Resolution Enhancement Compression (REC) Synthetic Aperture Focusing Techniques (SAFT) for Ultrasound Imaging

Functional Description and Block Diagram

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Introduction

Recent work in ultrasound imaging discovered two techniques for improving the resolution and Signal-to-Noise Ratio (SNR) of ultrasound images. One technique is Resolution Enhancement Compression (REC) which involves pulse-compression that achieves an increase in axial resolution and bandwidth of the imaging system [1][2]. The other technique is Synthetic Aperture Focusing (SAF) is a beam-forming technique which utilizes different transmitting and receiving configuration of the ultrasound transducer elements. SAF improves the depth penetration, which will increase the SNR and hence the resolution of ultrasound images at the expense of axial resolution. Therefore, the goal of this project is to combine REC and SAFT to achieve a balance between depth penetration and SNR and axial resolution [4]. For this project, a series of simulations of the above techniques will be performed first in MATLAB using the Field II ultrasound imaging packages. Then, the simulation will be done on a GPGPU through C program. The MATLAB addons Field II (for ultrasound simulation) and Jacket (for GPGPU processing).

Project Goals

- Simulate a Linear Array Transducer in Field II using Conventional Pulsing (CP)
- 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
- Perform simulation in MATLAB using Field II simulator packages and then perform fast computation on GPGPU through C code
- Combine SAFT and REC to achieve higher axial resolution and deeper penetration
- (IF time allows) Perform spatial filtering and quantitative ultrasound.

System Block Diagram

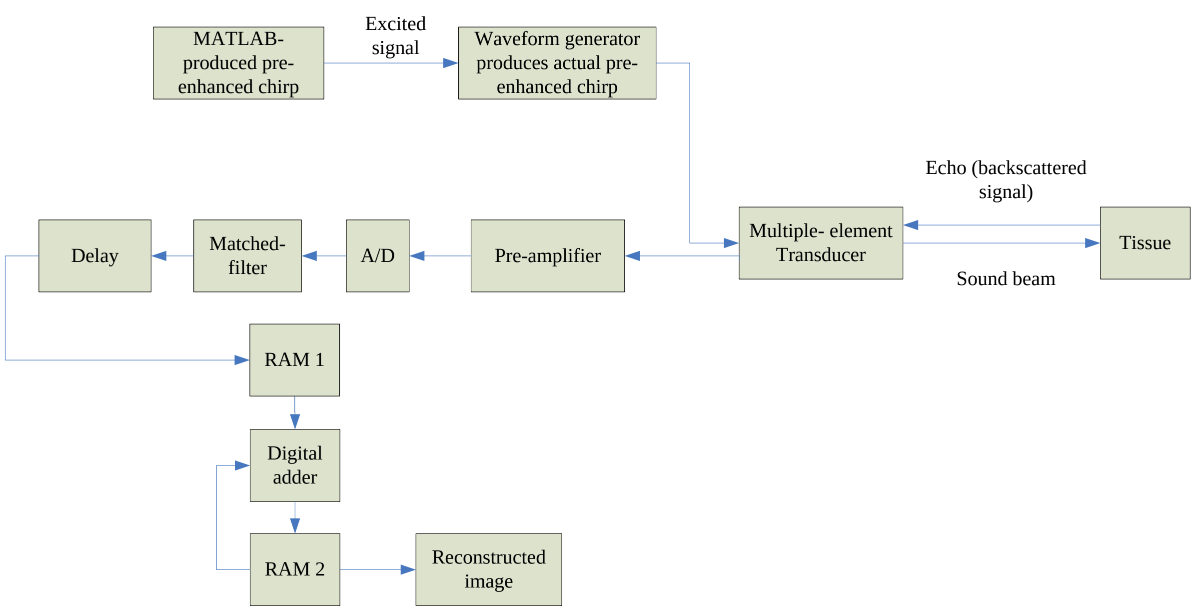

Figure 1: Overall system block diagram

Functional Description:

1/ 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 sub-band widths to improve axial resolution, contrast resolution, and reduce speckle [3]. The pre-enhanced chirp used in the REC technique is shown in Figure 1 below, and the Power Spectra of the received waveforms is shown in Figure 2.

