Multichannel imaging with the AMBER FMCW SAR

Matern Otten, TNO, matern.otten@tno.nl, The Netherlands
Wim van Rossum, TNO, wim.vanrossum@tno.nl, The Netherlands
Marcel van der Graaf, TNO, marcel.vandergraaf@tno.nl, The Netherlands
Wouter Vlothuizen, TNO, wouter.vlothuizen@tno.nl, The Netherlands
Reinier Tan, TNO, reinier.tan@tno.nl, The Netherlands

Abstract

An X-band Digital Array Synthetic Aperture Radar for a Short Range Tactical UAV is presented. The Frequency Modulated Continuous Wave radar principle in combination with digital beam forming over 24 receive channels is used to achieve low power and advanced imaging SAR capabilities on small platform. Novel SAR imaging modes are discussed, and some examples are given. Real-time processing for such a system becomes a challenging task, and a practical example of an approach using GPU processing is presented in this paper.

1 Introduction

The use of Unmanned Aerial Vehicles (UAVs) in military operations is growing rapidly. The traditionally large and heavy radar systems will be replaced by small, low power FMCW SAR systems. The imaging capabilities of smaller systems are limited in terms in range, but new capabilities arise through the use of Digital Beam Forming. The AMBER system was designed as a Digital Beam Forming FMCW SAR, for Short Range Tactical UAV. AMBER features a 24-channel receive array, and a switchable transmit antenna. The power consumption including data acquisition is about 60 W, and the system weighs 6 kg. The same technology is also very suitable for other compact airborne radar applications [3].

2 The AMBER System

TNO has developed an Affordable Multi Beam Radar (AMBER) [1][2] to meet payload requirements of a SRT-UAV. AMBER is an X-band Synthetic Aperture Radar based on the Frequency Modulated Continuous Wave (FMCW) principle and uses Digital Beam Forming (DBF). 48 Patch antennas connected to 24 receive channels and Analogue to Digital Converters form the receiver array of the AMBER system. The transmitter is an 8 element patch antenna that can be reconfigured to illuminate a wider area nearby or a narrower area at longer distance. The widest transmit beam allows maximum beam forming flexibility on receive, while the narrower beam provides higher antenna gain to allow imaging at longer range. The unique features of this SAR system are enabled by Digital Beam Forming, as explained in the following sections.

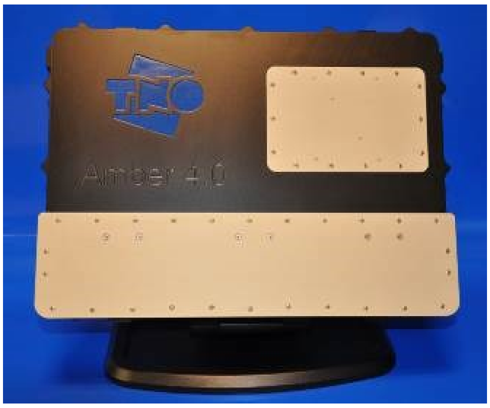

Figure 1: Photograph of the Affordable Multi-beam Radar (AMBER) System front side. The 8 element reconfigurable transmit antenna is in the upper right corner. The 24 element receiver patch array is at the bottom.

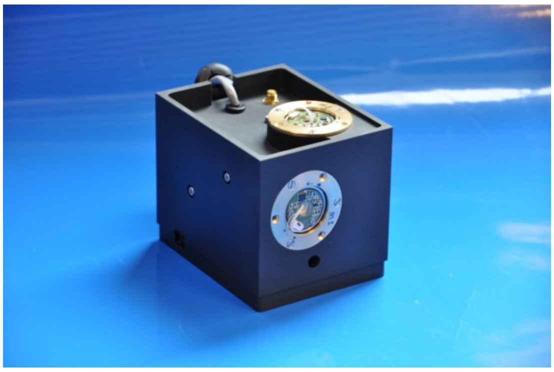

Figure 2: Photograph of the DriftLess™ Inertial Measurement Unit.

