CVUS

GPU Accelerated Transmission Image Reconstruction for 3D Quantitative Ultrasound Breast Imaging

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Abstract

CVUS ultrasound whole breast imaging system is used for the diagnosis of breast cancer. Unlike conventional ultrasound imaging in which reflected ultrasound is used to generate images, CVUS generates both 3D transmission and 3D reflection images. The transmission reconstruction uses an inverse-scattering algorithm, which can be described as a modified nonlinear conjugate gradient method that tries to match simulated scattered ultrasound to the collected signals. Over several years, the inverse-scattering algorithm was ported to two Tesla C1060 GPUs resulting in over 2x speed up in processing time over the 16-core Core 2 Cluster that was used previously. The release of Kepler GK110 gives more opportunities to optimize the performance of the original code. Its enhanced memory subsystem offers additional caching capabilities, which allows more active warps running at the same time, resulting in faster speed and better utilization of GPU. The hyper-Q feature enables multiple CPU cores to launch work on a single GPU simultaneously. This allows more flexibility in overlapping kernel execution and data communication between host and device, which usually occupies most of the transmission processing time. By sufficiently using the Kepler features, the ultimate processing speed is 4x faster than the C1060 GPUs for the image reconstruction.

Introduction to CVUS System

Figure 1: CVUS 3D ultrasound breast scanner

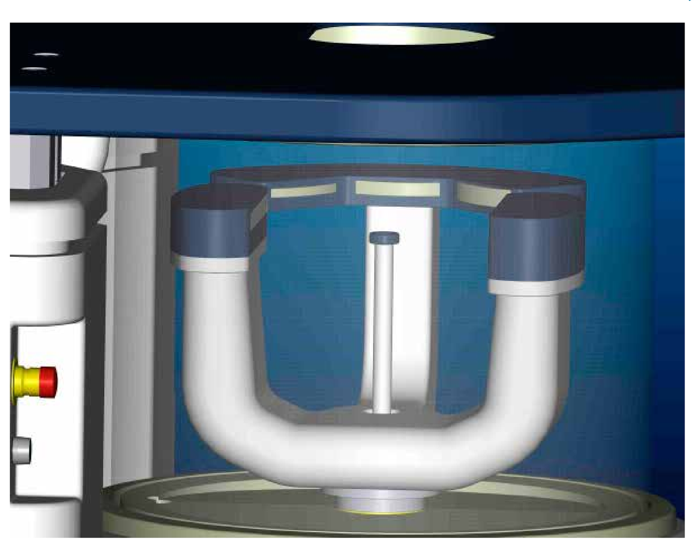


Figure 3: Side view of the water tank showing the Tri-channel on which the arrays are mounted. The Tri-channel rotates 360 clockwise and counter clockwise and moves up and down.

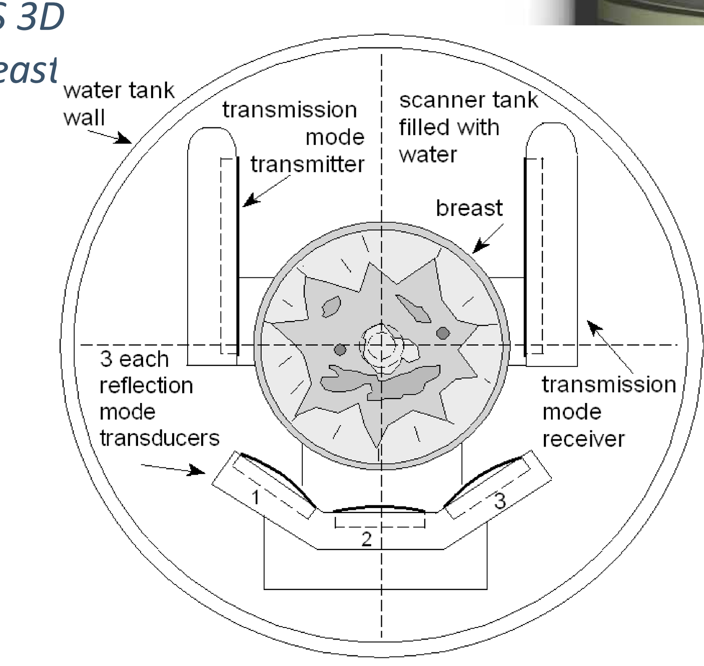


Figure 2: Geometry of the five arrays looking down into the breast scanner water tank

Introduction to Transmission Algorithm and Problems

The algorithm can be described as a modification of the nonlinear conjugate gradient method. It tries to find a model of the breast tissue that minimizes the difference between the acquired ultrasound data and a simulation of the ultrasound propagation via gamma, a complex number of speed of sound and attenuation. Gamma is iteratively modified until the simulated model is acceptable.

