Ultrasonic Imaging using Resolution Enhancement Compression and GPU-Accelerated Synthetic Aperture Techniques.

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Introduction

Ultrasound image quality can be characterized by two common imaging metrics: resolution and signal-to-noise ratio (SNR). Resolution refers to the extent an imaging system is able to distinguish between details within the image. SNR is a common measure of image clarity which compares the level of the desired signal to the level of corrupting noise.

Objective

Improve the resolution and SNR using a combination of pre- and post-processing imaging techniques.

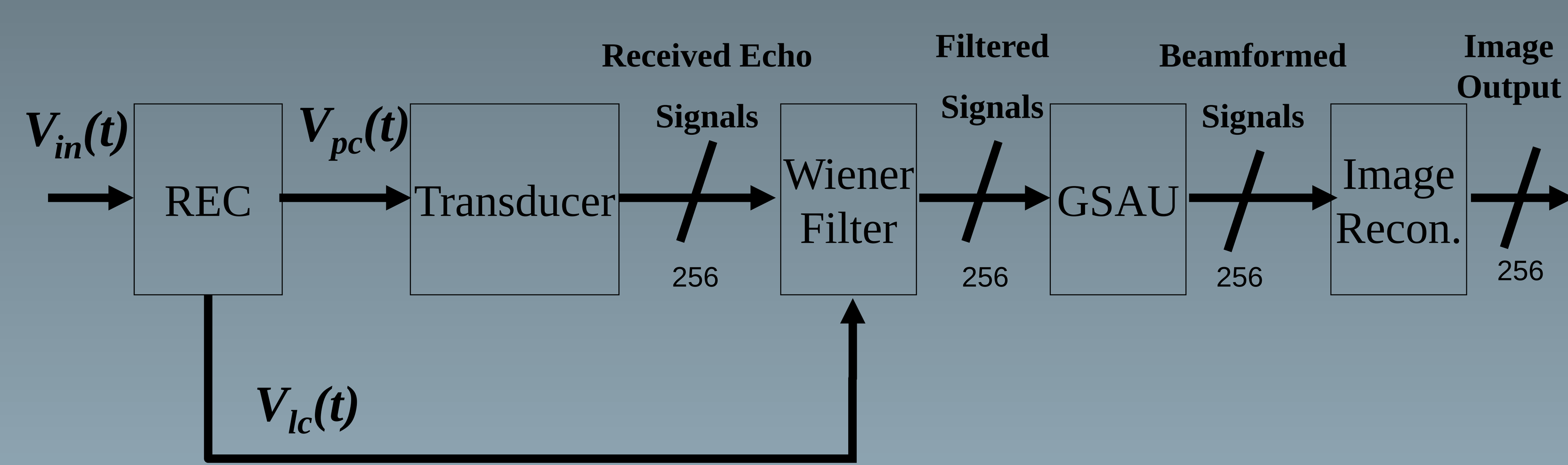
Motivation

Recent developments in ultrasonic imaging research have shown that a technique known as resolution enhancement compression (REC) may be utilized to improve axial resolution (resolution along the beam axis) and SNR [1,2]. An existing class of techniques known as synthetic aperture (SA) techniques have been utilized to augment lateral resolution (resolution perpendicular to the beam axis) and SNR [3]. One specific type of SA technique is the generic synthetic aperture ultrasound (GSAU) technique. Based on knowledge of linear time-invariant system theory, it was hypothesized that combining these techniques would allow for an overall improvement in resolution in both directions and further increases in SNR than when taken individually.

