Resolution Enhancement and Frequency Compounding Techniques in Ultrasound.

Proposal Type: Innovative Student
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Position: Graduate Student
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1. Abstract

Ultrasound non destructive evaluation uses high frequency ultrasound to interrogate materials without affecting their performance or structure. The overarching goal of this project is to effectively characterize and image Biofilms that are known to cause infections in the middle ear epithelial surfaces in children. The quality of B-scan images generated is primarily governed by the axial resolution and the contrast to noise ratio with regard to the target. The depth of penetration deteriorates with increase in frequency, and the presence of sub resolution scatterers that cause constructive and destructive interference of backscattered ultrasonic signals also known as speckle prevent the system from resolving them causing a reduction in contrast which translates to the poor quality of images. The objective of this study is to investigate the performance of post process 'resolution enhancement' techniques which help improve the axial resolution and 'frequency compounding' techniques which help improve the contrast to noise ratio. The performance of the techniques will be investigated individually and in combination.

Dollar Request: $6000
Desired Funding Dates: May 2011 - July 2011
2. Scientific Justification

We have previously demonstrated our ability to study colonies of bacteria called biofilms using high frequency ultrasound transducers and generate B-scan images as shown in Figure 1. The objective of this study is to use resolution enhancement and compression techniques (REC) to increase the axial resolution of the B-scan images and the useable bandwidth of the system. This will be followed by frequency compounding techniques (FC) to improve the contrast to noise ratio. A direct consequence of implementing FC techniques is a loss in axial resolution. However, having used the REC technique to increase the axial resolution in the first place compensates for the loss and presents images with the same or better axial resolution as compared to those generated using conventional short pulse techniques with the added improvement in the contrast to noise ratio. The resolution enhancement and compression technique addresses the problem of the Gaussian like shape of the impulse response of the transducer which causes a reduction in scattered energy from the side bands and therefore drifts away from the ideal scenario of equal weighting of all scatterers within the impulse response of the transducer. Pre-enhancing the input signal to the transducer by compensating for the Gaussian shape helps pick up more scattered energy for the side bands thereby mimicking the action of an ideal impulse response. The pre-enhanced signal can be generated such that it helps improve the bandwidth of the system. The second stage gets implemented post the REC technique, it comprises of frequency compounding and addresses the problem caused by speckle noise. Here the scattered signal is broken down into smaller bands of frequency using wavelet packet decomposition. The bands are filtered to reduce noise and then averaged. This process of adding the denoised sub-band signals is reported to have caused an improvement in the contrast to noise ratio.

![Figure 1. B-scan image showing a Biofilm in light green on top of a cover slip. Image produced using conventional short pulse techniques.](image-url)
2.1 REC Technique

This technique utilizes the principles of convolution equivalence. If we consider an ultrasonic imaging system with shift invariant impulse response \( h_1(nT,x) \), the total shift varying response of the imaging system is the convolution of the impulse response and the voltage waveform \( v_1(n) \) used to excite the source. The total shift-varying impulse response is not unique to a particular pulse-echo impulse response of the system. Some other pulse-echo impulse response \( h_2(nT,x) \) may exist that when convolved with a different voltage waveform \( v_2(n) \) will give the same total shift varying impulse response. Therefore a new pre-enhanced chirp signal representing \( v_2(n) \) can be generated with a modified impulse response with a bandwidth of our choice. [1,2,5] This operation gives us the benefits of a larger useable bandwidth and a compression of the received echoes from the scatterers resulting in an improved axial resolution. A Wiener filter is used as a compression filter. The concept of convolution equivalence is illustrated in Figure 2.

![Figure 2](image-url)

Figure 2. Convolution Equivalence, (a) Pulse with approximately 48% -3 dB pulse/echo bandwidth. (b) Pulse with approximately 97% -3 dB pulse/echo bandwidth. (c) Modified chirp used to excite the 48% bandwidth source. (d) Linear chirp used to excite the 97% bandwidth source. (e) Convolution of the pulses with their respective chirps sequences. [1]

2.2 Frequency Compounding

A radio frequency (RF) line or an A-line is obtained after analog to digital conversion of the backscattered echo. Frequency compounding techniques utilize the unique ability of the wavelet transform to analyze signals with time varying spectra. Wavelet decomposition is used to break down the RF- backscattered signals to smaller bands of frequency which are used to form sub band images. This is accomplished by the use of two quadrature mirror filters, followed by dyadic sub sampling. In order to improve the quality of these sub band images non-linear denoising filters are used to filter the wavelet coefficients, thresholding each wavelet vector according to Donocho’s scheme [4]. These filtered sub-band images are passed through an equalization and envelope detection stage followed by averaging to restore the original spectral bandwidth of the image. This results in improvement in contrast. If ‘S’ uncorrelated images are averaged the improvement in contrast is by a factor of \( \sqrt{S} \). [3]
2.3 Implementation

The pre-enhanced chirp signals will be generated with Matlab and downloaded to an arbitrary waveform generator. The signal from the generator will be amplified using a 2100L RF power amplifier. The amplified signal will be connected to a diplexer. The received echo signal will be displayed on an oscilloscope which also serves as an analog to digital converter. The received signal will be imported into Matlab for wavelet decomposition and subsequent filtering and generation of B-scan images. Figure 3 is a diagram of the entire setup. These techniques have been previously implemented on well-structured phantoms, this study will be a pioneering attempt to test them on a real target.

Figure 3. Experimental Setup
3. Budget Justification

The requested budget of $6000 will be used as summer salary for the PI Kunal Vaidya who will implement the aforementioned techniques under the direct supervision of Dr. María Helguera in her Biomedical and Materials Multimodal Imaging Lab. An undergraduate student will also be hired whose responsibilities will include data collection, pick up of biofilm samples from the department of Biological Sciences and assistance with analysis.

4. Project Plan

The investigative study will be carried out over the summer quarter starting May 2011. The sequence of imaging experiments will include:

- Culturing colonies of Biofilms on cover slips and imaging them using conventional short pulse techniques as a control case.
- Investigating the effect of the REC technique using transducer frequencies of 15MHz, 30 MHz and 50 MHZ. The effect on the axial resolution will be recorded and compared to that of images generated using conventional imaging techniques.
- The effect of frequency compounding techniques will be investigated independent of the REC technique. The improvement in contrast will be weighed against the loss in axial resolution.
- Based on these preliminary data the two techniques will be used to together. The loss in axial resolution due to FC will determine the nature of the pre-enhancement step in the REC technique.
- A comparative study will be presented and quality of improvement in images will be determined based on parameters like Signal to noise ratio (SNR), Bandwidth of the system, Modulation Transfer function used to determine axial resolution, Contrast to Noise Ratio used to quantify reduction in speckle noise and Margin Strength used to detect strength of edges in Bscan images.

Since the acquisition system has already been set up, most time will be spent on developing the software to implement the enhancement techniques.

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There are several conferences to which we anticipate submitting our contributions, these include IEEE Ultrasonics Symposium and SPIE Medical Imaging. We expect to write and submit a peer reviewed paper to the Journal of Microbiological Methods post completion of this study.
5. Bibliography