Massive, nonlinear optimization problem:
Unknowns: number of voxels = 296 (x) * 296 (y) * 202 (z) = 17.7 million
Acquired elements data:
Time-domain: 1536 (elements) * 180 (views) * 70 (levels) * 1536 (samples) = 29.7 billion
Frequency-domain: 19.4 million/freq * 82 (freqs) = 1.59 billion per waveform
Time consuming calculation: Fast Fourier Transform (FFT): 63 million 2D FFTs.

Algorithm Implementation and Code Design

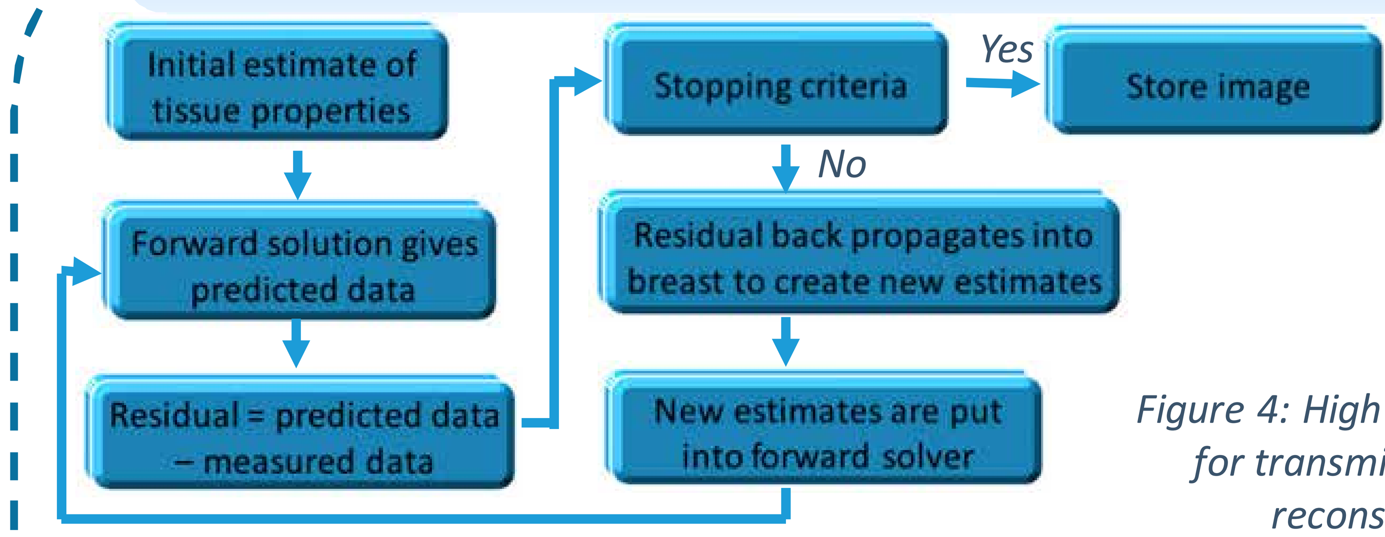


Figure 4: High level algorithm for transmission image reconstruction

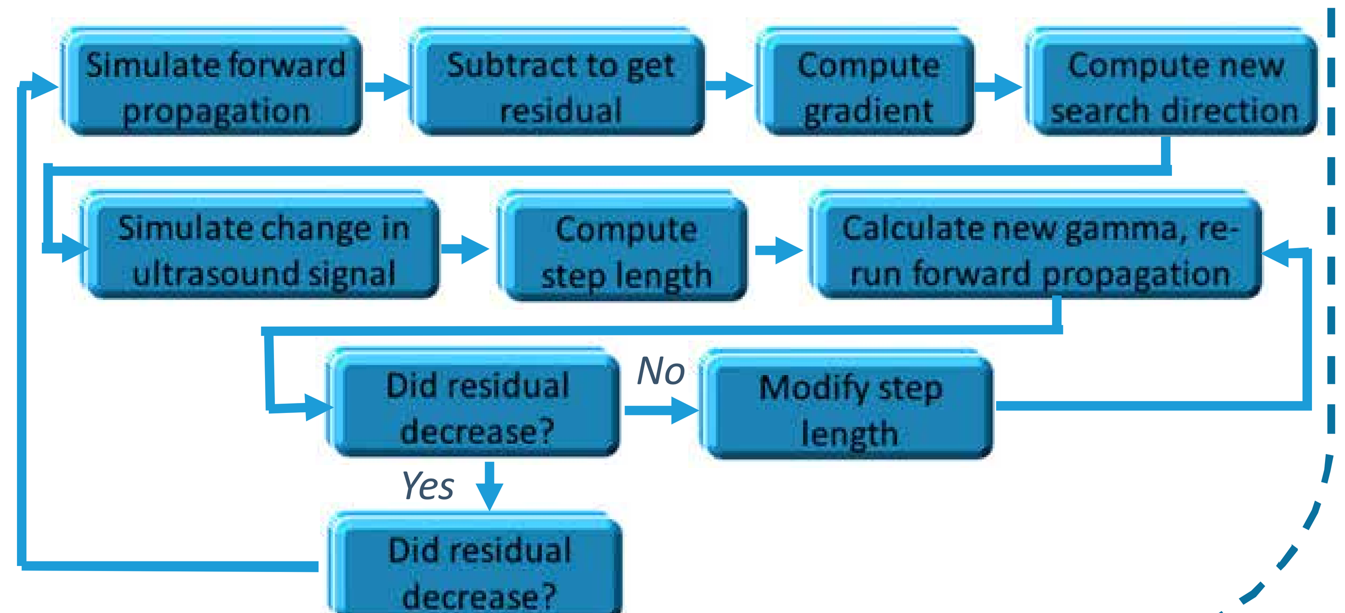
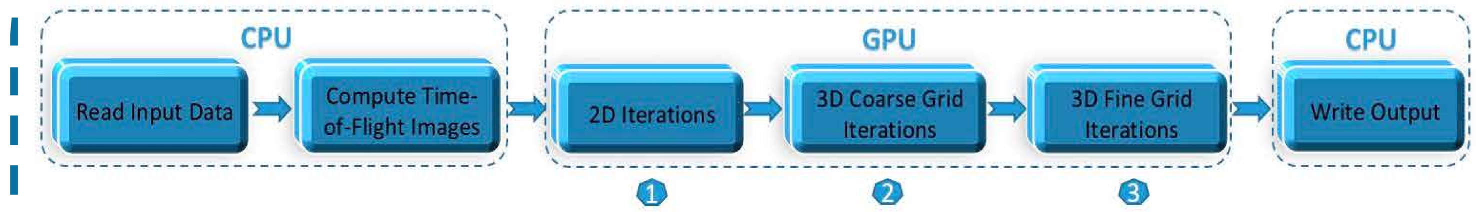


Figure 5: Detailed algorithm implementation for each iteration in transmission image reconstruction

