INTEGRATING SPACE-TIME PROCESSING INTO TIME-DOMAIN BACKPROJECTION PROCESS TO DETECT AND IMAGE MOVING OBJECTS

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1. INTRODUCTION

The ability to detect and image moving targets, even surrounded by strong clutter on the ground, makes Synthetic Aperture Radar (SAR) more and more important for Ground Moving Target Indication (GMTI). Moving target detection is most commonly performed by GMTI radars based on antenna array solutions without imaging capability while SAR systems do not facilitate detecting the presence of moving targets in an imaged scene. Moving targets are usually displaced and defocused in a SAR image. Distinguishing them from strong ground clutter requires much effort.

Moving target detection by focusing technique appears in some recent publications. The principle of the technique is to focus moving targets with correct Normalized Relative Speed (NRS) while defocus ground clutter, i.e. suppress ground clutter. The technique is suitable to Ultra-wideband (UWB) SAR systems and can be combined with space-time processing techniques, such as Displaced Phase Center Antenna (DPCA) [1], i.e. non-adaptive, and Space Time Adaptive Processing (STAP) [2], for reliable moving target detection and imaging. An example of this combination in dual-channel UWB SAR is presented in [3] where DPCA is considered as a data pre-processing technique. According to this approach, dual-channel SAR data is first processed by DPCA to suppress ground clutter. The detection by focusing technique is then applied to the data with clutter supression.

The goal of this paper is to present the possibility to integrate different space-time taxonomies into the time-domain local backprojection process to detect and image moving targets simultaneously. In this paper, two space-time processing taxonomies, which are considered, are DPCA and STAP. The integration is expected to lighten the strict requirements as well as improve the pratice of these taxonomies. The proposed approach is evaluated by simulations based on the LORA parameters [4].

2. SPACE-TIME PROCESSING

The ability to detect moving targets in an observed SAR scene is dependent strongly on the ability to suppress of ground clutter and noise. The ground clutter is interpreted as the radar backscattering in the observed SAR scene while the noise originates from thermal noise of the SAR system.

The simplest space-time processing technique is known as DPCA [1]. Basically, the technique is based on a side looking array with two antennas aligned along the flight track and spaced by a Pulse Repetition Interval (RPI). Two successive pulses transmitted and received in turn by the forward and backward antennas. The motion of the aircraft after one PRI places the backward antenna to the previous position of the forward antenna. This means that two successive pulses are transmitted and received at the same position in space and separated by one PRI in time. Simple ground clutter suppression is obtained by subtracting the second echo received by the backward antenna from the first echo received by the forward antenna. However, DPCA has very high demands on, for example the straight flight track, constant platform speed and identical channels. From the detection's point of view, DPCA is quite sensitive to the speed of the moving targets. The subtraction in DPCA can suppress the ground clutter but can also raise the noise level significantly.

STAP refers to an efficient space-time processing technique providing improved detection of moving targets obscured by ground clutter and noise. Let's have a look again at the theory of adaptive radar developed in [2]. According to Theorem 1, the optimum weights, which maximize Signal-to-Noise-Ratio (SNR), are given by

$$\mathbf{w} = \kappa \mathbf{R}^{-1} \mathbf{s}^* \tag{1}$$

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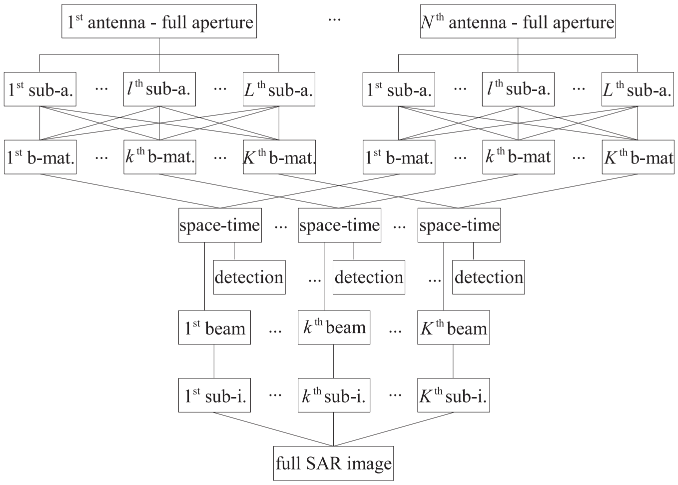

Fig. 1. Moving target detection and imaging scheme. In the scheme, the terms sub-a., b-mat. and sub-i. denote subaperture, beam-matrix and subimage, respectively.

