Resolution Enhancement Compression (REC)-Synthetic Aperture Focusing Techniques (SAFT)

Project Proposal

By: Hans Bethe

Advisor: Dr. Jóse R. Sánchez

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Project Summary

The aim of this project is to investigate two methods used in ultrasound imaging: resolution enhancement compression (REC) and synthetic aperture focusing techniques (SAFT). REC is employed to excite the transducer and can potentially improve axial resolution of ultrasound images. SAFT is employed to form ultrasound beam and can potentially improve lateral resolution. The investigation entails the following goals:

- Literature research of REC and SAFT through research papers
- Computer simulation of REC and SAFT using a set of specifications. The simulation will be performed through MATLAB and general purpose graphic processing unit (GPGPU).

Project Description

Introduction

Ultrasound imaging has been an indispensable technology in medicine. It offers doctors and medical researchers the ability to visually examine the internal organs inside their patients to determine if there are problems or anomalous features that are deleterious to the organs such as cancer tumor and lesions. One primary concern in ultrasound imaging is the resolution of the ultrasound images. Very often, the resolution is degraded by a multitude of problems such as: blurring, poor contrast between the background and the target objects, phantom images and so forth. As a result, methods that can mitigate these problems and consequently enhance the resolution of ultrasound images have been constantly investigated. Recently, two methods with high potential to fulfill the requirement for high resolution have been proposed and investigated by ultrasound researchers. One is termed resolution enhancement compression (REC) and the other is termed synthetic aperture focusing techniques (SAFT).

The resolution-enhancing potentials of REC and SAFT provide the motivation for undertaking this project, the aim of which is to investigate the two methods through literature research. Then, the methods are to be implemented through MATLAB and GPGPU to demonstrate their effectiveness in ultrasound imaging. One foreseeable significance of this project lies in the possibility of confirming the effectiveness of the two methods in enhancing ultrasound image resolution.

Background

I/ Resolution Enhancement Compression (REC)

Prior to the development of REC, the popular methods used to excite the transducer to emit ultrasound pulse is the conventional pulsing (CP). One problem inherent in this method was that it could enhance the resolution of ultrasound image only by increasing the excitation voltage, which was accompanied by the generation of additional heat that posed safety hazards to the patients undergoing ultrasound scanning. As a result, a more effective transducer excitation method was urgently needed and this context presented the impetus for the investigation and development of REC.

REC is a coded excitation technique, which involves either frequency modulation (FM) or phase modulation (PM) of the excitation signals. In reality, coded excitation amounts to wave-shaping technique designed to modify the shape of the excitation signal such that the effective bandwidth of the imaging system will be increased. This will decrease the duration of the emitted pulse, which will in turn improve the axial resolution of the images.

The enabling theory of REC is the convolution equivalence principle. This principle can be summarized as below:

$$h_1(t)*v_1(t) = h_2(t)*v_2(t)$$

In the context of this ultrasound imaging, $h_1(t)$ is the impulse response of the actual imaging system, $h_2(t)$ is the impulse response of the desired imaging system with bandwidth being larger than that of the actual imaging system. $v_1(t)$, $v_2(t)$ are the excitation signals applied to the imaging systems characterized by $h_1(t)$ and $h_2(t)$, respectively. This equation enables the generation of an excitation signal that can increase the bandwidth of the emitted pulse, which will in turn decrease its duration and improve axial resolution.

REC has many advantages over CP. One advantage is that is the emitted pulse can penetrate deeper in the internal body, which means that the emitted pulse can reach tissues and objects lying deep inside the body, thereby enabling the respective images of these tissues to be generated. The second advantage is that it can achieve a higher echo-signal-to-noise (eSNR) which will increase the resolution of the images. Another benefit of REC is that it offers the capability of creating the optimal excitation signal to increase the effective bandwidth, which will alter the pulse of the emitted pulse such that the axial resolution will be improved.

II/ Synthetic Aperture Focusing Techniques (SAFT)

SAFT is a beam-forming method. In the synthetic aperture imaging a single transducer element is used both, in transmit and receive modes. The transducer consists of multiple elements linearly arranged. Each element will emit an ultrasound pulse. Altogether, these ultrasound pulses will propagate in all direction toward. Some fraction of all pulses will reach the target object and reflect back as echoes. Since not all transducer elements are horizontally aligned with the target object, the echoes will return to their respective elements at different angles. In addition, the durations of the time traveling to and from the object corresponding to different echoes will also be different. The different durations of traveling times and the angles of return that contain information regarding the depths and size of the target objects. Hence, those temporal durations and the angles will be extracted from the echoes to reconstruct the images.