Significance

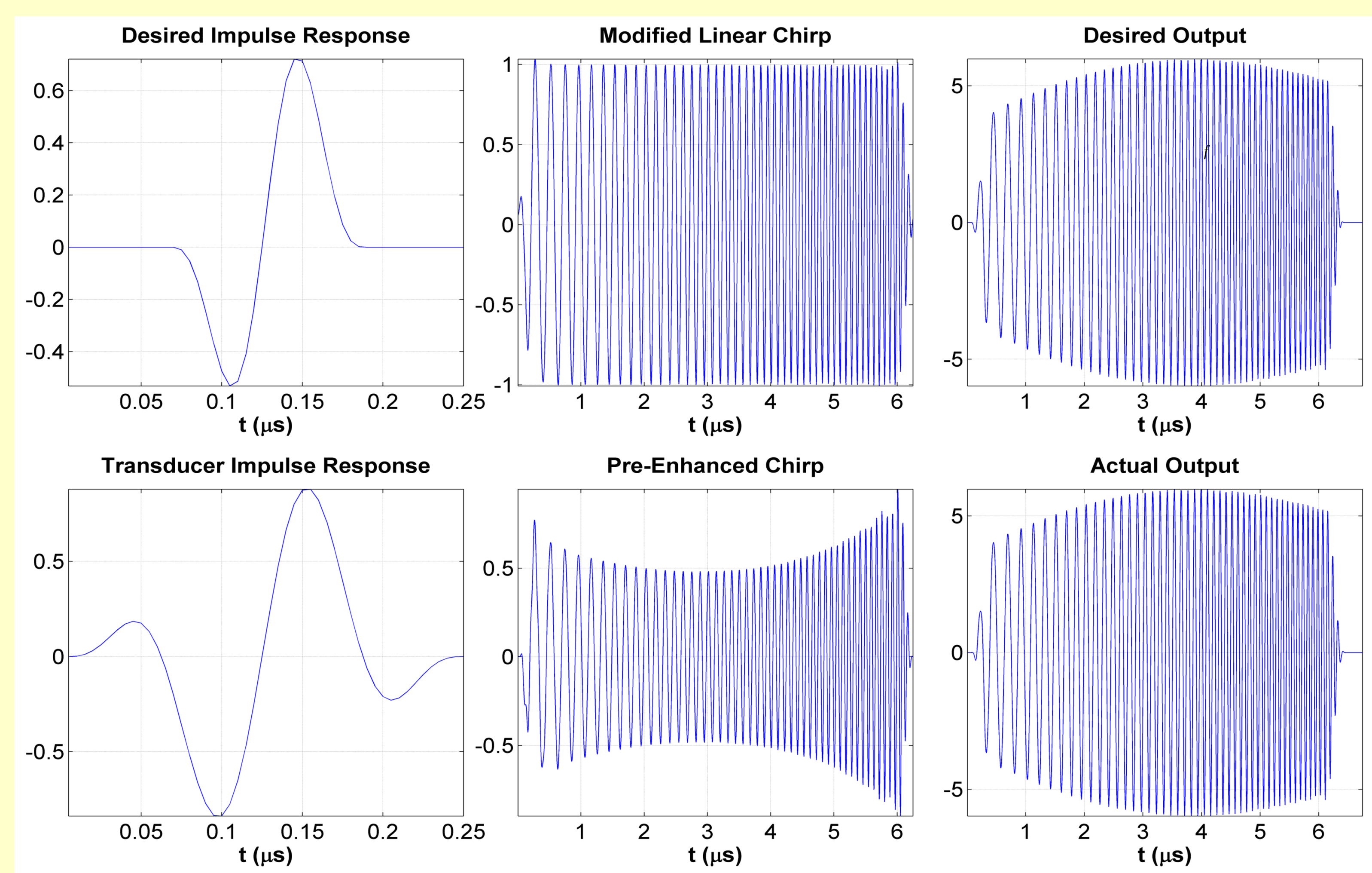
By improving the resolution and SNR of the received ultrasound images, smaller tumors could be identified sooner.

