Real-time Ultrasound Data Processing for Regional Anesthesia Guidance

Stephen Rosenzweig, Mark Palmeri, Samantha Lipman, and Kathy Nightingale
Duke University, Department of Biomedical Engineering, Durham, NC 27708, USA

Introduction

Ultrasound imaging techniques such as Doppler flow imaging and acoustic radiation force impulse (ARFI) imaging [1] require estimation of velocity or displacement from the received echoes. These values are computed offline due to the computational intensity of the algorithms. Real-time processing and display of images allows for real-time guidance of procedures, improving patient safety and efficacy.

In this work, four algorithms used in displacement estimation were accelerated using CUDA. The acquired data are radio-frequency (RF) data that are first quadrature demodulated into in-phase and quadrature components (IQ) using CUDA. The data are then upsampled using cubic spline interpolation before Loupas' algorithm estimates the displacements and the correlation coefficient magnitude is computed. The CUDA code for interpolation and Loupas' algorithm is compared to previously optimized C++ code.

Experimental Setup

Real-time processing has been implemented in pre-clinical regional anesthesia studies. The demodulation, interpolation, displacement estimation, and correlation algorithms were performed on RF data streamed from a modified Siemens SONOLINE™ Antares Scanner (Siemens Medical Solutions USA, Inc., Ultrasound Division, Mountain View, CA, USA). The data were processed on a Dell Precision M6400 laptop with 4GB RAM, an Intel® Core™2 Extreme Q9300 operating at 2.53GHz, and an NVIDIA Quadro FX 3700M. The laptop was used to provide images to complement the traditional B-mode images generated by the ultrasound scanner.