Kepler Architecture and Improvement

- More processors, better memory management, configuring shared memory and L1 cache → 2.3 X faster overall processing time
- Two copy engines Hyper-Q →overlap communication and kernel execution→ 1.11 X faster data transfer time.
- Texture objects → 1.01X calculation time.
- New 2D FFT calculation reduces transpose time → 1.58 X faster calculation time.

Result: Processing Speed Comparison



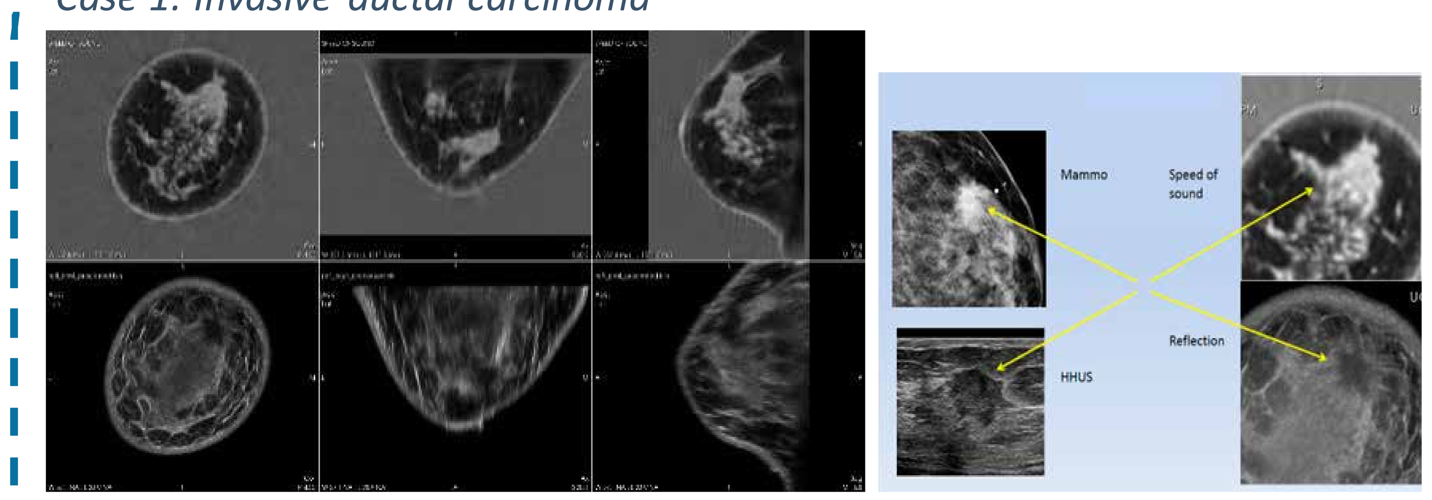
1 Iteration: 10 * 7 frequencies = 70 iterations
2 Iteration: 10 * 7 frequencies = 70 iterations
3 Iteration: 5 * 4 frequencies + 10 * 2 frequencies + 65 * 1 frequency + 30 * 1 frequency = 135 iterations