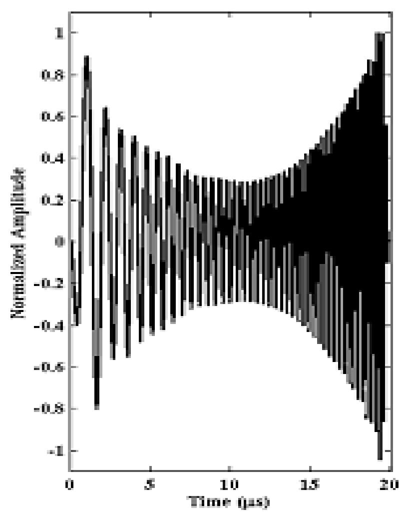

Figure 1: Pre-enhanced Chirp used in the REC technique [1]

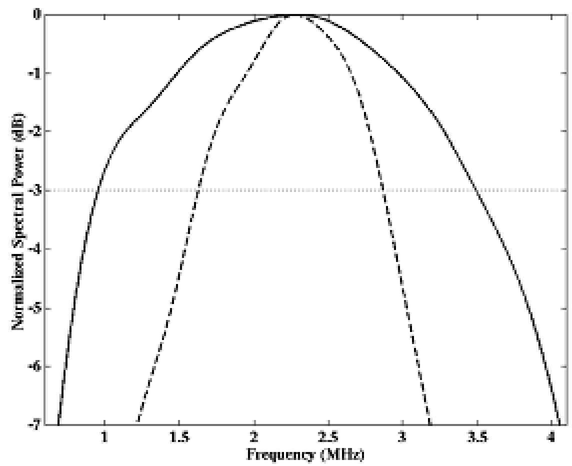

Figure 2: Power Spectra of reflected waveforms from the CP (dashed) and REC (solid line) techniques [1]

Synthetic Aperture Focusing Techniques

Synthetic Aperture Focusing (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 radar usage. In it's 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 3 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 4 below) [4]. The SRA technique has higher SNR and lower sidelobe levels compared to conventional SAF techniques, at the cost of longer acquisition time.

A faster alternative, called Synthetic Transmit Aperture (STA), involved 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 5 below)[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 6 [4]. Since STRA techniques can vary from either end of the spectrum, they can have a wide range of behavioral characteristics.

