is assumed that system transfer function is constant.

Then, x(t) can be expressed as

$$x(t) = Af(t-T_o) + \sum_{i=1}^{N} a_i \delta(t-\tau_i) * f(t). \qquad (3)$$

The Fourier transform of the echo signal from the object can be obtained from (1)

$$S(f) = AF(f)e^{-j2\pi f T_o} \qquad (4)$$

Since we assume that f(t) is an even function, F(f) in (4) is real.

The Fourier transform of the speckle noise in (2) can be obtained as

$$N(f) = F(f) \sum_{i=1}^{N} a_i e^{-j2\pi f \tau_i} = |B(f)| e^{-j2\pi f u(f)} \quad (5)$$

where B(f) and u(f) are random variables corresponding to the magnitude and phase component of N(f), respectively.

Hence, the corresponding phase of the Fourier transform of x(t) becomes

$$\Phi(f)=\arctan\left[\frac{AF(f)\sin(2\pi fT_o)+|B(f)|\sin(2\pi fu(f))}{AF(f)\cos(2\pi fT_o)+|B(f)|\cos(2\pi fu(f))}\right] \quad (6)$$

It follows from (6) that random phase components are dominant in the frequency region where the frequency domain SNR (A|F(f)/B(f)|) is low. However, linear phase components are present in the frequency region where the frequency domain SNR is high.

3. PHASE FILTERING ALGORITHM

In the Fourier representation of signals, spectral magnitude, and phase tend to play different roles [10,11]. In general, the signal cannot be completely recovered from knowledge of either spectral magnitude or phase alone since the magnitude and phase of the Fourier transform are independent functions. Under the special condition that the signal is minimum phase or maximum phase, the log magnitude and phase are related through the Hilbert transform[12]. However, many signals of practical importance are not minimum phase or maximum phase [10].

In this paper, we report a method that uses the important fact that the spectral phase reflects the location (temporal occurrence) of events more than magnitude. It follows from (4) that a translation in position (time or space) of a signal has no effect on the Fourier transform magnitude and affects only the phase by adding a linear phase term. Since we assume that the ultrasound echo signal from the resolved object whose size is larger than the ultrasound wavelength is an even function, echo signals from the objects affect only the phase by adding a linear phase term. Since we assume that the ultrasound echo signal from the resolved object whose size is larger than the ultrasound wavelength is an even function, echo signals from the objects affect only the phase by adding a linear phase term dependent upon a translation in position. Therefore, we can remove the random phase component of $\Phi(f)$ in (6) using an appropriate filter withouth affecting the position of resolved scatterers. Reconstruction of signal using the filtered phase may seriously distort the signal waveform. However, this reconstructed signal may in fact contain sharper time events by removing speckle noise. In ultrasonic imaging for diagnostic purpose , the RF (radio frequency) weveshape is not as important as the time position of events because shapes and positions are determined from the envelope of the signal. Thus we developed phase filtering to remove speckle in ultransonic imaging.

The most important procedure in the PF algorithm is the determination of an appropriate filter for removing the random component of the phase. It follows from (6) that the corresponding phase of the Fourier transform of x(t) for high SNR is

$$\Phi(f) = 2\pi fT_o \; . \quad (7)$$

The spectral magnitude of the Fourier transform of $\Phi(f)$ in (7) shows that most of the spectral components are distributed in the lower frequency region. Becouse u(f) is a random variable, the spectral components of the Fourier transform of $\Phi(f)$ are distributed throughout the frequency domain for low SNR. Therefore, lowpass filtering of $\Phi(f)$ in (6) results in removing the phase components of $\Phi(f)$ due to speckle noise but leaves the low frequency non-random components. Experimental results show that the performance of the PF algorithm is not sensitive to the cutoff frequency of the low-pass filtering of $\Phi(f)$.

4. SIMULATIONS AND EXPERIMENTS

A. Simulations

Computer-generated speckle noise in Fig. 1a composed of interfering echoes was produced by convolving a sequence of random amplitudes and phase. The interfering echoes were uniformly distributed except for a small region containing a reflector. A region 30 data points long containing one reflector was embedded in speckle noise composed of 2048 data points with 1500 randomly distributed scatterers. The envelope of the generated signal in Fig. 1a had a Rayleigh distribution with a mean to standard deviation ratio of 1.87. Figure 1b shows that the PF algorithm applied to the signal enhances the resolved reflector signal while suppressing the speckle noise.