The motion compensation for AMBER is facilitated by another new development, called DriftLess™. In this new GPS-IMU, the inherent and significant offsets on the output of the commercial grade inertial sensors used are reduced by a factor of about 100. This is achieved by a patented and innovative algorithm that makes use of periodical mechanical rotation with servo motors of a double set of MEMS inertial sensors [4].

3 Multi-beam SAR imaging modes

It is well known that the traditional single-channel SAR limit which presents a trade-off between resolution and swath width can be surpassed by employing multiple receive channels. As a practical outcome of this fundamental improvement, new ways of deploying the SAR sensor in operational scenarios are possible. A few of these new possibilities are mentioned here. *Simultaneous STRIP and SPOT mode:* while in a conventional SAR, a choice has to be made between high resolution in a small fixed area, low resolution on a continuous strip, or a compromise (sliding SPOT), the wide beam and multiple receive channels allow a long integration time without physical beam steering. Thus typical SPOT-resolution is possible in a continuous strip mapping mode. In practice, to limit the amount of real-time processing on a small platform, one can think of low resolution strip map processing combined with simultaneous SPOT processing on selected regions of interest.

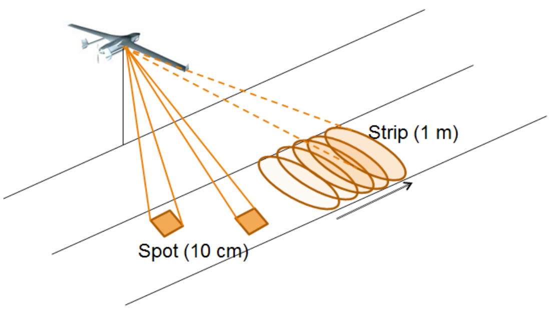

Figure 3: Simultaneous STRIP-SPOT modes.

Simultaneous SAR-GMTI: whereas GMTI is typically scanning (wide area, short integration) and SAR is non-scanning (long integration), these two modes of operation can now be performed simultaneously. Multiple channels can be processed to produce several virtual GMTI scans, and detect, locate, and track moving targets, while processing with a longer integration time produces the SAR background image. In this way SAR maps with instantaneous moving target overlays can be produced. Alternatively, independent Strip SAR and GMTI modes can be employed simultaneously in a time-sharing fashion, where only a small portion of time is used for SAR (see ‘covert SAR’), and a larger portion for GMTI. Both modes can operate with optimum performance, without the drawbacks of interleaved SAR-GMTI modes in a conventional system.

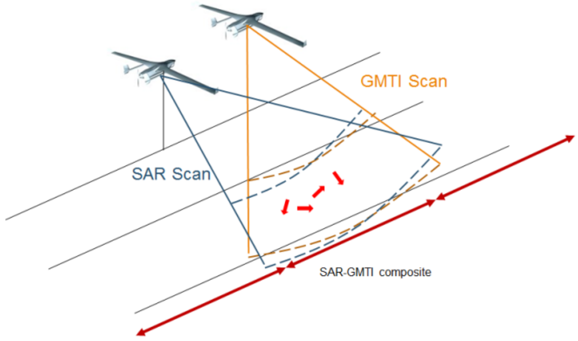

Figure 4: Simultaneous STRIP-SAR and GMTI by time division, with continuous coverage.

