CUDA Accelerated Real Time Signal Processing in High Performance Diagnostic Ultrasound Imaging

Ismayil Guracar
Senior Key Expert
Siemens Medical Solutions USA, Inc
Ultrasound Business Unit
Real time Ultrasound Signal Processing

1. Introduction to Diagnostic Ultrasonic Imaging
2. Speckle Reduction Processing Example
3. Cardiac Imaging in real time 2D and 3D
Diagnostic Imaging Instrument

A machine for the acquisition of imaging information to affect diagnosis and treatment of disease
High frequency sound
- typically from 1 to 20 MHz
- $\lambda = 1.5 \text{ mm} \sim 77 \mu\text{m}$
- speed of sound in tissue 1540 m/sec
  - 15 cm round trip propagation in 200 $\mu$sec
  - 80 transmit/receive events can sample a region at 60 Hz
- transmit and receive waves into the body from a piezoelectric transducer: 128 to 512 elements
- phased array transmit and receive beam forming
ACUSON SC2000™ Ultrasound System
Signal Processing Pipeline

Quadro2000
CUDA
Conventional 2D Cardiac Imaging

Real time cross sectional imaging

- Typical frame rates 30-60 Hz
- Data rates on the order of 10 Megasamples per second
- Multiple views and transducer orientations needed to acquire a complete diagnostic exam
3D Imaging

Real time volumetric imaging

- Typical frame rates 20-30 Hz
- Data rates on the order of 100 Megasamples per second
- All data required for cardiac exam acquired in a single heartbeat

More Diagnostic Information from a Single Exam
Speckle is a random process inherent in any coherent imaging system
- laser speckle example

Speckle reduces lesion conspicuity:
- subtle variations in backscatter are obscured by the random noise from speckle

Some speckle reduction techniques
- spatial averaging
  - spatial resolution traded for speckle reduction
- spatial compounding
  - temporal resolution traded off for spatial diversity acquisition and averaging
Steered Spatial Compounding
Speckle Reduction Using Combined Measurements from a Diversity of Steering Angles

0 degree steering angle
Steered Spatial Compounding
Speckle Reduction Using Combined Measurements from a Diversity of Steering Angles
non-compounded image  7-way compounded image
Scan Geometry Transformation Using CUDA Texture Lookups

Geometric transformation with bilinear interpolation using a sequence of 2D texture lookups in the kernel core

- For a given sample in the target Cartesian grid at (x,y) first find the transformation coordinates
- Using transformation coordinates (r,p) perform bilinear interpolation of the nearest data points in the acquired grid

```c
acousticCoordinate.r = tex2D(scanGeometryTransformationTexture, cartesian.x, cartesian.y).x;
acousticCoordinate.p = tex2D(scanGeometryTransformationTexture, cartesian.x, cartesian.y).y;
transformedData = tex2D(acousticData, acousticCoordinate.r, acousticCoordinate.p);
```
Performance Measurements

*Imaging Condition Example*

- ACUSON SC2000 with 9L4 vascular transducer
- 55 mm imaging depth at 9 MHz
- 7-way compounding
- Frame rate: 61 frames/sec
- Data rate: 10 Megasamples/sec

**CPU Implementation: scan convert and compound**
- Uses one active CPU core of a quad core 2.33 GHz Xeon
- Performance achieved: 86 Megasamples/sec
- Imaging condition requires \( \frac{10}{86} = 12\% \) of the available CPU compute power

**CUDA Implementation: scan convert and compound**
- Quadro2000
- Performance achieved: 694 Megasamples/sec
- Imaging condition requires \( \frac{10}{694} = 1.4\% \) of the available GPU compute power

The CUDA implementation increased data processing rate performance by a factor of nearly 8 over single core processors and theoretically greater than a factor of 2 over a fully utilized quad core processor.
Small aperture:
- the heart is relatively far away from the probe and often imaged between two ribs—spatial diversity impractical

Demanding data rates:
- about 100 Mega Samples/second
- 20 Hz frame rate minimum

Morphology based filtering techniques
- non linear processing with surface filters oriented parallel to chamber surface
- reduces loss in resolution compared to conventional spatial filtering
- improves heart muscle / blood chamber interface visibility
Cardiac Volume Imaging – with and without speckle filtering
Performance Measurements

Imaging Condition

- ACUSON SC2000™ volume imaging ultrasound system with 4Z1c matrix transducer
- 160 mm imaging depth at 2.8 MHz
- Volume rate: 19 volumes/sec
- Data rate: 90 MB/sec

CPU Based Software Implementation

- Uses six active CPU cores of a dual quad core 2.13 GHz Xeon
- Performance achieved: 141.7 Megasamples/sec
- Imaging condition requires 90/141.7×6/8 = 47.6% of the total available CPU compute power

Kepler 2000D CUDA Implementation

- Performance achieved: 289 Megasamples/sec
- Imaging condition requires 31.1% of the GPU available compute power

CUDA implementation speed increased by a factor of 1.9 over dual quad core processors and greater than a factor of 11 over a single core

Main memory bandwidth demand reduced by an order of magnitude
Engineeering development to do list...

To do:
- Leverage improvements in GPU technology to further improve the signal processing pipeline
- Move to all-software image formation to completely displace custom FPGA hardware
- Meet increasing parallel receive beam former information rates
- Better, faster, smaller, cheaper…
Thank you for your attention!

Ismayil Guracar
Senior Key Expert
Siemens Medical Solutions, USA Inc
Ultrasound Business Unit

685 E. Middlefield Road
Mountain View, CA 94043
Phone: (650) 969-9112
ismayil.guracar@siemens.com