The two important characteristics of the SAFT involves two main processes. One is apodization, a process whereby the strengths of the excitation signals applied to various elements of the transducer are not uniform across the transducer. The elements closer to the center will be excited by stronger signals while the elements located in the regions farther away from the center of the transducer will receive weaker excitation signals. Apodization can help control the beam width which determines the lateral resolution of ultrasound images.

The second process is delay and sum. Since the distances between the transducer elements and the target object are not the same for all transducer elements, the echoes corresponding to the elements are not in phase with each other. This is the delay problem that must be accounted for in order to ensure that the echoes are not summed prematurely and hence canceling out each other, resulting in low resolution images.

Functional Description

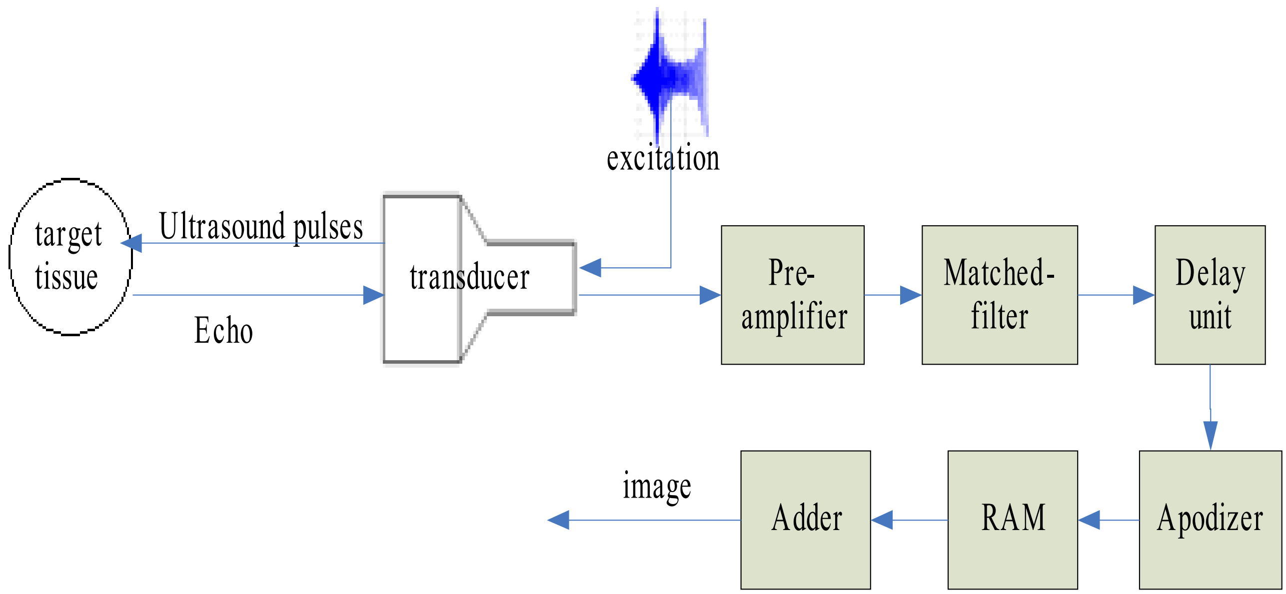

Figure 1: Imaging System Block Diagram

The purposes of the components in Fig. 1 are described below:

- The pre-amplifier recovers the strengths of the echoes after traveling in a lossy medium which corrupts the echoes with noise.
- The matched filter is integrated to suppress the noise that is amplified by the pre-amplifier, there by increasing signal to noise ratio (SNR).
- Delay unit accounts for the out-of-phase problems encountered by the echoes due to the differences in traveling distances to and from the objects back to the transducer elements.
- Apodization suppresses the side lobes.
- Random Access Memory (RAM) stores the processed echoes.
- Adder combines the echoes to produce the images.

