Resolution Enhancement Compression and Synthetic Aperture Focusing Techniques of Ultrasound Images

Functional Description and Block Diagram

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Introduction:

Recent work on imaging has revealed two different types of techniques for improving the resolution and signal-to-noise ratio (SNR) of ultrasound images. Resolution Enhancement Compression (REC) is a pulse-compression technique, which is known to increase the axial resolution and bandwidth of the imaging system [1][2]. Synthetic Aperture Focusing (SAF) is a collection of beamformation techniques, which utilize different transmitting and receiving configuration of the ultrasound transducer elements to improve the penetration depth and spatial image resolution. The combination of both types of techniques appears promising, suggesting an overall improvement in terms of resolution, SNR, and penetration depth [4]. For this project, a series of simulations of the above techniques are proposed utilizing the MATLAB addons Field II, which is used for ultrasound simulation, and Jacket, which is used for General Purpose Graphics Processing Unit (GPGPU) processing.

Project Goals:

- Simulate a linear array transducer in Field II using conventional pulsing (CP) for comparison purposes
- Investigate the performance of REC on the linear array transducer
- Investigate the performance of various SAF techniques:
  - Synthetic Transmit Aperture
  - Synthetic Receive Aperture
  - Synthetic Transmit and Receive Aperture
- Utilize the MATLAB addon Jacket to process the images in parallel using a General Purpose Graphics Processing Unit (GPGPU).
- Combine REC and SAFT to achieve higher spatial resolution and deeper penetration
- Perform spatial filtering and quantitative ultrasound (time permitting).

System Block Diagram:

The complete system block diagram of an ultrasound system is presented in Figure 1.
Figure 1: Complete System Block Diagram

Functional Description:

**Transducer**
The transducer converts electrical signals to ultrasonic signals and vice-versa. It consists of a number of piezoelectric elements which transmit and receive ultrasonic signals independently of each other. The different transmitting and receiving configurations of these elements are the basis of Synthetic Aperture Focus Techniques (SAFT), each of which is associated with a unique ultrasound imaging characteristic and the corresponding unique ultrasound image.

**Pre-amplifier**
Since the echo signals travel through human tissue, which is a lossy medium, they will undergo signal strength attenuation. In order to compensate for this loss, the signals must be amplified to prepare them for processing. However, by amplifying the received signal, any additive noise will be amplified as well.

**Matched Filter**
In order to remove this amplified noise, the received echo signals are passed through a matched filter. A matched filter is the optimal filter for maximizing the SNR in the presence of additive noise. It is implemented by correlating the excitation signal with the received signal from the transducer, given by:

\[ r_m(t) = r(t) * g(-t) \]

where \( g(t) \) is the excitation signal, \( r(t) \) is the received echo signal, and \( r_m(t) \) is the match filtered signal.
Delay Unit
Since the individual sound beams emitted from individual elements of the transducer will have to ravel different distances to reach the same point, their corresponding echo signals will clearly not return to the transducer at the same time. The delay time associated with the round trip signal propagation is given by

\[ t_p(x_i) = \frac{2}{c} \sqrt{z_p^2 + (x_i - x_p)^2} \]

From Figure 2 above, it is evident that \(x_i\) corresponding to different sound beams will vary and thus the delay time \(t_p\) will vary accordingly. If the delay unit is not incorporated into the system, the resulting ultrasound image will suffer from phase delay smearing.

Apodizer
An apodizer is an array of gain coefficients which serve to shape the beam profile of the received signals. By weighting the received signals appropriately, it is possible to reduce the side-lobes of the beam. As a result of this side-lobe reduction, the lateral resolution will be significantly improved.
Resolution Enhancement Compression

Resolution Enhancement Compression (REC) is a type of coded excitation technique that utilizes digital signal processing (DSP) to improve the resolution of ultrasound images by using a pre-enhanced chirp as an excitation signal. This type of technique involves shaping the pulse and modulating the frequency in order to counteract the system response of the ultrasonic transducer. By doing so, it artificially broadens the signal spectrum, resulting in increased penetration depth, improved SNR, and improved axial resolution of the image [1]. Several variants of REC have been studied previously, including REC-FC, which combines REC with Frequency Compounding to reduce speckle [2], and Enhanced REC-FC (eREC-FC) which combines several REC-FC images at different subband widths to improve axial resolution, contrast resolution, and reduce speckle [3]. The pre-enhanced chirp used in the REC technique is shown in Figure 4 below, and the power spectra of the received waveforms is shown in Figure 5.
Synthetic Aperture Focusing Techniques

SAF is a type of beamformation technique originating from the radar community. Its purpose is to improve the lateral resolution and SNR of ultrasound images. In its simplest form, SAF works by transmitting and receiving on a single transducer element and then combining the individual images to reconstruct a full image (see Figure 6 below) [4].

A multitude of SAF variants exist as well. One such variant, called a Synthetic Receive Aperture (SRA), works by transmitting on all the transducer elements simultaneously and individually receiving on one element at a time, producing sections of high resolution images which are combined to produce one image (see Figure 7 below) [4]. The SRA technique has higher SNR and lower side-lobe levels compared to conventional SAF techniques, at the cost of longer acquisition time.
A faster alternative, called Synthetic Transmit Aperture (STA), involves transmitting on each element individually and receiving low resolution images on all elements, summing them together to form a single, high resolution image (see Figure 8) [4]. Though STA techniques are faster, the SNR and penetration depths are less than that of SRA.

A third class of SAF techniques is a hybrid class called Synthetic Transmit and Receive Aperture (STRA), which allows for any combination of transmitting and receiving elements, examples of which are shown in Figure 9 [4]. Because STRA techniques can vary from either end of the spectrum, they can have a wide range of behavioral characteristics.
Figure 9: Various Configurations of Synthetic Transmit and Receive Apertures. Each row represents a transmit event, with filled squares representing the active receiving elements [4].

References