where the asterisk denotes complex conjugation operation, κ is a nonzero complex number and $\mathbf{R}$ is the noise covariance matrix. The echo from a moving target at a given range delay is denoted by $\mathbf{s}$ and defined by a column vector

$$\mathbf{s} = \left[s_1 \cdots s_m \cdots s_{NM}\right]^{\mathrm{T}} \tag{2}$$

where N is the number of antennas and M is the number of samples yielded by each antennas. The subscript T denotes transpose operator. In the case of detection of moving targets obscured by ground clutter and noise, NM coefficients of the optimum filter, which maximize Signal-to-Clutter-Noise-Ratio (SCNR), is also found from (1). However, $\mathbf{R}$ is now interpreted as the clutter-plus-noise covariance matrix

$$\mathbf{R} = E\left\{(\mathbf{c}+\mathbf{n})(\mathbf{c}+\mathbf{n})^{\mathrm{H}}\right\} \tag{3}$$

where $\mathbf{c}$ and $\mathbf{n}$ denote clutter and noise, respectively. The subscript H denotes complex conjugate transpose (Hermitian transpose) operation. Computing the optimum weights in STAP is impractical mainly due to large number of operations to solve the STAP equations.

3. INTEGRATING SPACE-TIME PROCESSING INTO BACKPROJECTION PROCESS

The integrating the space-time processing techniques, which are mentioned in the previous section, should satisfy several criteria as follows. The integration should lighten the strict demands of DPCA. DPCA might therefore not be considered as a data pre-process as suggested in [3] but a data process after motion compensations. The integration should also improve the practice of solving STAP equations. For these reasons, we propose to integrate the space-time processing techniques into the beam-forming stage in the local backprojection process in order to detect moving targets and image them. Fig. 1 show the proposed scheme.

According to the moving target detection and imaging scheme, the range-compressed SAR data collected by each antenna is processed separately in the begging of the beam-forming stage. Each antenna creates K beam-matrices with the dimension of $M \times P$ where P is the number of beam samples. Without space-time processing, the k-th beam is formed by summing columns of the k-th beam-matrix.

We introduce here a stacked beam-matrix $\mathbf{Z}$ which is a combination of the beam-matrices of N antennas in one subaperture. The stacked beam-matrix has dimensions of $NM \times P$. For DPCA implemented on dual-channel SAR data, the k-th stacked beam-matrix is arranged by the k-th beam-matrix of the forward-channel data and the k-th beam-matrix of the backward-channel. The p-th beam sample of the k-th beam is found by

$$\mathbf{y}(p) = \sum_{m=1}^{NM} \mathbf{w}(m)\,\mathbf{Z}(m,p) \tag{4}$$

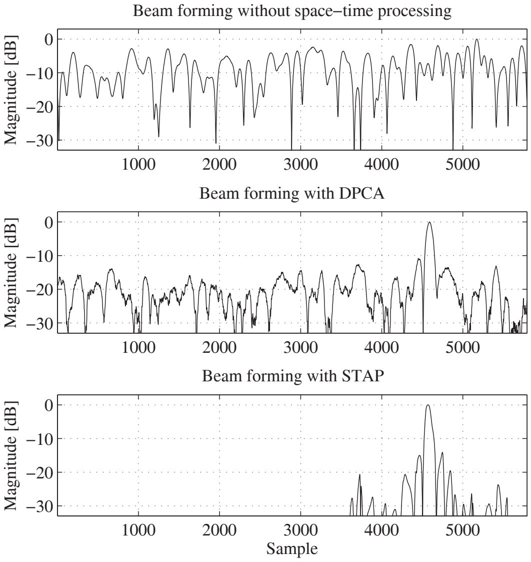

Fig. 2. An example of the beams formed in the beam-forming stage. (a) by the forward-channel SAR data, i.e. no space-time processing, (b) by the dual-channel SAR data with DPCA, (c) by the dual-channel SAR data with STAP.

where $N = 2$ and

$$\mathbf{w} = [+1 - 1 \cdots + 1 - 1]^{\mathrm{T}} \tag{5}$$

For STAP implemented on N channel SAR data ($N \geq 2$), the k-th stacked beam-matrix is arranged by N the k-th beam-matrices. The p-th beam sample of the k-th beam is estimated by (5). However, the optimum weights $\mathbf{w}$ are found from (1). The dimension of the clutter-plus-noise covariance matrix, which is used to estimated $\mathbf{w}$, is given by $NM \times NM$ and depends on the number of aperture positions in one subaperture.

