Our customer, a US based medical device company, develops and manufactures MRI scanners. Cardiovascular Magnetic Resonance (CMR) Imaging is a medical imaging technology for non-invasive assessment of the cardiovascular system. One of the main differences from ordinary Magnetic Resonance Imaging (MRI) is the use of rapid imaging techniques or sequences to produce sharp images of a beating human heart.

The process of MRI image reconstruction involves 2D & 3D Fast Fourier Transform (FFT) over multi-channel multi-sequence raw data frames (k-space) acquired directly from MR scanner. The total amount of data acquired in a single batch can reach whooping 128 GiB! Additionally, parallel imaging methods may be used to reduce scan times (GRAPPA). When parallel imaging methods are used, only partial data is acquired. The missing data is mathematically calculated from available raw data before applying Fourier Transform. Parallel imaging methods involve mathematically demanding operation called Singular Value Decomposition (SVD). For a single scan SVD must be performed hundreds of times.

ELEKS developed a library of specialized functions to perform extremely fast and efficient MRI images reconstruction and SVD processing using NVIDIA® CUDA™. Now these operations take less than a second compared to 28 seconds for FFT and 18.5 seconds for SVD processing (over benchmark datasets using single-threaded reference CPU implementation). And the maximum achieved SVD acceleration is 155x on a benchmark dataset of 96 512x384 frames acquired from 8 coils in YZ orientation.

"Eleks did an outstanding job on this project. Not only did they completed the project in time and within budget, they took the initiative to improve and optimize the code that was outside the scope of their work to minimize overall processing time. We are very pleased with the outcome, the work product and the documentation."

*Chief Technical Officer, US MRI Manufacturer*
Solution overview

Parallel 2D & 3D Inverse FFT on CUDA™. Image reconstruction using 2D & 3D inverse Fast Fourier Transform is implemented using NVIDIA® cuFFT library. Special consideration was given for the large data frame cases, when there is not enough memory on-board to perform FFT. To overcome this limitation ELEKS engineers implemented a mathematically correct algorithm to run FFT over portions of the large data frame with subsequent aggregation of partial results.

High-performance batch SVD processing on CUDA™. SVD is a largely iterative algorithm, and parallelization of a single iteration does not give any significant benefits, especially for smaller image sizes. Therefore, the only realistic way to accelerate this operation is to run SVD processing over all frames and coils in parallel. Unfortunately, at that time no libraries on the market provided suitable SVD implementation with batching. ELEKS developers solved this problem by porting SVD algorithm to CUDA and running it over all frames and coils in parallel.

Since the customer’s application is written in C#, a .Net wrapper over C++ functions was implemented and number of samples were provided.

Based on extensive benchmarking on various NVIDIA® GPU cards, ELEKS recommended NVIDIA® GTX 680 as the one providing best cost/performance ratio for image reconstruction tasks, especially when combined with PCI Express 3.0 bus.

Scope of Services

• Analysis of the problem and available solutions on the market
• Mathematical research and development of algorithms
• Review and analysis of existing source code and libraries
• Implementation of CUDA™ code, C++ library and .Net wrapper
• Visual and binary reconciliation of final images
• Benchmarking of CUDA™ implementation on various NVIDIA® CUDA™ GPUs.
• Consulting as to the applicability of CUDA™ and selection of hardware.

Advantages

• Less than a second processing time for MRI image post-processing operations
• High-quality software fully reconciled and ready to use
• Hardware selection recommendations backed by experience and extensive benchmarks
• Complete API reference.