SAR FOCUSING OF P-BAND ICE SOUNDING DATA USING BACK-PROJECTION

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ABSTRACT

SAR processing can be applied to ice sounder data to improve along-track resolution and clutter suppression. This paper presents a time-domain back-projection technique for SAR focusing of ice sounder data. With this technique, variations in flight track and ice surface slope can be accurately accommodated at the expense of computation time. The back-projection algorithm can be easily parallelized however, and can advantageously be implemented on a graphics processing unit (GPU). Results from using the back-projection algorithm on POLARIS ice sounder data from North Greenland shows that the quality of data is improved by the processing, and the performance of the GPU implementation is addressed.

Index Terms— SAR, radar, ice sounding, back-projection, GPU

1. INTRODUCTION

SAR processing is an established technique for providing improved along-track resolution and clutter suppression for coherent ice sounder systems. Published methods, e.g. [1][2], are usually based on frequency domain methods such as the range-Doppler algorithm, extended to account for the refraction at the air/ice interface. These methods are fast, but inherently apply block processing to speed up the processing. For this to work properly, assumptions must be made on both the flight track and the ice surface slope, both of which are usually modeled as linear within a certain along-track block size. Furthermore, methods such as the range-Doppler algorithm are not well-suited when the synthetic aperture becomes comparable to the target range, a situation that may well arise for airborne systems. A different approach is to use time-domain methods such as matched filtering or back-projection. These methods are computationally very intensive, but allows for more accurate accommodation of sensor motion and surface geometry. Direct back-projection (DBP) is well-known technique for focusing wideband SAR data, and fast implementations (FBP) also exist, with computational performance approaching that of frequency domain algorithms [3]. In the following, an approach for applying DBP to ice sounder data is described and tested on P-band ice sounder data

acquired by ESA's POLARIS ice sounder. To reduce the computation time, the back-projection algorithm can be implemented on a graphics processing unit (GPU).
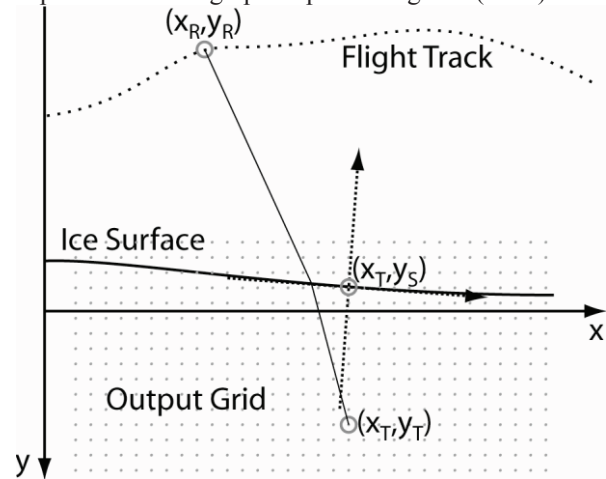

Figure 1 Ice sounder back-projection geometry

2. ICE SOUNDER GEOMETRY

The ice sounder geometry is illustrated in Figure 1. To perform SAR focusing and geocoding, knowledge of the flight track is required. This is usually measured by a combination of a GPS and an Inertial Navigation Unit (INU). Furthermore, the ice surface topography should be known. Depending on the radar operating mode (pulse length and range offset), this may be estimated from the sounding data itself, or by additional sensors, such as laser or radar altimeters. The POLARIS system provides a shallow/deep sounding mode, which alternates between short and long pulses, imaging the surface/top part of the ice, and the bedrock, respectively.