For moving target detection, two hypotheses on $\mathbf{Z}$ are given: a moving target exists (hypothesis $\mathbf{H}_{\mathbf{1}}$) or no moving target exists (hypothesis $\mathbf{H_0}$) in the processed SAR scene (subimage). If Λ is a detection threshold, the Likelihood Ratio Test (LRT) for moving target detection is given by

$$\begin{array}{c} \mathbf{H_1} : |\mathbf{y}(p)| \geq \Lambda \\ \mathbf{H_0} : |\mathbf{y}(p)| < \Lambda \end{array} \tag{6}$$

For the real weight given by (5) in DPCA, the clutter suppressed beams can be used directly to image the moving targets. However, the complex optimum weight given by (1) in STAP damages the phase history of the moving targets. Imaging the moving targets therefore requires further procedures to retrieve the phase history, for example given in [3]. For Ultra-wideband (UWB) SAR, focusing moving targets with Normalized Relative Speed (NRS) is added in the subimage formation stage.

4. SIMULATION RESULTS AND EVALUATION

In this section, we demonstrate the proposed integration of the space-time processing techniques into the backprojection process. The reference system for simulations is LORA working in the frequency range of $307.2 - 332.8$ MHz. For GMTI purposes, this system is configured as a bistatic SAR system with three antennas (one transmits and two receive simultaneously). With the given element spacing, the displacement of the phase center of the forward and backward antenna is approximately $\lambda/2$, i.e. five aperture positions with LORA parameters.

In the simulation, the ground scene is simulated by one arbitrary moving target. The targets are point-like scatters and its Radar Cross Section (RCS) is normalized to $\sigma = 1$. The ground clutter is simulated by random stationary point targets spreading over all the ground scene. The RCS of these stationary point targets belong to the range $0 < \sigma \leq 4$. The thermal noise is assumed to be AWGN and Signal to Noise Ratio (SNR) is 10 dB.

Fig. 2.a plots an example of the beams which are formed only by the forward-channel SAR data. It is almost impossible to detect the moving target from the surrounding ground clutter and noise. Fig. 3.a shows the SAR image formed by the beams

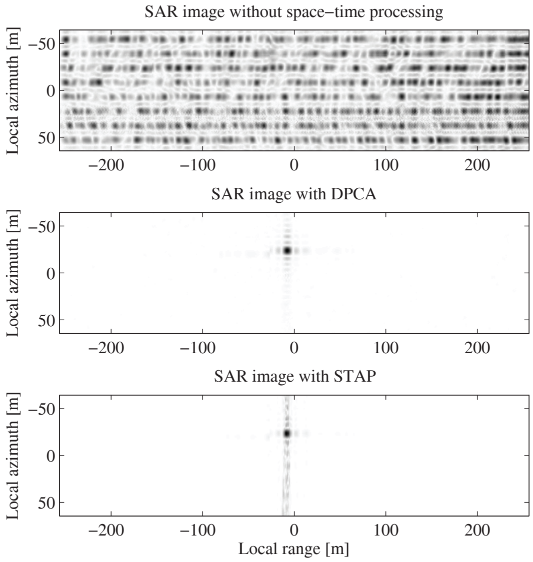

Fig. 3. SAR image of the moving target formed in the backprojection stage. (a) with the beams processed without space-time processing, (b) with the beams processed by DPCA, (c) with the beams processed by STAP.

without space-time processing in the beam-forming stage. No image of the moving target is achieved since it is totally hidden by the ground clutter.

In the first demonstration, we apply DPCA on dual-channel SAR data with the following procedures. The forward-channel SAR data is delayed by five aperture positions. The stacked beam-matrices are created from dual-channel beam-matrices. The beams are formed by (4) where the weighting vector to perform the subtraction $\mathbf{w}$ is given by (5). An example of the beams formed by the dual-channel SAR data with DPCA is plotted in Fig. 2.b with the SCNR of about 20 dB. If the detection threshold is set, for example $\Lambda = -10$ dB, the moving target is detected. The image of the moving target, a point-like scattering, is formed by these beams and shown in Fig. 3.b. The noise can be seen clearly in the SAR image due to the reduction in SNR. This can be explained by the subtraction in DPCA which also subtracts the signal level, especially for slow moving targets such as boat, ferry or ship.

In the next demonstration, STAP is implemented on dual-channel SAR data. We do not go into detail of such as signal behavior or clutter-plus-noise covariance matrix estimation, and assume that such knowledge is available. The stacked beam-matrices are arranged from dual-channel beam-matrices. The beams are also formed by (4), however, the optimum weights $\mathbf{w}$ is found by (1). Fig. 2.c sketches an example of the beams formed with STAP where ground clutter and noise are almost completely suppressed The moving target can be detected with the same detection threshold $\Lambda = -10$ dB. The SAR image of the moving target with much lower noise level is shown on Fig. 3.c.

5. REFERENCES

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