Covert SAR: on a slow flying small UAV, the time to cover a large area by strip mapping SAR is relatively long, compared to fast platforms. Exploiting the wide-beam illumination and DBF, an area can be imaged that is much larger than the distance covered during coherent integration time. This means that a larger area can be covered much faster, but also that a strip mode can be performed with the radar switched off for large parts of the time. The integration time T_i can be approximated by:

$$T_i = \frac{R \cdot \lambda}{2 \cdot \rho \cdot V} \qquad (1)$$

where R is range, λ wavelength, ρ resolution, and V is velocity. The time T_a to strip-map an area of length L_a, is approximated by:

$$T_a = \frac{L_a}{V} \qquad (2)$$

If the illumination beam width is Θ_B, the area that can be imaged at once is roughly:

$$L_a = R \cdot \theta_B \qquad (3)$$

From this we learn that the ratio between the conventional imaging time and the multi-beam imaging time is:

$$\frac{T_a}{T_i} = \frac{2 \cdot \rho \cdot \theta_B}{\lambda} \qquad (4)$$

Taking the example of a 30° transmit beam for AMBER, and 30 cm resolution at X-band, we find a ratio of 10. This implies the radar could be switched off 90% of the time in a continuous mapping mode at this resolution. In fact the AMBER transmitter can transmit even much wider (80°), at the expense of range performance. Apart from the Low Probability of Intercept advantage, this ‘spare’ time could also be used for other radar modes, or for passive modes, like emitter detection.

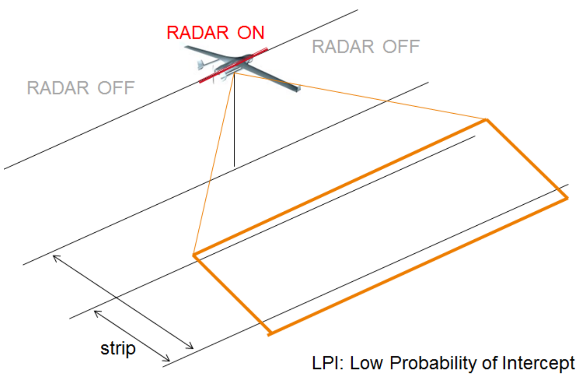

Figure 5: Example of a covert or LPI SAR mode.

Other new multi-beam possibilities are shadow reduction by multi-aspect strip map imaging in urban areas, repeat pass coherent change detection with optimized digital yaw steering, and simultaneous Strip SAR and ISAR on selected targets. By exploiting the advances in digital processing power in the coming years, forms of streaming, video-like SAR will become possible, by combining 'static' SAR imagery at high update rates, with simultaneous GMTI information or ISAR imagery.

4 New SAR modes with AMBER

AMBER was first demonstrated on a helicopter in April 2012 near the city of Naarden in The Netherlands. A second and third campaign were conducted in Marnehuizen, in October 2012, and May 2013, flying on the Stemme S15 aircraft (**Figure 6**). In **Figure 7** an example is shown of a high resolution image of Marnehuizen. The resolution is higher than what is achievable in a regular strip mode, while the size is much more than what can be covered in a regular SPOT mode. In a real time implementation on a small platform, it may be decided to process the larger image at medium resolution, and selected parts at high resolution. To the operator, this then represents a simultaneous STRIP and SPOT mode.

Figure 6: AMBER installed in a pod for flights on a motor glider. On the front, two GPS antennas are mounted.

Figure 7: Example of a STRIP-SPOT mode: a 70 Mpixel image at high resolution. The box demarcates the approximate size of a conventional single-beam SPOT image at this resolution.

The image of Naarden is an example of a wide-beam SAR mode that could be used as a 'covert' SAR mode. As can be seen from the image, the time to acquire the data is much shorter than the time to pass the imaged area. The data acquisition took 2.5 seconds, while imaging in conventional strip map mode would have taken around 30 seconds.

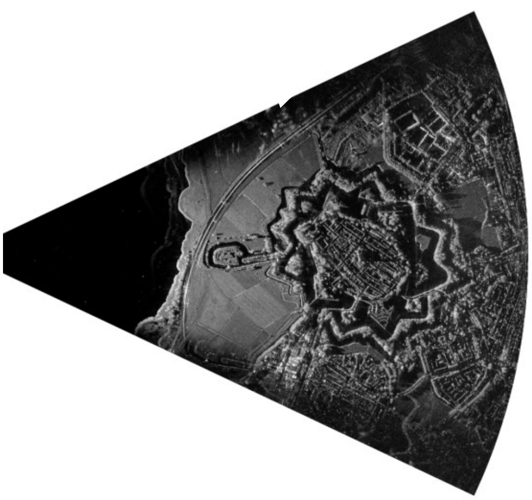

Figure 8: Wide beam SAR image of the Naarden fortress.