3. BACK-PROJECTION ALGORITHM

The DBP algorithm itself is simple, and can be described by[3]:

$$s_o(x_T, y_T) = \sum_{|x_R - x_T| < L/2} s_i[x_R, \tau_{rt}] \exp{(j2\pi f_c \tau_{rt})}$$

where (x_T, y_T) is the output pixel position, (x_R, y_R) is the sensor postion, $s_o(x_T, y_T)$ is the focused output pixel, $s_i(x, \tau)$ is the (complex baseband) input data matrix, ordered by

along-track position and time delay, L is the synthetic aperture length, f_C is the radar center frequency, and τ_{rt} is the total round-trip delay from sensor to target, through air and ice. Thus for each output pixel, a summation is made over all input lines within the synthetic aperture. The value of the input signal at each sensor position must be interpolated from the sampled data. The round-trip time delay, τ_{rt}, is not straightforward to calculate, as it depends on the refractive properties of the ice. Assuming, however, a constant relative permittivity of the ice, ε_r, and a known flat (possibly tilted) ice surface the round-trip delay can be found by using Snell's law of refraction, resulting in a fourth order equation[2] which for each output pixel position, must be solved for all sensor positions within the aperture. With a limited aperture and a flat horizontal surface, however, a small-angle approximation can be applied, resulting in:

$$\tau_{rt} = \frac{2}{c}\left(r_{air} + \sqrt{\varepsilon_r}r_{ice}\right) \approx$$
$$\frac{2}{c}\left(h\sqrt{1 + \left(\frac{x_R - x_T}{h + d/\sqrt{\varepsilon_r}}\right)^2} + d\sqrt{\varepsilon_r + \left(\frac{x_R - x_T}{h + d/\sqrt{\varepsilon_r}}\right)^2} \right)$$

where c is the speed of light in air, h is the sensor altitude over the ice and d is the depth of the output pixel in the ice. For higher accuracy, an alternative is to tabulate the deviation between the approximation above and the actual fourth order equation solutions for a sufficiently dense grid of normalized $(x_R$-$x_T,d)$ combinations, normalizing by setting h=1. When the ice surface is sloped, one can, for each output along-track position, x_T, fit a line to the ice surface around x_T and calculate the local surface height, y_S, and slope θ_S. Then by doing a coordinate transformation (see also Figure 1):

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\theta_S & \sin\theta_S \\ \sin\theta_S & \cos\theta_S \end{bmatrix} \begin{bmatrix} x - x_T \\ y - y_S \end{bmatrix}$$

one can substitute $h = y_R'$, $d = -y_T'$, $x_R = x_R'$, and $x_T = x_T'$ when calculating τ_{rt}, either by using the approximation above or a table lookup. The advantage of the DBP algorithm over frequency domain algorithms is that the variations in sensor flight track and surface height/slope can readily be accommodated and updated for each along-track position. Furthermore, the output grid can be selected arbitrarily (within the coverage of the data), and one can for example chose an output spacing constant in space rather than in time delay. The disadvantage of DBP is the high number of computations required

4. IMPLEMENTATION

The DBP algorithm described above is straightforward to implement on a PC. Due to the large number of computations involved, it is very time-consuming to focus long tracks, since for every output pixel, L/δ_x interpolations and phase multiplications are required, where L is the aperture length and δ_x the along-track spacing of the input data. In addition to this, τ_{rt} must be calculated the same number of times. For the ice sounder geometry, it is not immediately clear whether the fast FBP approach described in [3] can be used. However, the DBP algorithm lends itself well to implementation on a GPU [4], since it can be parallelized to a large degree. Furthermore, the interpolation step can be implemented by using the GPU texture units. They provide very fast, albeit low-precision, linear interpolation. To provide sufficiently accurate interpolation, the input data can be upsampled using FFT's prior to the interpolation, something which only needs to be done once for every input line.

5. RESULTS

5.1. Focusing
The DBP algorithm was applied to data acquired with the POLARIS ice sounder. POLARIS is a fully polarimetric, airborne P-band ice sounder developed for ESA by DTU Space, and operates at 435 MHz, with a bandwidth up to 85 MHz. The input data to the DBP algorithm were acquired with 30 MHz bandwidth, at the NEEM drilling site in Northern Greenland, in October 2009. The along-track sample spacing (after online presuming) was approximately 1 m, and a 300 m aperture was used for the back-projection. The results are shown in Figure 2, where the same data data processed using only incoherent averaging or coherent averaging are also shown. The focusing can be seen to improve the signal-to-noise ratio, and the bedrock appears more clearly defined than without focusing. **In the final paper, further examples and quantification of the focusing quality will be provided. If possible, the back-projection algorithm will also be compared to a conventional SAR focusing algorithm**.