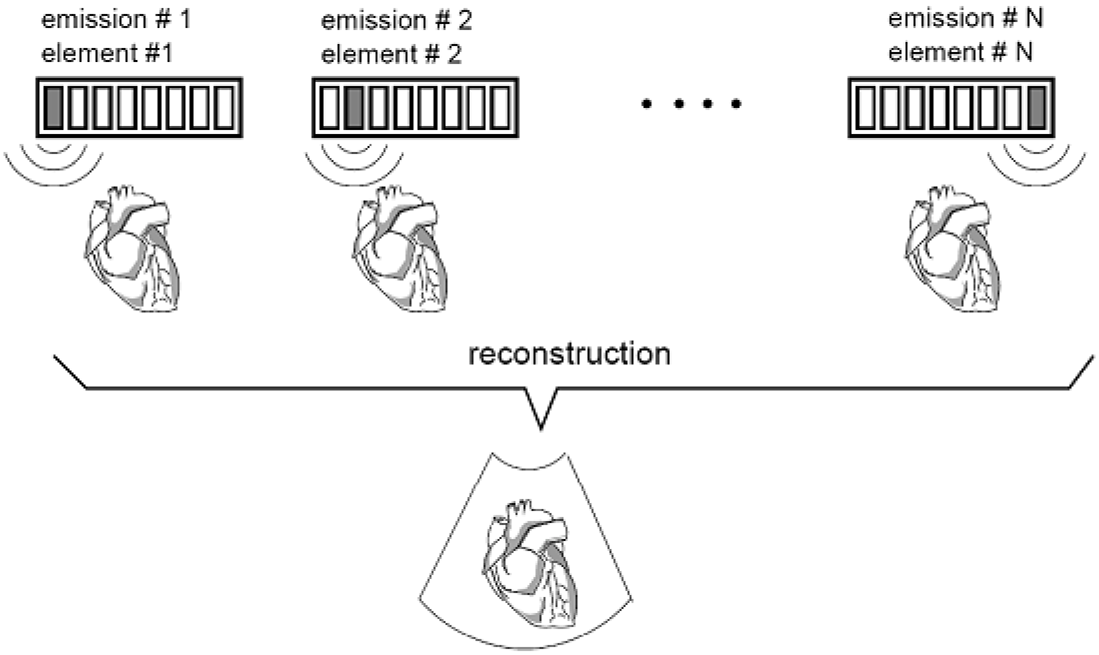

Figure 3: Conventional Synthetic Aperture [4]