Figure 9 shows an example of simultaneous SAR-GMTI mode, acquired over Marnehuizen. The GMTI data is processed by forming a virtual beam scan over the area, and localizing the detected target in azimuth by phase comparison between receive channel subgroups.

The same dataset is processed with longer integration time to produce the background SAR image, so these SAR and GMTI modes are truly simultaneous.

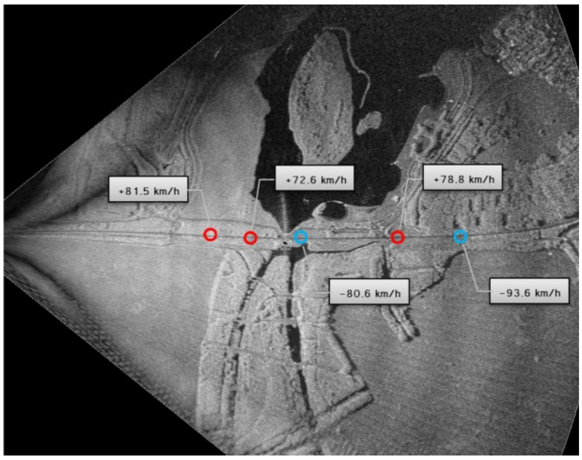

Figure 9: Wide area simultaneous SAR-GMTI image with moving targets projected at their actual positions on the road.

5 Real Time Processing

Taking into account the large flexibility in imaging modes, a Back Projection processing method is chosen [5][6], as it is not burdened by approximations and limitations of most frequency domain approaches. Based on the predicted processing load and tests performed with Back Projection we propose a flexible processing architecture based on FPGA, CPU and GPU elements. The CPU and GPU are located in a small processing cabinet which connects to the FPGA that control the AMBER radar via a 10 Gbps optical link.

Operation	Gflops/s	Remarks
Decimation-I/Q	2	24 channels
Beam Forming	0.1	
Range FFT	0.3	Per SPOT
Back Projection	75	area

Table 1: The estimated processing load for a Spot SAR mode, 500 m x 500 m, at 10 cm resolution, using Back Projection.

The processing steps are mapped to these resources. Decimation/IQ demodulation is mapped to the FPGA, because of its regular structure which suits the FPGA programming model, and because of the data reduction. Beam forming in its simplest form is also suitable for FPGA implementation, and leads to significant data reduction unless many beams are formed. If many (or wider) beams are required, beam forming is done on the GPU as part of the multi-dimensional Back Projection. Back Projection requires significant processing power and is well suited to implementation on a GPU because it can be parallelized due to its regular structure. Our first, not yet fully optimized results on a GTX680M GPU that is representative for current flight capable hardware shows an over 400 fold increase in processing speed with respect to the Matlab implementation, with results indistinguishable from **Figure 7**. With reasonable limits to the area to be imaged, real time performance is definitely within scope of currently available hardware. All other processing steps are performed on the CPU. The CPU also performs the coordination of the data flows between the various resources.

6 Conclusion

The Digital Beam Forming SAR system AMBER has been validated in flight, showing that advanced SAR en GMTI functionality using DBF is feasible within a very compact design. Advantages of the digital array are numerous, making it possible to perform novel SAR an GMTI modes, such as simultaneous STRIP and SPOT SAR imaging, covert Wide Beam SAR, Wide Beam non-scanning GMTI, and simultaneous SAR-GMTI. A real time processor is in development, and first processing results are presented. Advances in digital processing technology and DBF will open up a vast spectrum of new SAR imaging modes and operations.

7 Acknowledgment

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