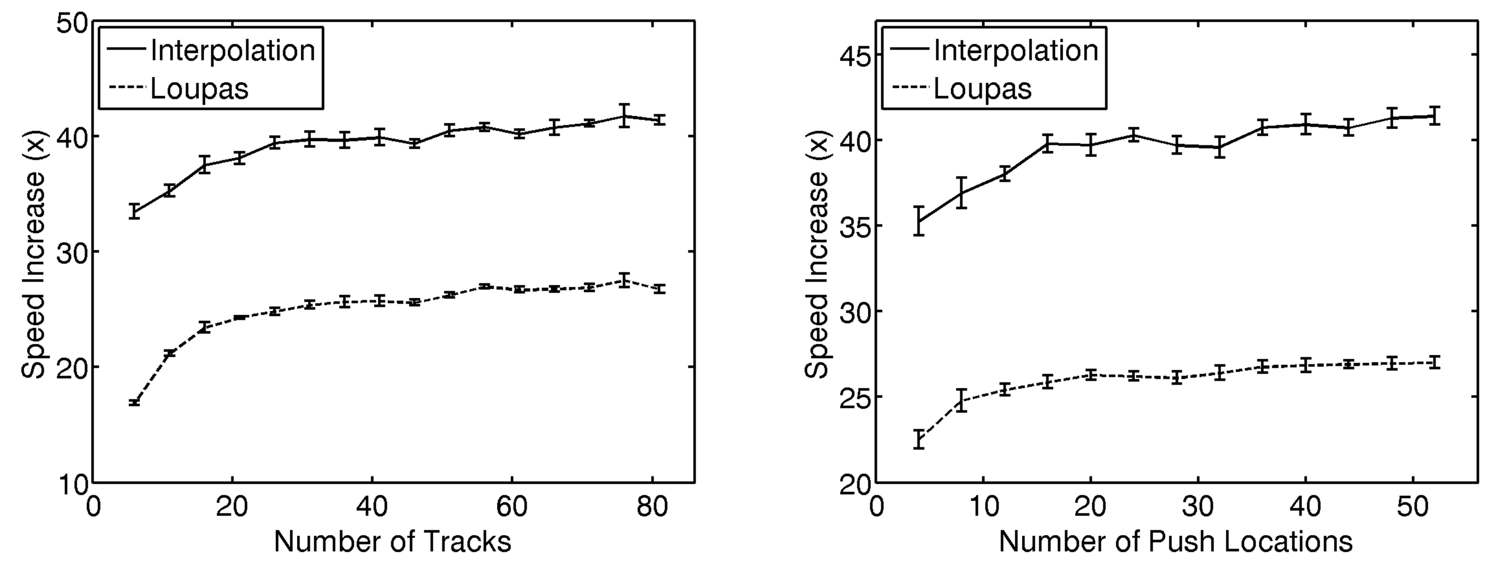
Methods

The raw data acquired are 16-bit integers in an array that can be upwards of 50 million points. Quadrature demodulation of the RF data was performed on a point-by-point basis with each thread multiplying the data by both sine and cosine, then using a boxcar low pass filter. The data were then upsampled using cubic spline interpolation to improve the precision of the displacement estimates, which are computed by an algorithm presented by Loupas *et al* [2]. The algorithm estimates the phase shift of the complex data with a correction for depth dependent attenuation. The data used by Loupas' algorithm were also used to compute the magnitude of the complex correlation coefficient.

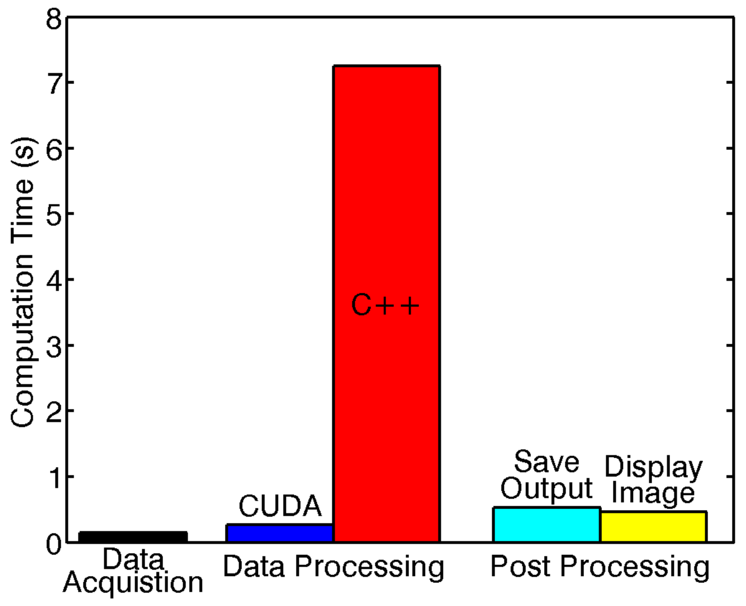
The CUDA implementations of both the interpolation and displacement estimation algorithms were tested on 10 data sets acquired with a Siemens SONOLINE™ Antares Scanner to determine the speed increase over previously optimized C++ code. All four algorithms were then used in the regional anesthesia studies to display dynamic real-time images.

Computational Results

Cubic spline interpolation and Loupas' algorithm were used on the 10 sample data sets to estimate the displacement of the tissue-mimicking phantom from a reference location through 80 time steps (tracks) at 52 locations. The below plots summarize the resulting acceleration using GPUs over previously optimized C++ code, where the error bars are the standard deviation over the 10 data sets.

