Application of Hybrid ATI/DPCA Method for Moving Human Target Detection in Forest Environments
DaHan Liao, Member, IEEE
U.S. Army Research Laboratory, Adelphi, MD, U.S.A.

Abstract—Moving human target sensing for airborne foliage-penetration (FOPEN) radar applications is considered. Target detection, parameter estimation, and image re-focusing—along with clutter suppression—are obtained with a hybrid along-track interferometry (ATI)/displaced phase center antenna (DPCA) technique that exploits the responses from a multi-channel sensing configuration. The processing algorithm is evaluated using the scattering returns from large-scale, full-wave electromagnetic simulations of a scene consisting of a walking human embedded in a forest stand. Within the prescribed simulation framework, analysis is also performed to examine the effects of the trees and the human gait movement on target localization and image quality.

I. INTRODUCTION

UNDERSTANDABLY, as forests cover approximately 30% of the globe’s land surface, the detection of moving targets concealed in forest environments is a problem of continued interest, especially as pertinent to airborne military surveillance applications. Although various clutter suppression techniques have been developed in the general area of ground moving target indication (GMTI), including change detection [1], along-track interferometry (ATI) [2], displaced phase center antenna (DPCA) [3], [4], and space-time adaptive processing, the focus of most existing works has been on the detection of surface vehicles (from either spaceborne or airborne platforms). The detection of moving humans hidden under tree cover—which poses a greater challenge due to the need to discriminate responses that have both very weak intensities and very small Doppler components—has been addressed in far fewer studies. For example, the sensing of human targets in foliage has been considered by [5]—wherein the signatures of the walking human in single-pass, single-channel synthetic aperture radar (SAR) images are examined, and by [6]—wherein adaptive array processing is applied to detect dismounts. Given that there has been an increased impetus in attaining SAR imaging and GMTI simultaneously, a hybrid ATI/DPCA method is exploited for moving human target detection in this work. The technique assumes the availability of single-pass data from a multi-channel foliage-penetration (FOPEN) radar, and enables target velocity parameter estimation and—subsequently—target re-focusing in the SAR imaging domain. Verification of the processing algorithm is obtained with scattering data from a numerical solver that fully characterizes the electromagnetic responses of a scene containing realistic tree structures and a walking human.

II. HYBRID ATI/DPCA METHOD

With the sensing scenario of consideration as depicted in Fig. 1, an airborne platform of the following configuration is assumed: the radar has two transmitters and three receivers; the receiver array—with inter-element separation distance $d$—is linearly arranged in the along-track (or azimuth) direction; furthermore, the two transmitters are co-located with the first two receivers. Over coherent processing time $T$, the platform is assumed to be flying with velocity $v_p$ along a linear flight path, and the sensing geometry is akin to that of the stripmap mode; and the human target, located at reference position $(x_t, y_t)$ at the midpoint of the coherent processing time, is walking with constant velocity vector $(v_x, v_y)$ along a straight line. The scattering data collection proceeds as follows: at each azimuth sampling time $t_k$, the scene is illuminated by transmitter 1 and the scattered fields are captured at receivers 1 and 2; then at azimuth sampling time $t_k + d/v_p$, the scene is illuminated by transmitter 2 and the scattered fields are captured at receivers 2 and 3. In essence, four sets of scattered fields are generated, viz.: $c_{11}$, $c_{21}$, $c_{22}$, and $c_{32}$, where in each case, the first subscript index denotes the receiver number and the second denotes the transmitter number. For DPCA processing, the operation $c_{11} - c_{22}$ is performed, the resultant of which can be estimated as a linear FM signal. The parameters of this linear FM signal—which are defined by the unknown target velocity and reference position vectors—are determined using a fractional Fourier transform procedure [7]. The target reference position vector itself is deduced with the phase of the output from a clutter-suppressed ATI operation of the form $(c_{11} - c_{22})(c_{21} - c_{32})^\ast$. Once the linear FM parameters and reference position vector are found, the target velocity vector $(v_x, v_y)$ can be calculated. Subsequently, having estimated the target parameters, phase compensation on the clutter-suppressed signal $c_{11} - c_{22}$ can be carried out to de-blur the target response—as well as to relocate it to its correct position—in the imaging domain.

