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MULTISPECTRAL ULTRASOUND IMAGING AND ANALYSIS OF SPECKLE GENERATING MEDIUM

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ABSTRACT

The potential of a pulse compression technique has been experimentally evaluated for speckle reduction processing. Multifrequency and multibandwidth data were obtained from a speckle generating medium using frequency modulated pulses. Speckle decorrelation factors were calculated and compared with theoretical predictions. This technique is shown to be as effective as some of the other proposed methods, but may have some additional advantages that need further exploration.

INTRODUCTION

Speckle is believed to be a significant degrading factor in ultrasonic imaging, and likely impairs detectability of low contrast tumors and clinical scans. Speckle reduction can be achieved by averaging image frames with decorrelated speckle patterns. This can be done either by spatial compounding or by frequency compounding [1,2,3] techniques. In the latter case, a certain degree of decorrelation is achieved by changing the frequency spectrum of the echo signal. This objective can be achieved either by using a broad band interrogating pulse and consequently subjecting the echo signal to narrow band filtration over different frequency ranges (frequency diversity processing [2]), or by performing what could be termed as multispectral imaging [1,5]. One can use interrogating pulses of different center frequency and bandwidth and if the respective backscattered speckle signals are sufficiently decorrelated, average them to increase signal to noise ratio (SNR). The resolution cell volume of an imaging system, to a first order, depends on the center frequency fo (because of diffraction effects) and the bandwidth Af (because the pulse width depends inversely on Af). Apart from the frequency dependent scattering effects, the change in resolution cell volume is the single most dominant factor in achieving speckle decorrelation. In this paper, we present experimental results on multispectral imaging using frequency modulation (FM) pulses. Speckle correlation was measured for 143 different combination pairs of fo and Af. Advantages of FM pulse scheme is also pointed out.

METHODS

An experimental system to perform imaging with frequency modulated (FM) pulse has been developed by us [4]. The system operates by transmitting a longer duration (10-20 µs) frequency modulated signal, which on reception is compressed (via digital crosscorrelation processing) into a short pulse of desired axial resolution and sensitivity. Major advantages are, among others, flexibility in choosing any operating center frequency fo and bandwidth Af and increased sensitivity over short pulse due to large time bandwidth product involved in pulse compression process. The reader is referred to other publications for more details [5].

A panametric unfocused piezoelectric circular disk transducer with a diameter of 1.27 cm, was used to transmit the FM pulse into the phantom. It had a center frequency of 2.4 MHz and a 6dB bandwidth of about 1.8 MHz. Using a programmed arbitrary waveform generator, the transducer was driven with FM pulses of various different center frequencies fo and bandwidths Af within its operating range. For every fo, Af was varied from .5 MHz to 1.5 MHz in steps of 0.1 MHz; fo was varied from 1.6 MHz to 2.8 MHz also in steps of 0.1 MHz. In all, there were 143 different combination of fo and Af. Experiments were done in a water tank. The speckle generating medium was a water-filled sponge with cell size much less than the resolution of the imaging system. For pulse compression processing, the backscattered RF signals, digitized at 50 MHz were correlated with the FM pulse used to drive the transducer. The region of interest was approximately 1.5 cm in depth, located 9 cm from the transducer. Separate experiments were also performed with specular wire target embedded in sponge at 9 cm depth. These were used to determine the axial resolution or pulse width subsequent to pulse compression processing.

RESULTS AND ANALYSIS

Effectiveness of speckle averaging depends on the degree of decorrelation one can achieve between different multispectral component images. Therefore, normalized correlation coefficients were calculated for every combination of fo and Af. The reference trace was the backscattered data for fo = 2.2 MHz and Af = 1 MHz. Correlations were performed on the RF signal after pulse compression processing and the results are shown in Fig. 1.