System Block Diagram



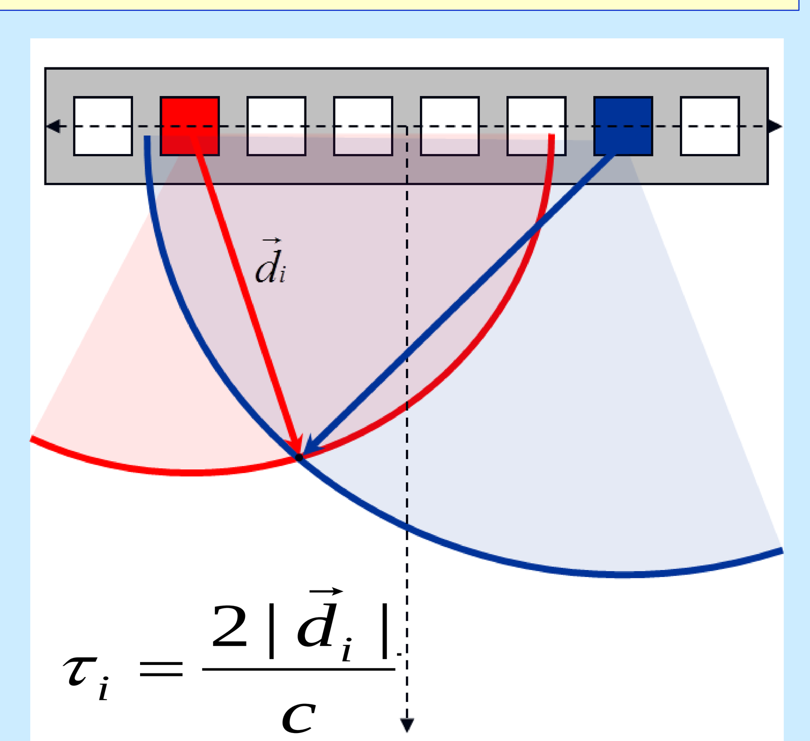
REC Overview

REC utilizes the convolution equivalence principle to synthetically exchange the transducer's response with a desired response. The desired response is excited by a linear chirp to produce the desired output. The desired output is then deconvolved by the transducer impulse response to generate a pre-enhanced chirp, which is then used to excite the transducer.



GSAU Overview

The GSAU technique involves transmitting and receiving on each ultrasonic element of the transducer one at a time. This scheme results in cylindrical wavefronts which causes the received signals to have directional ambiguity. This directional ambiguity can be overcome by summing the different images from each transmit event, since they should only all overlap at one point.



$$f(\vec{x}_p) = \sum_i \vec{r}_i(\tau_i(\vec{x}_p, \vec{x}_i))$$

Wiener Filter

In order to achieve the greatest possible effect from the REC technique, the received signals must then be passed through a Wiener filter. The Wiener filter acts as a hybrid between a matched filter and an inverse filter, suppressing the noise and deconvolving the signal.

$$\beta_{REC}(f) = \frac{V_{lc}^*(f)}{|V_{lc}(f)|^2 + \gamma \,\mathrm{eSNR}^{-1}(f)}$$

$$\mathrm{eSNR}(f) = \frac{\mathrm{PSD}_{sig}(f)}{\mathrm{PSD}_{noise}(f)}$$

GPU Programming

Due to the massive amount of computations that have to be performed for each pixel, conventional implementations of GSAU tend to run slowly. Using a graphics processing unit (GPU) instead of a conventional processor (CPU) may speed up the performance of the GSAU technique so that it may be used in real-time applications.

Image Quality Metrics

Resolution

Resolution is typically calculated from the modulation transfer function (MTF), one of the most common imaging benchmarks. The MTF is the normalized magnitude of the Fourier transform of the spatial impulse response. The characteristic wave number k_0 is measured at the point where the MTF crosses a value of 0.1. The resolution λ is then expressed as a function of k_0.

