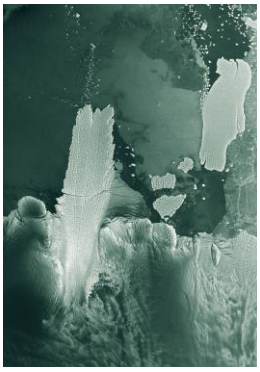
New On-board Data Processing Techniques Help Satellites Provide Better Arctic Ocean Monitoring

For some time, scientific articles and news reports have been highlighting the changes in the extent of Arctic sea-ice. The commercial exploitation of the region is also growing, with rapid increases in oil & gas exploration, fishing, and new shipping routes underway. This raises major challenges in monitoring and protecting this pristine area, while enabling sustainable exploitation to take place. In addition to monitoring sea ice, it will also be essential to monitor shipping (to observe both fishing and traffic), detect natural and man-made oil slicks, identify icebergs, and support navigation in the sea ice.

To achieve this over such massive areas, scientists use a type of radar instrumentation flown on satellites known as Synthetic Aperture Radar, or SAR. This uses complex data processing to obtain detailed images of sea ice and the sea surface. The fine resolution of SAR yields exciting views of the two-dimensional ocean surface, its interactions with the atmosphere, long waves, and currents. It can even measure sea ice thickness and detect small leads, enabling ships to be routed through ice-covered regions.



Oil Slick Imaged by SAR *Icebergs Imaged by SAR*
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However, the complex data processing of SAR images is currently carried out on the ground, creating delays in obtaining the images. And bandwidth limitations in data transmission to earth adds a further delay. These and other applications such as offshore engineering and surveillance for disaster monitoring would benefit from the generation of SAR products in real time.

To solve this problem, Astrium Ltd and BAE Systems Advanced Technology Centre have been working together on a CEOI funded initiative to investigate the feasibility of generating real-time SAR images on-board the spacecraft.

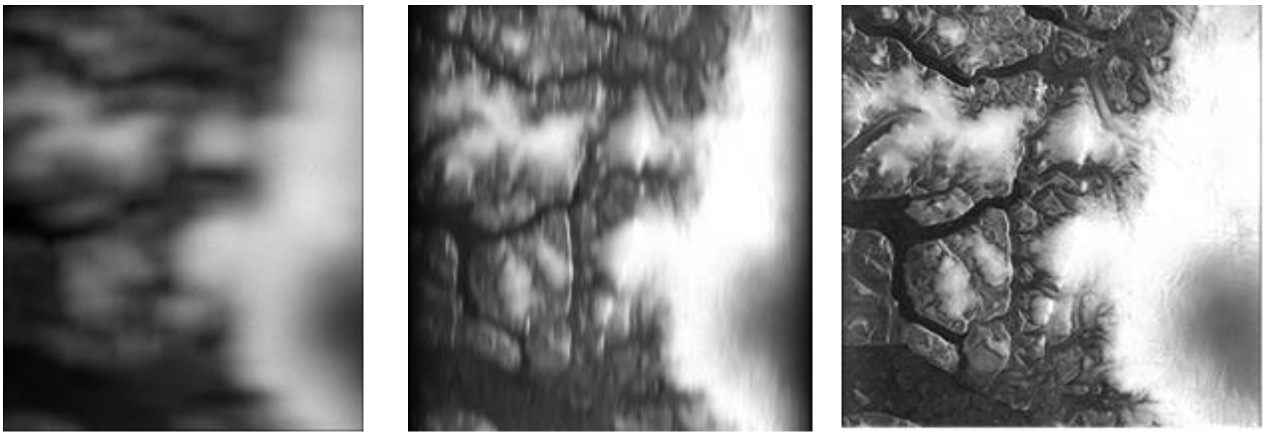
The space-borne SAR sensor captures the raw radar echo data (Level 0). The data is then passed through a suitable focussing algorithm to generate the radar images (Level 1). The image data is subsequently made available to the wider user community for higher level processing to generate maps of geophysical features of interest, for example digital elevation maps and ice flow maps.

In all space-borne SAR systems to date the role of the space segment is restricted to capturing the Level 0 data, which is stored in the spacecraft's mass memory and periodically transmitted to the ground segment for further processing.

By processing the data on-board, the Level 1 product, consisting of detected images and complex, phase preserving products suitable for subsequent interferometric processing, can be downloaded for immediate use. Further, by smoothing the Level 1 product on board, (which involves trading spatial resolution for improved image signal to noise), the volume of image data to be transmitted is reduced considerably compared to the raw echo data. This removes a significant constraint in current systems which are limited by the bandwidth of the downlink transmission system.