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Decorrrelation for different bandwidths $\Delta f$ for a fixed center frequency $f_o$ is not as significant as in the multispectral (different $f_o$ for fixed $\Delta f$) cases. Figure 2 shows the decrease in correlation as $f_o$ differs from the reference $f_o = 2.2$ MHz for three different constant bandwidth ($\Delta f = 0.5, 1.0$ and $1.5$ MHz). As $\Delta f$ decreases, RF speckle decorrelation increases, indicating that compound frequency averaging would be most effective in speckle averaging. Melton and Magnin have proposed a simple model for predicting the degree of speckle decorrelation as a function of $f_o$ and $\Delta f$. The model assumes a gaussian shaped amplitude modulated sine wave of frequency $f_o$ as the interrogating pulse. The pulse bandwidth therefore is related to the gaussian pulse width parameter. The model predicts a normalized cross correlation coefficient for RF signals:

$$\frac{2 \left( \frac{\text{BW}_1 \cdot \text{BW}_R}{(\text{BW}_1)^2 + (\text{BW}_R)^2} \right)^{1/2} \cdot \exp \left[ \frac{(f_o - f_o^R)^2}{(\text{BW}_1)^2 + (\text{BW}_R)^2} \right]}$$

where $\text{BW}_1$ and $\text{BW}_R$ are the 37% value half bandwidths of the signal in question and the reference signal respectively. Similarly $f_o$ and $f_o^R$ are the center frequencies of the interrogating pulses for the signal in question and the reference. The bandwidths $\Delta f$ reported for our measurements are 6dB full bandwidths. Therefore one half of the reported values were used for equation (1) without any attempt to correct for the 37% factor. Figure 3 shows the model prediction over the entire matrix formed by various $\Delta f$ and $f_o$. There is qualitative agreement with the measurements shown in Fig. 1 over the same matrix. The difference between the model predictions and the measurements is shown in Fig. 8. Quantitatively the agreement is good over a large central portion of the matrix. It gets worse at low bandwidths and center frequencies that are at the extremes of the transducer operating bandwidth. Figure 5, 6 and 7 compare the measurements to the model prediction for three different fixed bandwidths ($\Delta f = 0.5, 1.0$ and $1.5$ MHz) respectively. The symbols are measurements and the solid line is model. Another experimental data available to us, i.e. 6dB pulse width (full width at half maximum FWHM) after pulse compression processing, is shown in Fig. 4. This information was obtained by recording a specular reflection from a wire target in the center of ROI. From these values, pulse widths (37% value) were calculated as $T_p = \text{FWHM pulse width} \times (2 \times 0.8325)$. The bandwidth to be used in equation (1), according to the theory is then given by $1/\pi T_p$. The new model predictions calculated from measured pulse widths is shown by dashed lines. Considering that the simple model is an approximation to reality, the overall agreement is quite good.

**SUMMARY**

We have demonstrated the use of FM pulse imaging scheme to obtain multispectral data from a speckle generating medium. Its potential for speckle reduction was evaluated by computing correlation coefficients. Measured coefficients were also compared with model predictions. Our results are consistent with other published reports and show that significant speckle decorrelation can be achieved with this technique, if one averages frames acquired with center frequencies at the extreme ends of the transducer operating bandwidth, and a small enough $\Delta f$. At these extremes, the transducer response is low. However, this response limitation can be overcome by increasing the linear frequency sweep time duration in the FM pulse imaging scheme. In a frequency dependent attenuating medium, proper choices of $f_o$ and $\Delta f$ spanning the entire operating bandwidth of transducer may be necessary. The flexibility inherent in FM pulse scheme can be exploited here.

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**REFERENCES**


Figure 1 Measured RF speckle decorrelation as a function of $f_0$ and $\Delta f$ of the FM pulse.

Figure 2 Measured RF speckle decorrelation vs $f_0$ for three difference $\Delta f$.

Figure 3 RF decorrelation calculated from model predictions.

Figure 4 Measured 6dB pulse width after pulse compression.

Figure 5 RF decorrelation vs $f_0$ for fixed $\Delta f = 0.5$ MHz. Comparison with model predictions.

Figure 6 RF decorrelation vs $f_0$ for fixed $\Delta f = 1.0$ MHz. Comparison with model prediction.

Figure 7 RF decorrelation vs $f_0$ for fixed $\Delta f = 1.5$ MHz. Comparison with model predictions.

Figure 8 Difference between model predictions and measured speckle decorrelation.