Preliminary design of a SAR-GMTI processing system for RADARSAT-2 MODEX data

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Abstract—**The RADARSAT-2 satellite includes an experimental mode, called the Moving Object Detection Experiment (MODEX), which is to be used to perform ground moving target indication (GMTI) using a C-band Synthetic Aperture Radar (SAR). During MODEX operation, the SAR antenna is partitioned into two sub-apertures along the satellite track to sequentially observe the same scene from the same spatial point. By appropriate processing of the returned signals from each channel, detection of temporal changes in the scene (i.e. moving targets) can be accomplished. The MODEX configuration will be used by the Canadian Department of National Defence RADARSAT-2 GMTI Demonstration Project, which aims to develop a SAR-GMTI processing system to investigate the military and commercial utility of space-based moving target measurements. This paper discusses a conceptual SAR-GMTI processor design in terms of selected algorithms and their performance, such as Along Tack Interferometry (ATI), Displaced Phase Center Antenna (DPCA) and iterative Moving Target (Terrain) Matched Filtering (MTMF). Processing issues arising in Space Based Radar (SBR) GMTI are also discussed. It is anticipated that the ultimate processor design will incorporate these algorithms as independent processing configurations, along with selection rules that will optimize their use to the contents of the imaged scene.**

I. OVERVIEW

The RADARSAT-2 GMTI project aims to demonstrate the utility of space-based SAR moving target measurements. In addition to the development and testing of moving target detection and parameter estimation algorithms, this involves defining a space-based SAR-GMTI processor architecture. While it is too early to define the final processor architecture to be used, enough work is presently in progress to define a conceptual processor model in terms of the basic SAR-GMTI algorithms, their capabilities and limitations, and the data correction/formatting that must be performed in order to use them. The following addresses the most important of these issues.

II. MAIN PROCESSING ALGORITHM DESCRIPTIONS

This section discusses the main image-based SAR-GMTI target detection and parameter estimation algorithms. These are invoked after the SAR data from the two channels have been appropriately pre-processed. This issue is dealt with in the next section. Non-imaging techniques, where analysis is done on the 'raw' data prior to stationary world SAR processing, is also briefly discussed at the end of the section.

A. SAR-ATI

SAR Along-Track Interferometry (ATI) exploits the correlation of the two registered, balanced channels by computing an interferogram of the two. This is done by generating SAR images of each channel and then computing the product of the first with the complex conjugate of the second. The interferometric phase is the argument of this complex product. In a noise free world, the stationary elements of the scene are completely correlated and have zero phase difference, allowing for extraction of moving target signals. In practice, the stationary elements will not be completely correlated, due to phase noise in the radar.

When the ideal (noise free) ATI signal is viewed in the complex plane, the stationary scene elements are distributed along the positive, real axis and moving targets along constant non-zero phase radials, whose value is proportional to the target radial velocity. For real data, stationary elements contain contributions from the radar phase noise that distribute the stationary samples over a range of phases centered around zero. Separation of movers from stationary elements requires a Constant False Alarm Rate (CFAR) algorithm based on the ATI marginal phase probability density function. Analyses by Gierull [5,7] and Sikaneta and Gierull [13] show that a robust, scene-content independent PDF exists for land data and that it can be generated using parameter estimates from the SAR data itself. Chiu [2] has also developed a dynamic, adaptive ATI moving target extraction routine.

A CFAR detection threshold function can therefore be defined and all points in the complex plane falling outside the stationary world envelope can be identified as candidate movers. Targets moving at constant velocity are clustered about a constant phase radial. An estimate of the target radial velocity can be obtained directly from the interferometric phase, as the two are proportional. However, in the case of non-negligible clutter contribution to the target signal, the velocity estimate is more challenging [1,3,6].

B. SAR-DPCA

The Displaced Phase Center Antenna (DPCA) technique uses the complex SAR data of the two balanced, registered channels, where the second channel views the same scene as the first, but one pulse repetition interval (PRI) later. As such, taking the difference between the processed images leads to theoretically perfect cancellation of clutter from stationary scene elements. Since SAR processing is a linear operation, this is equivalent to doing the subtraction on the raw data and SAR processing this difference data. In practice, stationary signals are suppressed to the radar noise floor. Since the DPCA magnitude is proportional to the sine of the normalized target radial velocity, slow moving targets can be strongly suppressed, rendering them undetectable and leaving only moving targets of sufficient radial velocity available for detection.

When the DPCA signal is plotted in the complex plane, stationary scene elements (and noise) map to a circular cluster symmetrically distributed about the origin. Near the origin, the signal is dominated by noise, while moving targets appear as outlying points. Since outliers often arise from phase-noise modulated scene components, they contribute strongly to the GMTI false alarm rate for slow moving targets. Work is presently in progress to adaptively minimize false alarms by locally estimating clutter rejection threshold parameters from measurements of the SAR scene [9].

Aside from detection, both the DPCA and ATI techniques can also provide estimates of target position and radial velocity. The technique to use in any particular case will depend on several factors. DPCA, with its theoretically perfect clutter cancellation, would appear to have an advantage over ATI. On the other hand, unpublished studies conducted by the DRDC-Ottawa R2-GMTI group have shown DPCA to be significantly more sensitive to channel imbalances than ATI techniques. Simulations by Chiu [4] have shown that moving target detection performance for ATI and DPCA are essentially identical for strong, fast moving targets, but that for slow, weak ones, ATI may perform marginally better.