$$\lambda = \frac{1}{2}\frac{2\pi}{k_0}$$

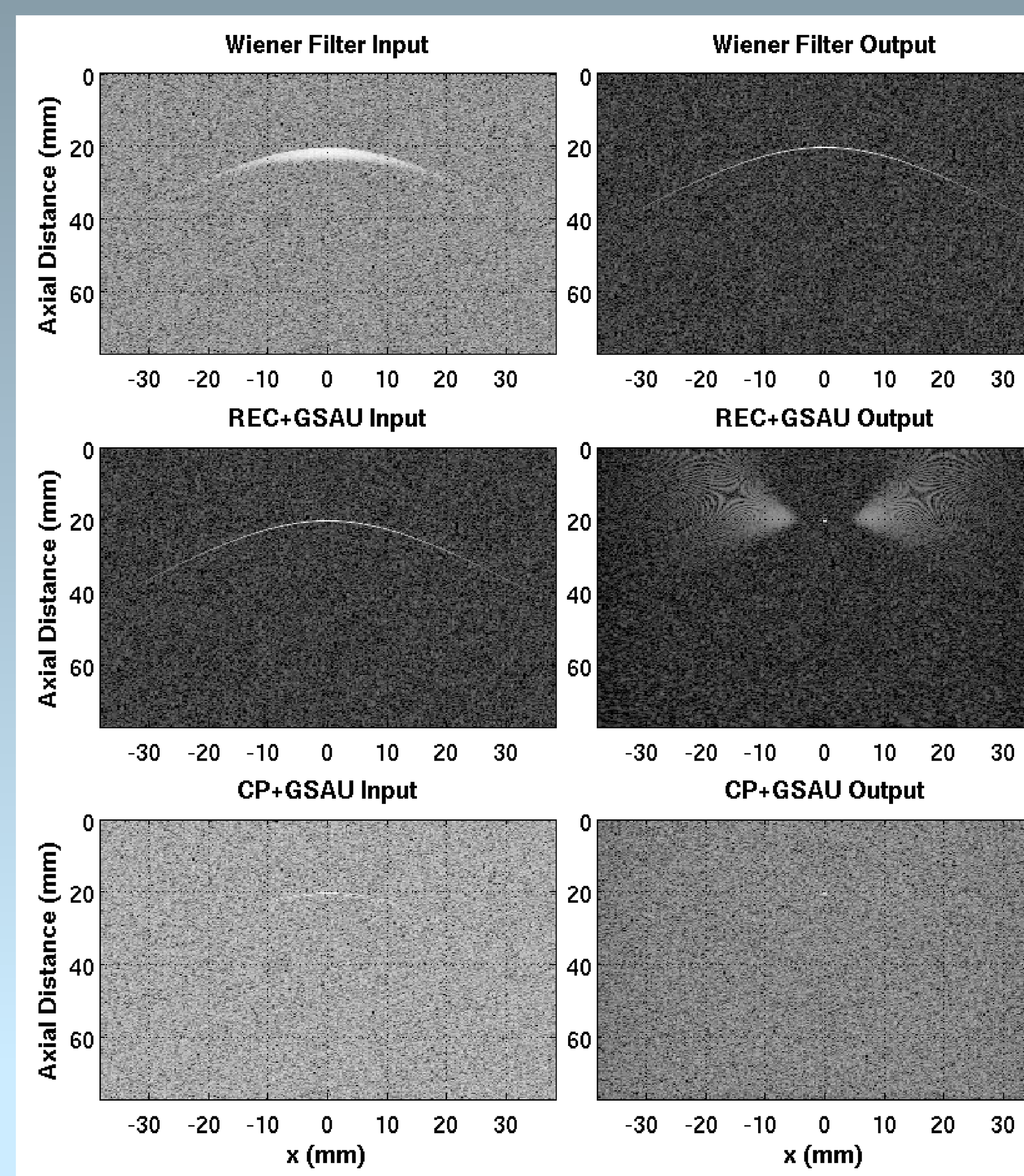
SNR:

The SNR is evaluated along the scan line containing the imaged point. It is typically expressed in decibels (dB) due to the possibility of wide dynamic ranges.

$$SNR_{dB} = 10\log_{10}\left(\frac{P_{sig}}{P_{noise}}\right)$$

Results

Images were captured of a point centered 20 mm before and after Weiner filtering and beamforming, using the REC technique. Significant improvement in the SNR was observed when compared to a conventional pulsing (CP) technique. Switching to the GPU from the CPU resulted in a factor of 116 speedup, reducing the computation time from 30 s to 0.25 s.



Conclusions

Based on preliminary results, it appears that the REC and GSAU techniques improve the SNR and spatial resolution of the images. Using a GPU for parallel computations of each pixel allows for real-time processing of the GSAU algorithm.

References

[1] M. Oelze, "Bandwidth and resolution enhancement through pulse compression," *IEEE Trans. Ultrason., Ferroelec., Freq. Contr.*, vol. 54, no. 4, 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," *IEEE Trans. Ultrason., Ferroelec. and Freq. Contr.*, vol. 56, no. 7, pp. 1327-1339, Jul. 2009.

[3] S. Nikolov, "Synthetic aperture tissue and flow ultrasound imaging," Ph.D. dissertation, Technical University of Denmark, 2001. [Online]. Available: https://svetoslavnikolov.wordpress.com/synthetic-aperture-ultrasound-imaging/