Functional Requirements

Synthetic Aperture Focus Techniques (SAFT)

- The transducer shall consist of an array of elements arranged linearly.
- The ultrasound simulations shall be performed using the MATLAB add-on Field II.
- The synthetic aperture system shall store the received signals from the transducer elements in RAM.
- The total memory usage shall not exceed 2 gigabytes.
- The delay and sum calculations shall be performed on a GPGPU.
- The total synthetic aperture processing time shall be less than 1 second.
- The SNR of the output images shall be at least 50 dB.
- The simulated transducer shall have these specifications:

Parameters	Values
Center frequency (denoted as f_0)	2 MHz
Sampling Frequency (denoted as f_s)	400 MHz
Number of elements in the transducer array	128
Element's width	200 µm
Element's kerf	40 µm
Element's height	5 mm
Focus of ultrasound beam	40 mm

Table 1: Requirements for SAFT simulation

Resolution Enhancement Compression (REC)

- The actual impulse response of the transducer (denoted as $h_1(t)$) shall have a center frequency f_0 of 2 MHz.
- $h_1(t)$ shall have a bandwidth of about 83% (Here, percent bandwidth = 6dB bandwidth of the spectrum of $h_1(t)$ divided by f_0)
- The sampling frequency f_s shall be 400 MHz.
- The desired impulse response (denoted as $h_2(t)$) shall have a bandwidth about 1.5 times the bandwidth of $h_1(t)$.
- The linear chirp (denoted as $V_{lin\ chirp}(t)$) shall have a bandwidth that is about 1.14 times the bandwidth of $h_2(t)$
- The side lobes of $V_{lin\ chirp}(t)$ shall be reduced below 40 dB.

The implementation of REC can be described as the following:

- $h_1(t)$ is created by applying a Hanning window with certain width factor so that the windowed signal has a shape that can simulate the impulse response of the actual system.
- $h_2(t)$ with bandwidth larger than that of $h_1(t)$ is created by applying to $h_1(t)$ another Hanning window with smaller width to compress $h_1(t)$ in time, which will broaden the spectrum of $h_2(t)$ in the frequency domain.
- A linear chirp is then created. Its spectrum will then be obtained, then multiplied with the spectrum of $h_2(t)$ and divided by an inverse filter characterized by $h_1(t)$. The resulting spectrum corresponds to the pre-enhanced chirp. The pre-enhanced chirp will be obtained by evaluating the inverse Fourier transform of the spectrum of the pre-enhanced chirp.
- The pre-enhanced chirp will be convolved with the impulse response of the system to generate a simulated emitted ultrasound pulse and the echo.
- The echo will be subjected to pulse compression
- The envelope of the compressed pulse will be extracted to determine the axial resolution of the system.

Preliminary Computer Simulation Results

Hitherto, most of the effort and time have been devoted to simulate REC through MATLAB. The simulation resulted in the generation of the pre-enhanced chirp that will be used to excite the transducer. In addition, pulse compression process was implemented. The simulation result is shown in Fig. 2 on the next page.