Host	Device	Programming Paradigm	Code	Processing Time *1
16-core Intel Core2 Cluster	—	Fortran cluster	Fortran code	180 min. (approximated)
Intel Xeon E5-2620 @ 2.00 GHz	Tesla C1060 GPU	CUDA C and C++	Original CUDA code	80 min. 56 sec.
Intel Xeon E5-2620 @ 2.00 GHz	Kepler 20c GPU	CUDA C and C++	Original CUDA code	35 min. 23 sec.
Intel Xeon E5-2620 @ 2.00 GHz	Kepler 20c GPU	CUDA C and C++	Modified CUDA code*2	20 min. (approximated *3)

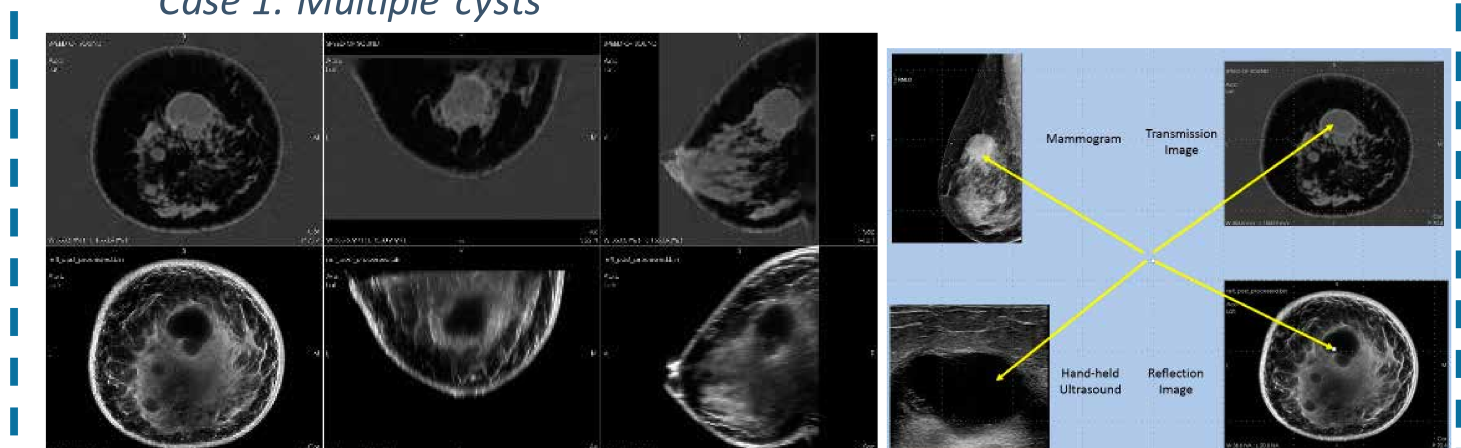
*1: The processing time is based on full tank scan (70 levels).
*2: The modified CUDA code uses new memory management, FFT calculation, texture objects and overlapping computation and communication (host with device).
*3 : The approximated processing time is based on unit test result, not on the actual code.

Images

Case 1: Invasive ductal carcinoma



Case 1: Multiple cysts



Left images are from CVUS system. Top row: transmission (speed of sound) images (left to right: axial, coronal and sagittal); bottom row: reflection images (left to right: axial, coronal and sagittal). Right images: compared with mammogram and hand held ultrasound.

CVUS system is for investigational use only, not cleared by FDA.