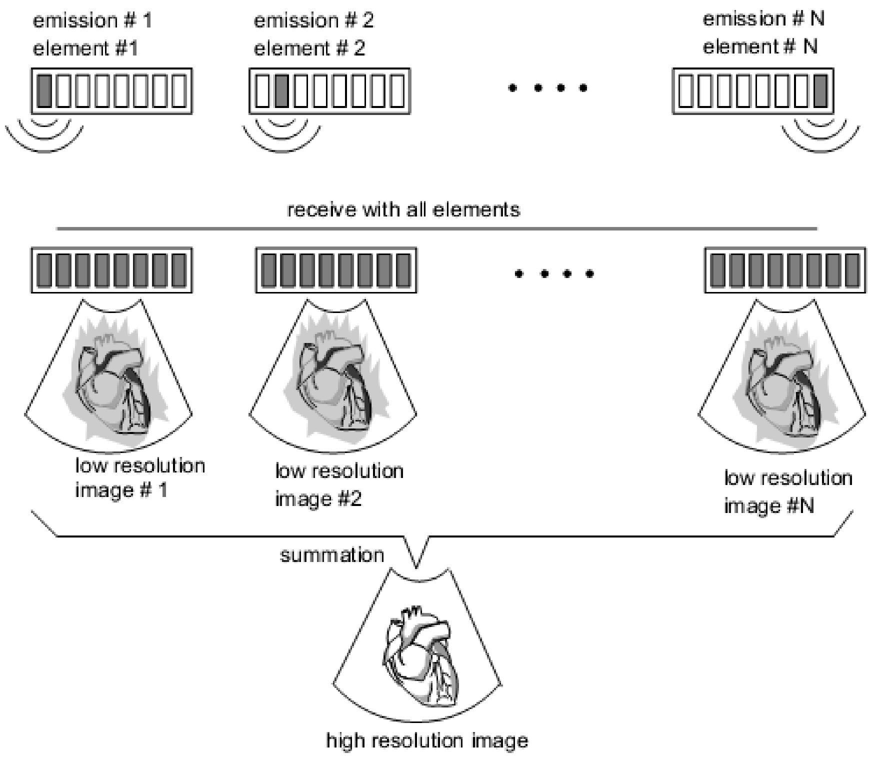

Figure 4: Simple Model of Synthetic Transmit Aperture

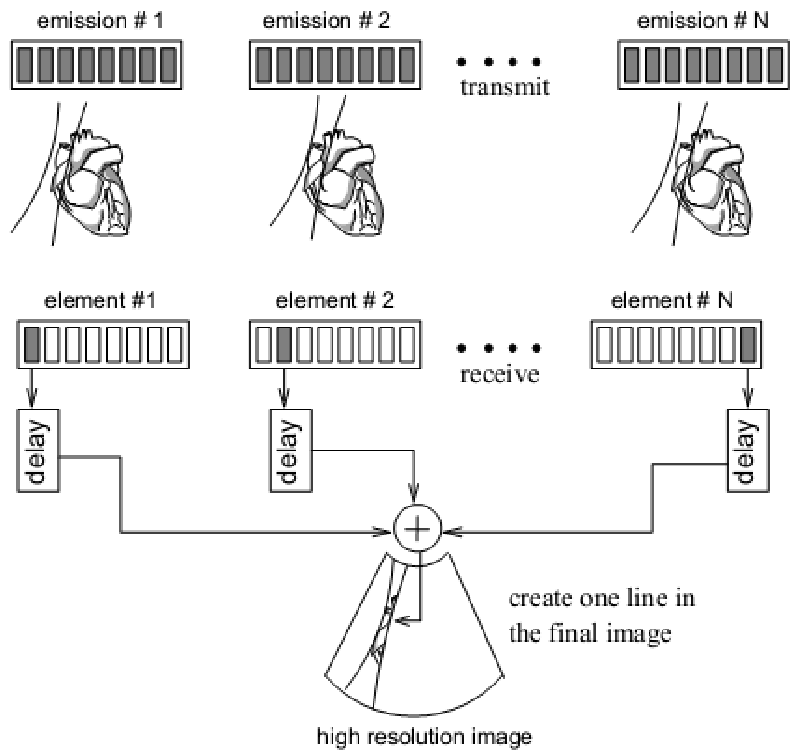

Figure 5: Synthetic Receive Aperture [4]

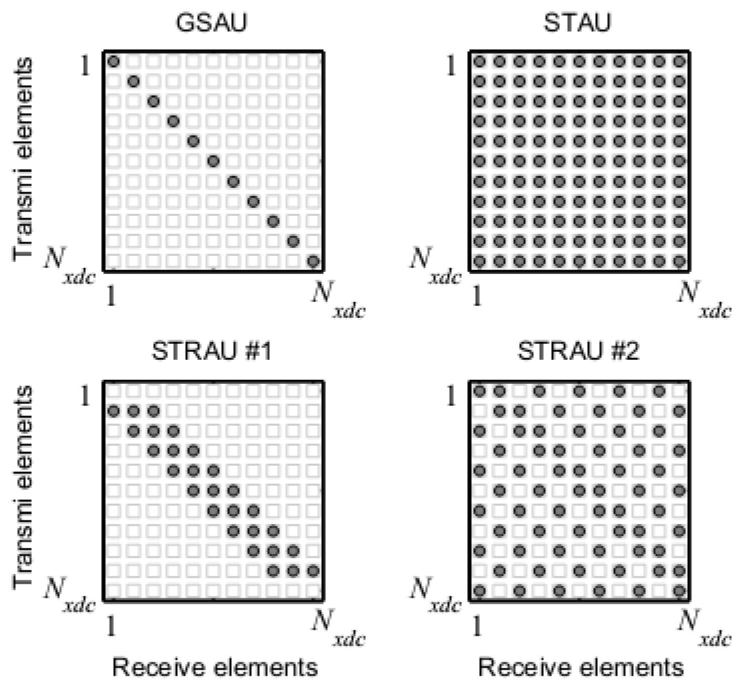

Figure 6: Various Configurations of Synthetic Transmit and Receive Apertures. Each row represents a transmit event, with filled squares representing the active receiving elements [4].

References

[1] M. Oelze, “Bandwidth and Resolution Enhancement through Pulse Compression,” *Ultrasonics, Ferroelectrics and Frequency Control*, vol. 54, pp. 768 –781, Apr. 2007.

[2] J. Sanchez and M. Oelze, “An Ultrasonic Imaging Speckle Suppression and Contrast Enhancement Technique by Means of Frequency Compounding and Coded Excitation,” in *Ultrasonics Symposium, 2007. IEEE*, pp. 464 –467, Oct. 2007.

[3] J. Ullom, M. Oelze, and J. Sanchez, “Ultrasound Speckle Reduction using Coded Excitation, Frequency Compounding, and Postprocessing Despeckling Filters,” in *Ultrasonics Symposium, 2010 IEEE*, pp. 2291 –2294, Oct. 2010.

[4] S. I. Nikolov, *Synthetic Aperture Tissue and Flow Ultrasound Imaging*. PhD thesis, Technical University of Denmark, Aug. 2001.

[5] J.A.Zagzebski, *Essentials of Ultrasound Physics.* Mosby, 1996