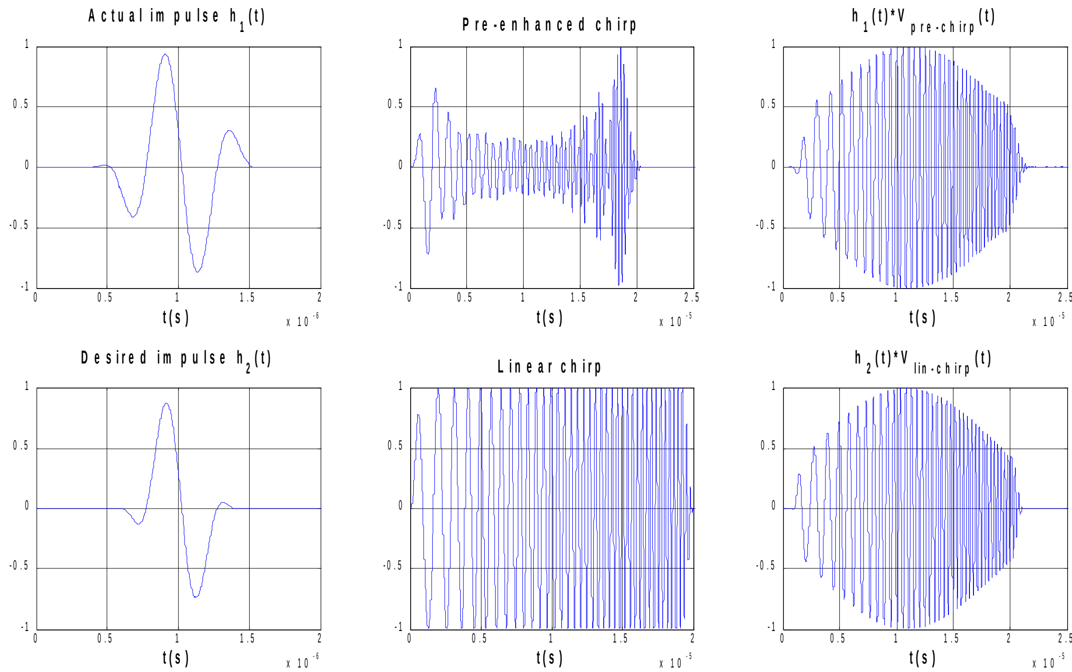

Figure 2: Computer simulation results of REC

Summary of work done and plan for future tasks

Significant progress has been made on the REC. Specifically, most of the main signals were generated. They are: the simulated impulse responses $h_1(t)$ and $h_2(t)$, the linear chirp, the pre-enhanced chirp and the pulse emitted from the transducer. The linear chirp, the pre-enhanced chirp and the pulse emitted from the transducer all closely approach the standard wave shapes presented in the literature.

The next step will be to determine the axial resolution associated with REC. Once that is done, the next step will involve simulating SAFT in MATLAB. As soon as the MATLAB simulation is done, REC and SAFT will altogether be simulated through GPGPU. When GPGPU simulation is completed, the final paper shall be composed and the project shall be presented by the end of next spring.