C. Iterative Moving Terrain Matched Filtering (MTMF)

The first step in using imaging techniques such as described above is to process the scene with a stationary world matched filter (SWMF). When the motion assumptions that define a matched filter (e.g. stationary world) and the velocity of a scene element (e.g. moving target) are mismatched, the corresponding signal of the scene element is mis-focussed (along track velocity mismatch) and/or displaced in azimuth (radial velocity mismatch) in the SAR image. A severe mismatch results in inability to detect the scene element in the processed image. The matched filter required to focus a moving target is simply the time-reversed phase history of each point comprising the target. Hence, if target velocity offsets are accounted for in the SAR phase history of the target, a moving terrain matched filter can be constructed. An iterative process using a MTMF and starting from the stationary world assumption has been shown to be effective in detection and measurement of moving targets [12]. Use of an iterative MTMF with SAR-ATI can be adapted to automatically extract moving targets from most terrain types, although a target velocity estimate (obtained, for example using non-imaging techniques as described below) may sometimes be needed to act as a search seed in the automatic algorithm [11].

D. Non imaging techniques for two aperture SAR-GMTI

Although the DPCA and ATI algorithms were discussed in SAR-imaging terms, both techniques can also be applied to raw (usually range compressed) data without the need to produce a SAR image. One promising non-imaging approach is based on a short time spectral analysis [3,10]. An interferogram is formed from raw range-compressed, data and segmented into short time azimuth segments. Amplitude and phase spectra are computed for each segment. A CFAR algorithm applied to this spectral sequence allows moving targets to be detected automatically and their positions and radial velocities to be estimated.

III. MAIN FEATURES OF A SAR-GMTI PROCESSOR

This section discusses a preliminary design for a RADARSAT-2 SAR-GMTI processor in a conceptual fashion, giving an overview of the main anticipated processing branches as well as the correction and formatting of the data for use by these branches. Architecturally, the processor will be defined as a series of independent processor configurations (PC's) that are executed without intervention of an operator. These PC's are invoked from a man-machine interface (MMI – the main function). All PC's import and export required data from/to and data pool, through the MMI. The pool contains all relevant data that are commonly accessible by all PC's. This 'parallel' design reduces the amount of branch points, as in a 'tree' structure based design, which can be error prone and hard to maintain, particularly when new branches must be added. The conceptual processor design incorporates the operations listed below [11]. At this point, it should be stressed again that these operations would be performed by independent PC's invoked through the MMI. As such, the following is a list (not necessarily complete) of tasks needing to be performed and is not meant to imply either a specific architecture or any direction of data flow.

- A front-end downlink data decryption, unpacking and reformatting module creates the raw fore and aft channel inputs to the processor data pool.
- The raw signal files from each channel are range-compressed.
- The range-compressed data are processed by a digital channel-balancing module to remove systematic amplitude and phase errors. Both ATI and DPCA work well only if imperfections and imbalances between the channels, which shift and distort the

interferometric phase PDF, are removed and the data from both channels are time-registered. A detailed analysis of digital channel balancing and registration is found in [8].

- The digitally balanced data is corrected to compensate for earth rotation.
- There needs to be a file partitioning/data cropper module that can select and extract a sub scene for further processing. A range migration correction function should be invoked at this module's output. It would correct both for constant range-arc effects and also have inputs to allow for the compensation of motion induced range walk for targets under investigation. These data can then be used by two PC 'groups': one for non-imaging operations and a second for SAR (azimuth) processing operations.
- In the (non-imaging) short-time/frequency analysis group of PC's, candidate moving target position and velocity estimates are computed as per section II.D. The position estimates can then be used by the data cropper module to define sub scenes of interest. Velocity estimates can be used by a matched filter generation PC to be used in later SAR processing. Direct output of moving target parameters can be done with the use of an appropriate PC.
- In the (azimuth) SAR processing 'group' of PC's, fore and aft channel data are focused in azimuth. On the initial pass, the entire scene is processed with a SWMF. Subsequent iterative processing of sub scenes is possible using different matched filters (obtained from the aforementioned matched filter generator). The outputs are two single look complex files (SLC, one for each channel), which are radiometrically calibrated at this stage. They are then optionally rescaled in resolution (decimated) to form inputs to the ATI and DPCA PC's.
- In both the ATI and DPCA PC's (described in detail in the previous section), an adaptive CFAR detection function extracts moving targets. Location and velocity estimates are assembled.
- These data can be used as inputs to a target comparator module to identify parameter sets for iterative processing. Position data define scene-partitioning blocks; velocity data define matched filters and corrections for range migration due to motion. The non-imaging time-frequency PC group can provide directional ambiguity resolution information.
- SAR processing with a MTMF is iterated using the best parameter estimates to produce refined estimates of target coordinates and velocity, along with associated target strength and size data. Optionally, a target plane superimposed on a stationary world SAR image can be produced.
- These outputs can be used by a post-processing, formatting PC, which packs the data to standard NATO formats, or any other formats defined in the module.

Note that this conceptual design is very preliminary and will be refined according to ongoing research by the DRDC-Ottawa R2-GMTI group.

IV. CONCLUSION

This paper has dealt with a description of the main algorithms and processing issues involved in developing a SAR-GMTI processor for RADARSAT-2. A conceptual processor model has been proposed. While the processor concept is preliminary and will be refined according to ongoing research by the DRDC-Ottawa R2-GMTI team, the major issues involved in the design of a SAR-GMTI processor have been presented.

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