GPU Accelerated SAR Omega-K Focusing

Research
A parallel CUDA implementation of Omega-K algorithm for Synthetic Aperture Radar (SAR) data focusing is presented. Comparison with a multi-threaded CPU implementation, developed by ACS, currently operating in the context of European Space Agency (ESA) and Italian Space Agency (ASI) SAR missions (i.e. ASAR, CosmoskyMed), is shown. A speedup factor of 15x has been registered in the test environment (for the pure algorithmic part, excluding disk I/O operations), without quality degradation of the resulting image.

Motivation
SAR data processing is a computational intensive task. To give an idea, the data used for test is a Cosmo-SkyMed acquisition of 8 seconds, while an efficient CPU implementation of a SAR processor, takes several minutes to complete, even on a multi-processor server configuration.

On the other hand the focusing algorithm is inherently highly parallelizable, requiring the application of a series of filters in the frequency domain, where the output of each input value can be computed independently.

Algorithm description and implementation
Earth Observation SAR data is acquired by transmitting a radar signal and collecting Earth surface echoes from a moving satellite platform during a short time span. To produce the final image the scatters corresponding to the same ground target, along range (cross-track) and azimuth (along-track) direction, must be concentrated on the same point. Such process, known as focusing, is the purpose of the Omega-K algorithm.

The test input data is a range compressed image of 26620x18427 float complex values (respectively in azimuth and range direction), for a total occupation of about 3.7 GB. In order to overcome GPU memory limitation, the algorithm operates by subdividing the grid in a configurable number of azimuth blocks.

Once in device memory each block is processed entirely on GPU. CUDA streams allow concurrency of host/device data transfer and kernels execution for subsequent blocks. Follows a diagram of the processing chain for each block.

Results

1 Time comparison
Follows a time performance comparison of the overall Omega-K stage execution, between the operational parallel CPU implementation and the research GPU implementation, run on the same test machine. The goal of this research is to highlight performance gain in a real operational scenario, thus disk I/O times are included in the comparison.

The overall focusing time, has dropped from 208 seconds (CPU) to 19 seconds (GPU).

2 Quality comparison
The diagram shows a comparison of the focused image range and azimuth resolutions between CPU (blue) and GPU (red) implementations, for two punctual targets. The deviation is below the required threshold.

The first tests on phases preserving have shown that the implementation meets the requirement defined by ASI for this type of SAR acquisitions.

Test Hardware

<table>
<thead>
<tr>
<th>Test Hardware</th>
<th>CPU: 2 x Intel(R) Xeon(R) CPU E5-2660 (2 x 8 cores at 2.20GHz)</th>
<th>RAM: 12 GB</th>
<th>HDD: 4 x Seagate Cheetah 600GB 15K RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPU model:</td>
<td>Nvidia Tesla M2090</td>
<td>Memory: 6GB</td>
<td>Compute Architecture: Fermi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Capability:</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Conclusions
The research has shown the potential of GPU programming to perform near real time SAR data processing.
The next step is to port the entire processor on GPU, including the range compression and doppler estimation stages. Given the compute bound limit shown on the current hardware, would also be interesting to run the processor on a Kepler GPU and compare the results.