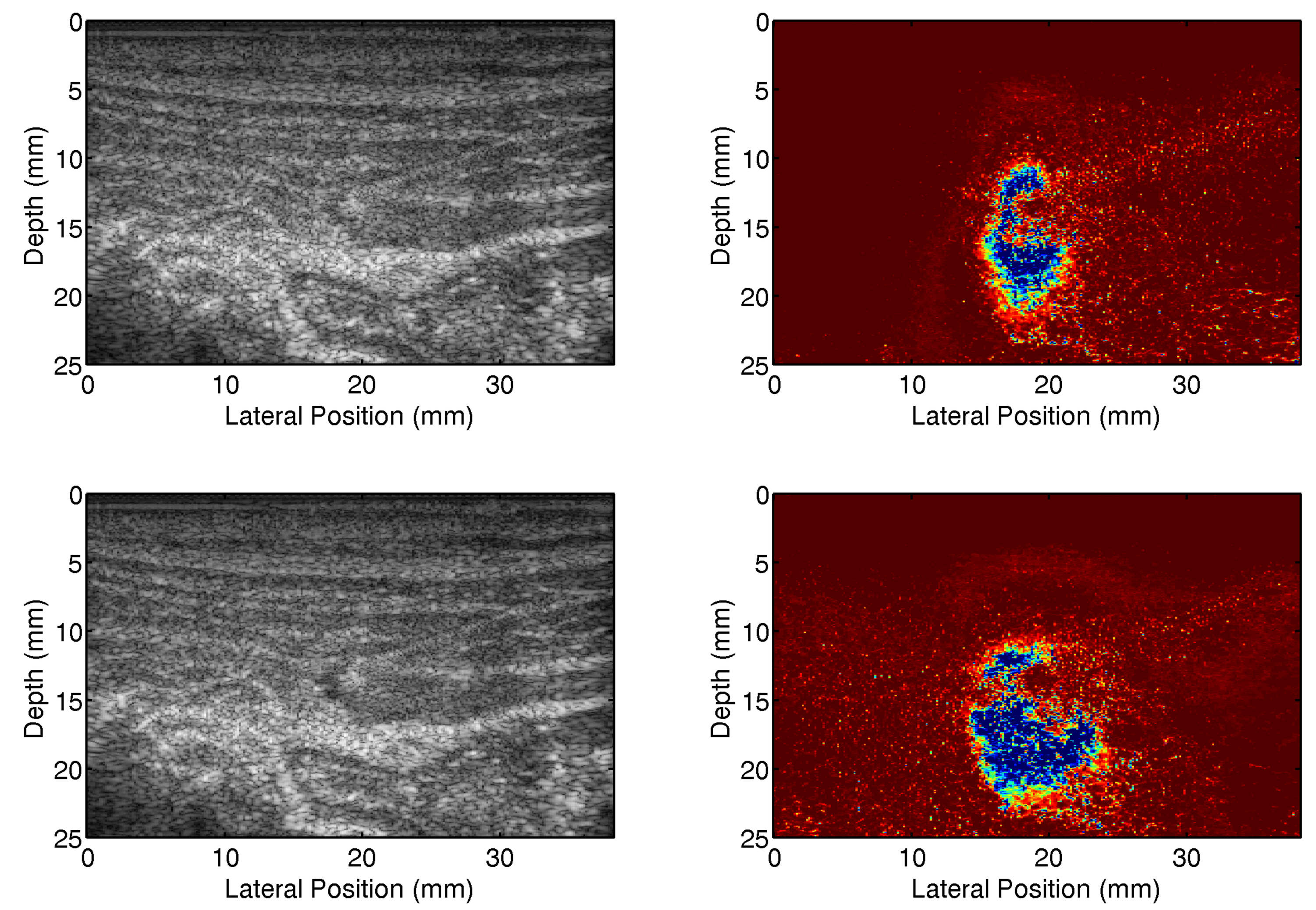


The average time required for each step from acquisition to display of the image is shown to the right. The data processing is 27x faster using CUDA, and takes less time than either saving the output or displaying an image using openGL.



Experimental Results

The GPU-accelerated code was used during the study previously described to estimate the displacement and compute the magnitude of the complex correlation coefficient at 256 lateral locations over 155 time steps (160MB data file). The data were processed in approximately 18 seconds as compared to 20 minutes using the conventional processing code. Traditional B-mode ultrasound images are shown below along with correlation coefficient images for two time steps, two seconds apart, as saline is being injected around a nerve. The study is investigating if the correlation images can show the saline that is not easily visible in the B-mode images.



Conclusions

Data processing using CUDA has been shown to significantly increase the speed of traditional algorithms used in ultrasound imaging. The ability to use GPUs to display images of the data in real-time was also demonstrated in a clinical research setting.

Acknowledgements

This work was supported by NIH grants R01 EB001040, R01 EB002312, and CA142824, the Coulter Foundation, and the Duke University Department of Anesthesiology. Special thanks to Siemens Medical Solutions USA, Inc., Ultrasound Division for their technical assistance, and Dr. Stuart Grant, Tom Milledge, and Dr. John Pormann for their valuable insights.

References

[1] K. Nightingale, M. Soo, R. Nightingale, and G. Trahey, "Acoustic radiation force impulse imaging: In vivo demonstration of clinical feasibility," Ultrasound Med Biol, vol. 28, pp. 227–235, 2002.

[2] T. Loupas, J. Powers, and R. Gill, "An axial velocity estimator for ultrasound blood flow imaging, based on a full evaluation of the doppler equation by means of a two-dimensional autocorrelation approach," Ultrasonics, Ferroelectrics and Frequency Control, IEEE Transactions on, vol. 42, no. 4, pp. 672 –688, July 1995.