PAMIR's On-Board Real-Time SAR Image Processing System

O. Valerio Minero, B. Kästner, A. Ribalta, P. Berens

Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR

omar.valerio@fhr.fraunhofer.de

1. Summary

Presentation of a system for on-board, real-time processing and visualization of SAR data, as acquired by the experimental X-band radar system: PAMIR. PAMIR is an airborne radar developed by Fraunhofer FHR in Wachtberg, Germany [1]. PAMIR support multiple SAR imaging modes used to obtain high-resolution images from the ground. (see Figure 1)
Previously, we were only able to produce high-resolution images, processing the SAR data offline. With the help of GPU's and the CUDA parallel computing language, now we are able to process and visualize high-resolution SAR images on-board while the data is being acquired in real-time.

2. Background

Synthetic Aperture Radar is a technique used to acquire high resolution ground images using a radar antenna mounted in an airborne platform. In order to obtain a good angular resolution a broad antenna aperture is needed. In SAR this large aperture is achieved by integrating radar measurements from the ground obtained as the sensor flies over the imaged area.

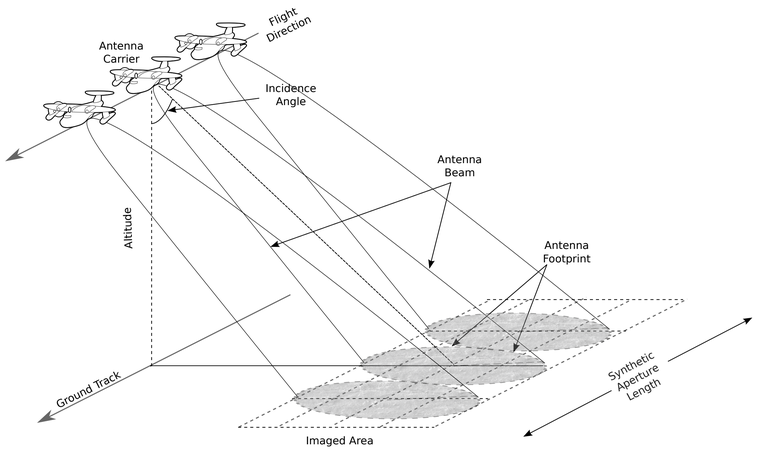

Figure 1: *Illustration of SAR image data acquisition using an airborne sensor.*

SAR images resolution is not affected by such factors as the distance or the prevailing weather conditions. In other words, a SAR system produces the same high resolution images in the presence of fog, clouds, smoke and/or during the night. That makes SAR, an ideal technology for conducting surveillance and recognition missions. However processing the raw data on-board is in general very computationally expensive.
In FHR, we wanted to develop a real-time SAR data processing and visualization system, that we could easily scale to process arbitrarily large amounts of radar data. A very important factor to consider, was our imaging method of choice: the Backprojection. In the past Backprojection was not a very popular method to use because of its computational cost. Backprojection is a particularly good match for the different levels of parallel processing computing offered by CUDA. The reason is that each pixel from the output image can be computed independently for each received radar pulse and several radar pulses can be integrated simultaneously launching concurrent Backprojection kernels.

3. SAR Image Formation

The formation of SAR Images is performed in two steps. The steps are as follows:

3.1 Pulse Compression

Once the raw pulses are acquired by PAMIR, they are simultaneously recorded and forwarded to the Real-Time Processor (RTP). Inside the RTP, the raw pulses are first going to be compressed using the CUDA FFT library. The compression step is used to obtain a high resolution image, since the received pulse has its energy spread after having been reflected. The compressed pulse, is then interpolated and becomes the input for our next step.

3.2 The Backprojection method

The next step is where the image is formed using a time-domain algorithm called Backprojection. Backprojection is a very well known and researched SAR imaging method. It's popularity is due to its resilience to platform motion effects, as well as being a method that lends itself to real-time processing. The main drawback is that it comes with a high computational cost, which is a function of the size of the problem. For an image of N_x by N_y pixels and N_a antenna aperture positions, the number of operations performed by the Backprojection method is given by:

$$\mathcal{O}(N_x \times N_y \times N_a). \tag{1}$$

In SAR images, the X coordinate is used for the azimuth direction (resolution in cross-range or flight direction), and the Y coordinate is associated with the range direction. Using those terms, the expression above can also be written as:

$$\mathcal{O}(N_\theta \times N_r \times N_a). \tag{2}$$

Looking at the expression above, is immediately apparent why GPU ends up being an exceptionally good match for our purpose.