5.2. Computational Performance
The results shown on Figure 2 were generated using a straightforward implementation of the DBP algorithm in MATLAB on a standard PC, taking 9 minutes to back-project the 60x6000 pixel image on Figure 2(c). However, 70% of that time was spent doing linear interpolations in the input data. The total number of interpolations was $60 \cdot 60000 \cdot 300 = 1.08$ billion. A preliminary implementation of just the interpolation and phase multiplication step of the DBP algorithm has been carried out, and shows that a standard, low-cost, NVidia GTX260 GPU can perform 2 billion linear interpolations and phase multiplications on complex data per second, taking advantage of the very fast texturing units in the GPU. **In the final version of the paper, the performance of the full algorithm implemented on the GPU will be evaluated, and results shown.**
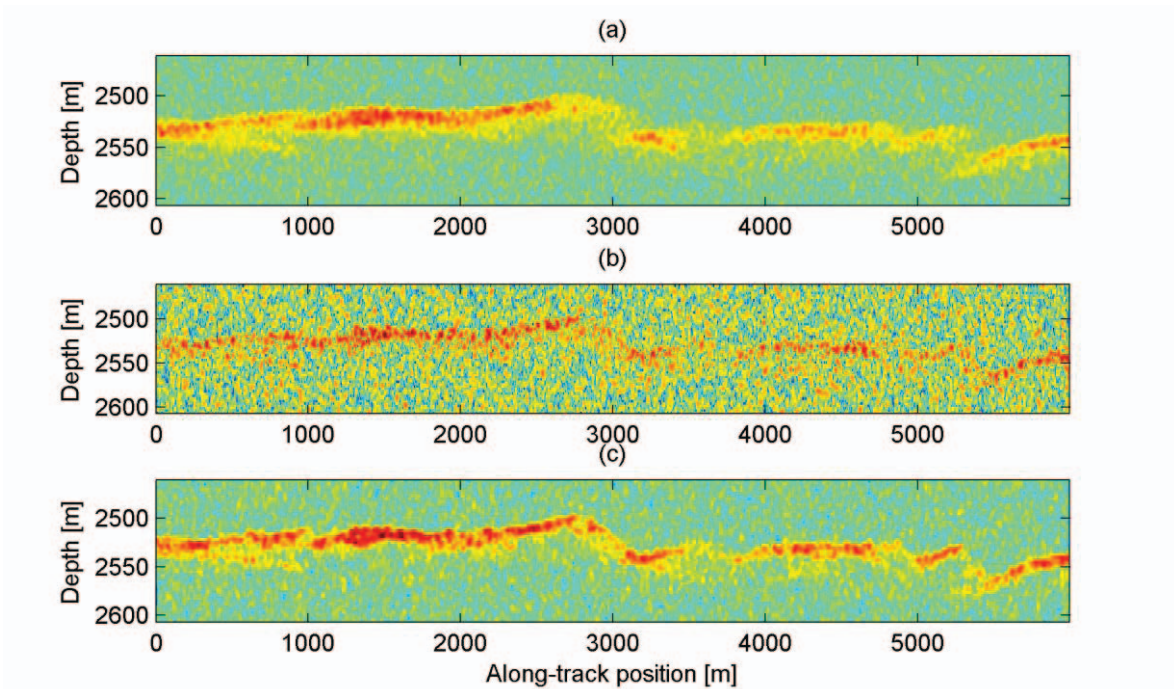
Figure 2 Bedrock at NEEM drilling site from POLARIS sensor, (a) Incoherent averaging (28 samples), (b) Coherent averaging (28 samples), (c) Back-projected, 300 m synthetic aperture, followed by 28 sample incoherent averaging

6. CONCLUSION

The DBP algorithm is an interesting method for SAR focusing of airborne ice sounding data, since it allows an accurate accommodation of surface slopes and sensor flight track variations. Preliminary results indicate that the algorithm does improve the along-track resolution and reduces clutter. Also, preliminary results indicate that the computational performance can be significantly improved by a parallel implementation of the algorithm on a GPU.

7. REFERENCES

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