The image focussing step in SAR applications is very computationally intensive. In Ground Segment systems the focussing algorithms are implemented in software running on powerful general purpose computers. However, recent technology advances, particularly in field programmable gate arrays (FPGA) means that it is now feasible to implement SAR image focussing in a space-borne processor.

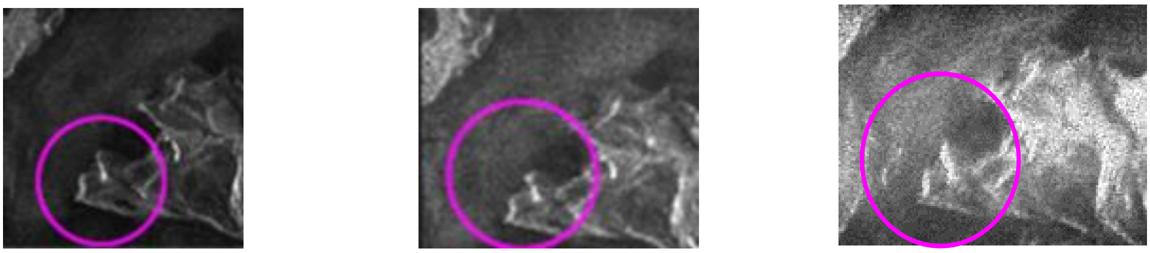
In the CEOI work, Astrium Ltd has addressed the problem of mapping SAR focussing algorithms into forms suitable for implementation in space qualified FPGA hardware, and BAE Systems has provided expertise in SAR imagery and quality assessment of test images produced in simulations of the space based processing.



Example output from the SAR processor at different stages in processing of an area of Greenland. Left to right: raw data magnitude, range compressed data, and the final processed image.

Two hardware-based image focussing algorithms have been studied and their performance simulated using ERS-2 echo datasets. The first is a novel approach to realising the range and azimuth focussing steps in the standard range-Doppler algorithm which avoids the use of large Fast Fourier Transforms (FFTs) and which is well suited to implementation on a relatively small FPGA. This technique would be ideally suited to a 'quick look' imaging system which would give very accurate imagery in systems with relatively narrow beam-width and relatively low spatial resolution.

The second approach which has been evaluated is the standard technique of 2D matched filtering, implemented by correlation of the SAR signature at each image pixel with the measured SAR data. By operating in a hybrid spatial wavenumber domain part of this processing can be speeded up using FFTs. This approach is completely general and does not suffer from the focussing limitations inherent in approximate methods, however it is considerably more expensive in terms of processing (multiplications and additions). Nevertheless, the computational requirements are within the capacity of the latest generation of space qualified FPGAs and ASICs.



Example of the distortion caused by squinting. Left: a headland is imaged in the correct position by processing at the European Space Agency (slower than real time). Middle: the position is incorrect when the correction for squinting is omitted in the image processing. Right: the position is correct in the Astrium Ltd real-time processor (simulation).

To illustrate, the space qualified version of the Xilinx Virtex 5 FPGA (XQR5VFX130) has 320 multipliers which can be clocked at 200 MHz, so in principle a single such device could perform 6 x 10^{10} multiplications per second. Power consumption is another very important consideration for a space processor. To give an example of what modern technology can offer, Astrium Ltd has recently delivered the payload processor for the Alphasat telecommunications satellite. Central to this processor is a digital signal processing ASIC implemented in 180 nm technology, which has a measured energy consumption of 0.1 nanojoules per (fixed point) multiplication. So performing 10^{10} multiplications per second in such a device would only consume 1 Watt of power.

Another feature of this latest FPGA technology is that the devices can be reprogrammed in flight, in much the same way as software running on a general purpose CPU can be reprogrammed. This opens up the possibility of hardware reconfiguration throughout the mission, even regularly on every orbit in order to change the imaging mode (for example, switching resolutions when imaging over land and imaging over ocean).

It should be noted that this work on SAR on-board processing is only one example of a general trend towards greater on-board processing of raw data acquired by instrument sensors. This is in response to the increasing resolution of modern sensors, at all wavebands, which means that in many cases it is simply impractical to store and forward the raw data to the ground.

The Centre for Earth Observation Instrumentation (CEOI) is funding a wide range of innovative new instruments that measure our weather, our atmosphere, the icecaps, and many other aspects of the natural environment. Many, like the ‘New On-board Data Processing Techniques for SAR’ are finding fascinating new applications in everyday life.

Further information about this technology and others funded by the CEOI can be found at www.ceoi.ac.uk.
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