III. NUMERICAL EXPERIMENTS WITH FULL-WAVE SIMULATION DATA

The scattering responses of the scene in Fig. 1 are obtained with the full-wave solver presented in [8]; specifically, the large-scale simulation framework employs a parallelized finite-difference time-domain algorithm for deriving the far-field responses of the scene over the 300–400 MHz band. The
A human target walking through a forest stand with 36 randomly generated trees. The forest stand is composed of 36 randomly generated trees situated directly over a flat, finitely conducting ground. A human target is assumed to be moving across the scene, with poses for its walk cycle synthesized from motion-capture data [9]. Essentially, frame-by-frame simulation of the scene is performed over the coherent processing time to capture the effects of both the displacement and the gait movement of the target. The overall dimensions of the computational domain are approximately 29 m × 29 m × 9 m. The trees, ground, and human model are assumed to be dielectrically homogeneous with relative dielectric constant and conductivity (εr, σ) of (13.9, 39 mS/m), (5.45, 20 mS/m), and (48.8, 662 mS/m), respectively.

The hh-polarized imaging results from the hybrid ATI/DPCA method discussed in the previous section are displayed in Fig. 2. For this sensing scenario, \( v_p = 100 \) m/s, \( (v_x, v_y) = (1.0 \) m/s, 0.75 m/s), and \( T = 16.9 \) s; the along-track direction is taken to be parallel to the x-axis; the radar is pointed toward \( \gamma \) with a depression angle of 15°, and the average slant range to the target is approximately 5.8 km.

It is seen from Fig. 2(a) that the target is detected and localized (the true target position is indicated with a cross marker in the images); however, there is also a significant amount of imaging artifact spreading in the cross-range direction. The main cause of this smearing does not stem from the presence of the trees: as evident from Fig. 2(b), for the same sensing setup, similar de-focusing appears in the image for the scene without the trees and with only the walking human. It is surmised that the manifestation of the artifact arises from the fact that the processing algorithm here presupposes a simple target moving with a single velocity vector, whereas in actuality, the walking human is a fluctuating complex target, with many body components moving with different velocity vectors. To verify this conjecture, the simulation scenario is reconsidered using a human target with a constant pose—that is, from one frame to the next, the target is simply displaced along its walking path, without its gait movement. The results in Figs. 2(c) and 2(d) confirm that the moving target, whether it is in the open or in the trees, can be well focused without the smearing effect if the movements of individual body parts are excluded. At least in this example and for the hh response, although the multi-scattering interactions of the trees and the target do introduce some additional image degradation, those effects seem to play a less significant role than the fluctuating nature of the composite target.

IV. CONCLUSIONS

A hybrid ATI/DPCA method is investigated for moving human target detection, parameter estimation, and localization as relevant to airborne FOPEN sensing. The processing algorithm is demonstrated with scattering data from an electromagnetic solver that fully characterizes the responses of a scene consisting of a moving human target in a forest stand. Numerical experiments indicate that the gait movement of the target can lead to image de-focusing and has to be included in order to completely understand the imaging response.

REFERENCES

[1] L. M. H. Ulander, B. Flood, P.-O. Frölding, A. Gustavsson, T. Jonsson, B. Larsson, M. Lundberg, D. Murdin, and G. Stenström, “Change Detection of Vehicle-Sized Targets in Forest Concealment Using VHF- and UHF-Band SAR,” IEEE Aerosp. Electron. Syst. Mag., 2011.
[2] R. Kapfer and M. E. Davis, “Along Track Interferometry for Foliage Penetration Moving Target Indication,” Proc. IEEE Radar Conf., 2008.
[3] H. Sun, L. Zhang, and X. Jin, “Parameter Estimations Based on DPCA-FrFT Algorithm for Three-Channel SAR-GMTI System,” Proc. Intelligent Comput. Tech. Automat. Conf., 2011.
[4] W.-Q. Wang and H. Shao, “Two-Antenna SAR With Waveform Diversity for Ground Moving Target Indication,” IEEE, Geosci. Remote Sens. Lett., 2011.
[5] T. K. Sjögren, L. M. H. Ulander, P.-O. Frölding, A. Gustavsson, G. Stenström, and T. Jonsson, “Detection of Moving Humans in UHF Wideband SAR,” Proc. SPIE, 2014.
[6] J. K. Jao, L. A. Begste, and P. R. Evans, “Adaptive GMTI Processing of FORESTER Field Test Data and Performance Results,” Proc. 54th Tri-Services Radar Symposium, 2004.
[7] V. A. Narayanan and K. M. Prabhu, “The Fractional Fourier Transform: Theory, Implementation and Error Analysis,” Microprocessors and Microsystems, 2003.
[8] D. H. Liao and T. Dogaru, “Large-Scale, Full-Wave Scattering Phenomenology Characterization of Realistic Trees,” Proc. IEEE Antennas Propagat. Soc. Symp., 2015.
[9] CMU, Graphics Lab Motion Capture Database, http://mocap.cs.cmu.edu/