4. Parallel Architecture

PAMIR is able to record SAR data using five different channels. It is therefore important to be able to perform SAR imaging in each of these channels simultaneously. For this purpose, the RTPCORE program has been engineered to execute multiple instances of Backprojection, each one of them fully dedicated to attend the incoming data of one of the five input channels. Using CUDA allows us to exploit the different levels of parallelism existing in our computation. The multiple channel processing is achieved through the use of CUDA Streams, effectively launched using OpenMP. Simultaneously the parallelism inherent in the Backprojection method implementation is achieved using individual CUDA kernels for each pulse (see Figure 2).

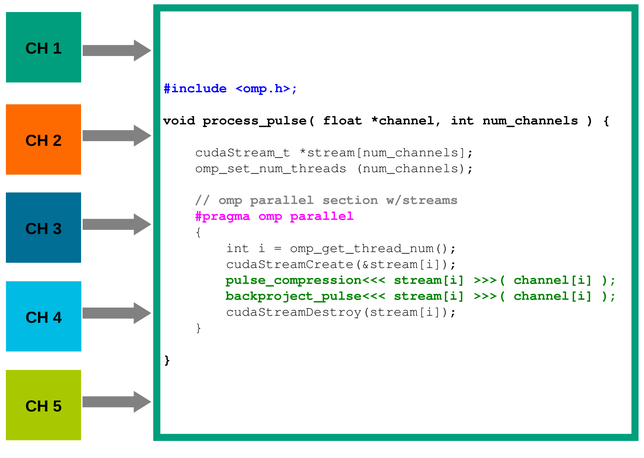

Figure 2: *Multichannel SAR image processing architecture using CUDA Streams.*

5. Experimental Results

PAMIR's real-time processor is already in its second year of existence and have been used in multiple missions with excellent results [2]. Some of the images from our last campaign and the visualization frontend are shown next.

Figure 3: *Equipment used to acquire SAR data during trials.*

Apart from using CUDA to generate high-resolution SAR images, the RTP also makes use of CUDA and CUDA Thrust to compute Pulse Histograms for each of the imaged channels (see Figure 4). Pulse Histograms are a very useful tool to diagnose, wheter the channel attenuation in use is appropriate.

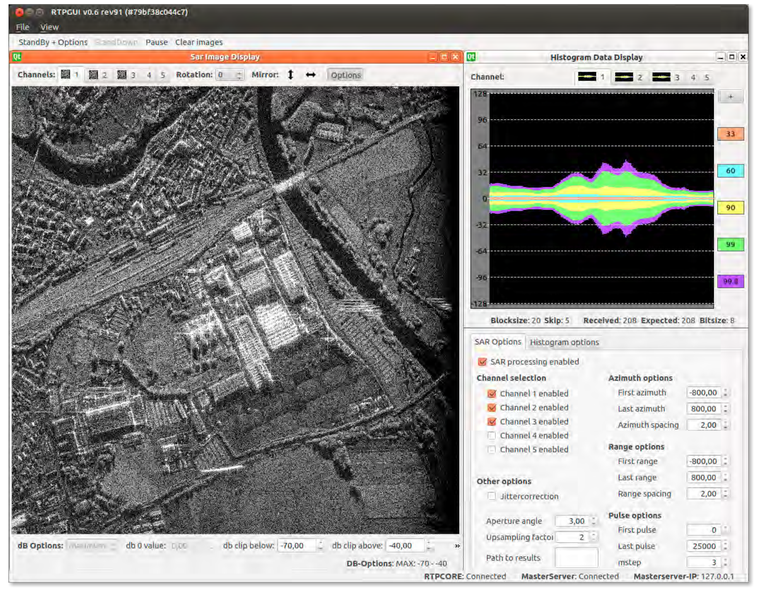

Figure 4: *The RTP GUI displaying a SAR Image and a Pulse Histogram.*

References

[1] J.H.G. Ender and A.R. Brenner. PAMIR – a wideband phased array SAR/MTI system. *IEEE Proceedings - Radar, Sonar and Navigation*, 150:165–172(7), June 2003.

[2] Omar Valerio Minero, Benjamin Kaestner, Angel Ribalta, and Patrick Berens. On-board sar data processing and visualization for pamir. In *EUSAR 2014; 10th European Conference on Synthetic Aperture Radar; Proceedings of*, pages 1–3, June 2014.

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