B. Experiments

The PF filtering algorithm was tested experimentally with a home made gelatin phantom containing a needle reflector and with a commercial tissue mimicking phantom (ecobloc). The home made phantom was designed with gelatine and graphite to 'produce speckle noise [13]. The ecobloc is a stable, sealed gray scale test object, designed by Ultra-Cal, Inc. (Escondido, CA) for the evaluation of B-scan or real-time ultrasound instruments. Both A-scan and B-scan data were obtained experimentally. An A-scan is a one-dimensional received signal amplitude versus time plot obtained at a single test point. A B-scan is a two-dimensional representation obtained by combining A-scans form equally spaced points along a test line. The experimental data were obtained using 5 MHz and 3.5 MHz focused transducers.

The B-scan envelope image in Fig. 2a obtained using a 5MHz focused transducer is composed of 100 equally spaced A-scans, each consisting of 1024 eight bit data points obtained at a sampling rate of 40 M samples/sec. Figure 2b is the reconstructed image after using the PF algorithm and shows of needle and suppression of speckle.

Figure 3a is the unprocessed envelope image showing tissue mimicking ecobloc with clear cyst without walls and clear cyst with walls. We used a 3.5 MHz focused transducer for the B-scans. Figure 3b is the image of Fig.3a after using the phase filtering algorithm.

As we can see in Fig. 3b, a clear cyst is not reconstructed when the phase filtering algorithm is used because we cannot differentiate a clear cyst from the area in which speckle noise is removed. However, we can select clear cyst by selecting the area when the variation of gray value is less than predetermined threshold value. For each A-line, the variation of the 8 bits gray value within the moving rectangular window with 10 samples is computed. If the computed variance is less than the predetermined threshold value, the samples within the window are assumed to be a part of a clear cyst. Figure 3c shows the reconstructed image with cyst after using the phase filtering algorithm and thresholding on local variance.

5. CONCLUSIONS

A method of ultrasonic image enhancement has been proposed using a phase filtering method. The phase filtering method proposed in this paper has been shown to reduce speckle noise by removing the random components of phase. It is very important to note that the reconstructed signal may sharpen narrow time events by removing speckle noise even though the signal is seriously distorted after the phase filtering algorithm is used. However, the location of resolved objects bear important information in ultrasonic images. Simulation and experimental results show that we can achieve a significant reduction of speckle noise associated with enhancement of resolved scatterers, indicating the feasibility of this algorithm in B-scan imaging systems.

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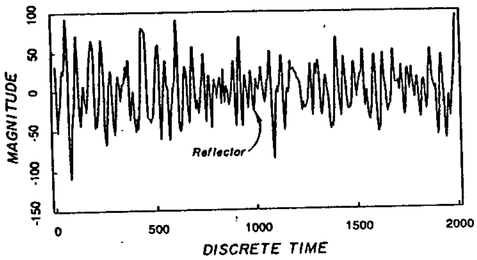

Figure 1a Computer-generated speckle noise with embedded resolved scatterer.

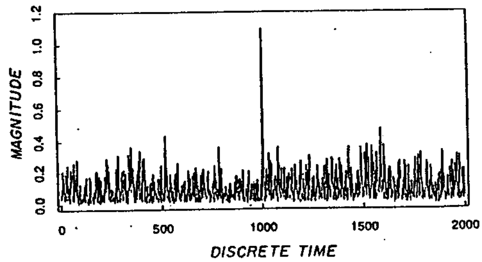

Figure 1b Resolved scatterer is enhanced suppressing the speckle noise using the PF algorithm.

Figure 2a Envelope image of homemade phantom with needle.

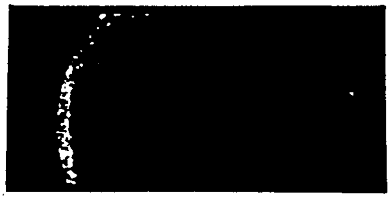

Figure 2b Image of homemade phantom with needle after using the PF algorithm.

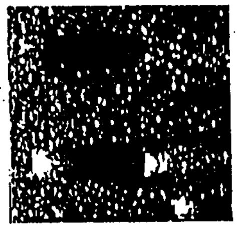

Figure 3a

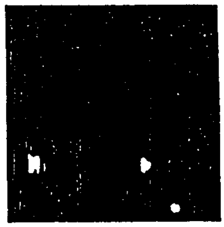

Figure 3b

Figure 3a Envelope image with ecobloc phantom containing cyst.

Figure 3b Image with ecobloc phantom containing cyst after using the PF algorithm.

Figure 3c Image of cyst areas in ecobloc phantom after using the PF