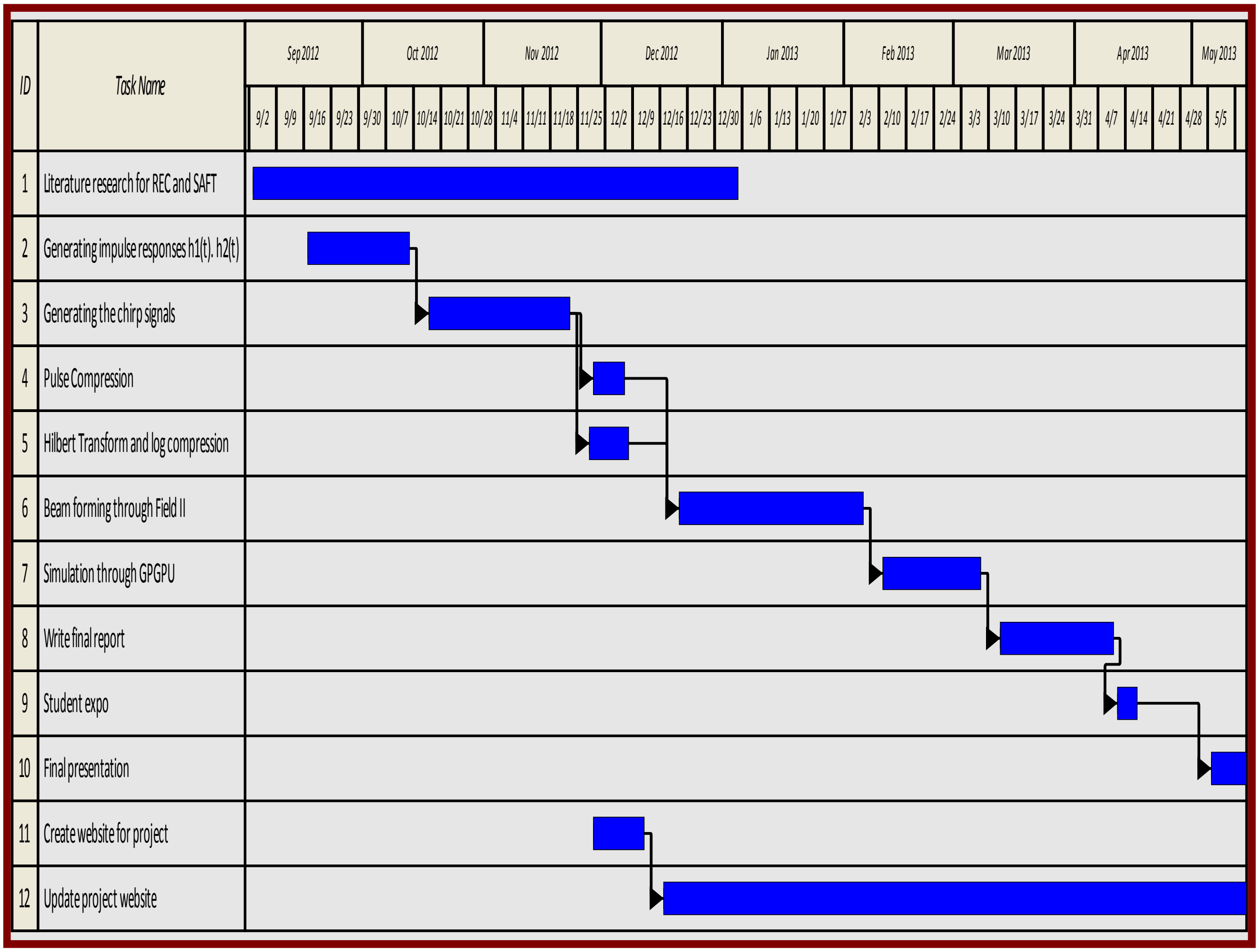

Figure 3: Gantt chart

References

[1] J. R. Sanchez, D. Pocci, and M. L. Oelze, “A Novel Coded Excitation Scheme to Improve Spatial and Contrast Resolution of Quantitative Ultrasound Imaging”, IEEE Trans. on Ultrasonics, Ferroelectric, and Frequency Control, vol. 56, no. 10, October 2009

[2] M. Oelze, “Bandwidth and Resolution Enhancement through Pulse Compression”, IEEE Trans. on Ultrasonics, Ferroelectric, and Frequency Control, vol. 54, no. 4, pp. 768-781, Apr. 2007.

[3] T. Misaridis and J. A. Jensen, “Use of Modulated Excitation Signals in Medical Ultrasound”, IEEE Trans. on Ultrasonics, Ferroelectric, and Frequency Control, vol. 52, no. 2, pp. 177-191, Feb. 2005.

[4] T. Stepinski, “An Implementation of Synthetic Aperture Focusing Technique in Frequency Domain”, IEEE Trans. on Ultrasonics, Ferroelectric, and Frequency Control, vol. 54, no. 7, July 2007.

[5] M. Oelze, “Improved Axial Resolution Using Pre-enhanced Chirps and Pulse Compression”, 2006 IEEE Ultrasonics Symposium

[6] S. I. Nikolov, “Synthetic Aperture Tissue and Flow Ultrasound Imaging”.

[7] J. A. Zagzebski, “Essentials of Ultrasound Physics’.

PATENTS:

1/ Patent application title: Ultrasound Signal Compression
Inventors: A. W. Wegener, M. V. Nanevicz
IPC8 Class: AA61B806FI
USPC Class: 600454
Class name: Ultrasonic doppler effect (e.g., fetal hr monitoring) blood flow studies
Publication date: 2012-06-21
Patent application number: 20120157852

Read more: http://www.faqs.org/patents/app/20120157852#ixzz2BcKil5qn

Read more: http://www.faqs.org/patents/app/20100305449#ixzz2BcL1AqBR

2/ Patent application title: Post-beamforming Compression in Ultrasound Systems
Inventors: A. W. Wegener
IPC8 Class: AA61B814FI
USPC Class: 600443
Class name: Detecting nuclear, electromagnetic, or ultrasonic radiation ultrasonic anatomic image produced by reflective scanning
Publication date: 2010-12-30
Patent application number: 20100331689

Read more: http://www.faqs.org/patents/app/20100331689#ixzz2BcLCOIDv

3/ Patent application title: System and Method for Adaptive Beamformer Apodization
Inventor: Hong Wang
Original Assignee: Siemens Medical Solutions USA, Inc.
Primary Examiner: Marvin M. Lateef
Secondary Examiner: Ali M. Imam
Current U.S. Classification: 600/443
International Classification: A61B/800

4/ Patent application title: Transducer Array Imaging System
Inventors: Kevin S. Randall, Jodi Schwartz Klessel, Anthony P. Lannutti, Joseph A. Urbano
Original Assignee: Penrith Corporation
Primary Examiner: Jacques M Saint Surin
Attorney: Condo Roccia LLP
Current U.S. Classification: 73/661; 73/620; 73/649; 600/443; 600/447

5/ Patent application title: Ultrasound imaging using coded excitation on transmit and selective filtering of fundamental and (sub)harmonic signals on receive
Inventors: Richard Yung Chiao, Ann Lindsay Hall, Kai Erik Thomenius
Original Assignee: General Electric Company
Current U.S. Classification: 600/447; 600/458
International Classification: A61B 800

6/ Patent application title: Ultrasonic imaging system with beamforming using unipolar or bipolar coded excitation

Inventors: Richard Yung Chiao, Lewis Jones Thomas, III
Original Assignee: General Electric Company
Primary Examiner: Ali M. Imam
Current U.S. Classification: 600/447
International Classification: A61B 800

7/ Patent application title: Synthetic aperture ultrasound imaging system
Inventors: J. Robert Fort, Norman S. Neidell, Douglas J. Morgan, Phillip C. Landmeier
Current U.S. Classification: 600/447; 73/597; 600/437
International Classification: A61B 800