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A Review on GMTI (Ground Moving Target Indication) RADAR

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ABSTRACT

MTI (Moving Target Indication) radar systems have been built for many years, based on system concepts evolved in the early 1950's. Digital techniques now permit easier implementation, but do not change the basic concepts; staggered repetition periods to eliminate blind speeds; and MTI cancellers with the velocity response shaped by feed forward and feedback techniques. Radar MTI may be specialized in terms of the type of clutter and environment: airborne MTI (AMTI), ground MTI (GMTI), etc., or may be combined mode: stationary and moving target indication (SMTI). The most common approach takes advantage of the Doppler effect. Many of the existing systems are very successful considering their performance, measured in terms of MTI improvement factor or sub clutter visibility. In this paper the basic MTI concepts and definitions are presented, and the real problems of modern surface-based MTI radar systems are discussed.

I. INTRODUCTION

RADAR (Radio Detection and Ranging) is a system used mainly in defence applications which is used to locate the target, that is, to find its exact position in the range which it covers. The drawback of conventional pulse RADAR is that it can determine only the range, that is, the distance of the target from RADAR antenna. It cannot determine whether the target is moving or not and in which direction it is moving. Thus in order to determine the motion of the target we use MTI (Moving Target Indication) RADAR. MTI RADAR has become a boon for detecting motion of the targets in the field of RADAR Engineering. MTI RADAR is defined as the RADAR in which the Doppler effect can be employed to differentiate between stationary and moving targets, with the former suppressed and only the latter displayed. In this process, the permanent echoes as well as those from very slow-moving objects (if desired) are not displayed on the PPI (plan position indicator), and the radar controller can pay attention to the real aircraft. Along with the detection of moving targets it also eliminates the effect of stationary objects or stationary clutters. This can be achieved by using the Delay line canceller.

II.EVOLUTION OF RADAR

Previously, RADAR systems were very simple. There were no separate antennas for transmitter and receiver. A single antenna used to function as transmitter and receiver. A gaseous device was called as duplexer was used to separate the transmitter and receiver subsystems. For certain time the single antenna used to work as a transmitter while for other time it used to function as a receiver. The transmitting and receiving functions were time multiplexed. The received echo was demodulated, amplified, and compared with the threshold level. But the disadvantage was that the doppler frequency shift due to motion of the target was not detected. Thus such a RADAR could not detect moving target. It was used only to detect stationary targets.

After World War-I when aircrafts were used in war for the first time there was a need to detect moving targets in which the conventional RADAR failed. Also as the aviation industry progressed there was also a need to control the motion of aircrafts to prevent fatal accidents. Thus a special RADAR system to detect moving targets was developed called as MTI (Moving Target Indication) RADAR was developed. Another type of RADAR used to detect moving targets was Pulse Dopplar RADAR. Both the RADAR systems used the concept of Dopplar frequency shift or dopplar effect to detect the moving targets. History was made when Croydon airport of London was the first airport to use ATC(Air Traffic Control) system in the year 1921. It used the RADARS used to detect moving targets.

III.GROUND MOVING TARGET INDICATION (GMTI)

Ground moving target indication (GMTI) is of great interest for surveillance and reconnaissance, but it is not an easy job because separating the moving targets' returns from stationary clutter is a technical challenge [9]. Moving target indication is twofold [10]: one is the detection of moving targets within severe ground clutter, and the other is the estimation of their parameters such as velocity and location. As such, radar clutter has received much recognition in recent years. Several clutter suppression approaches have been proposed, but they often require high pulsed repeated frequency (PRF), which is not desirable to avoid excessive data rate and PRF ambiguity problem [11]. It is well known that the moving target with a slant range velocity will generate a differential phase shift. This phase may be detected by interferometric combination of the signals from a two-channel along-track interferometry (ATI) synthetic aperture radar (SAR) system [12]. The ATI SAR was initially proposed for detecting ground moving targets, which uses two antennas to detect targets by providing essentially two identical views of the illuminated scene but at slightly different time. Several interferometry SAR (InSAR)-based moving targets detection algorithms have been proposed previously [13]. However, the stationary clutter unavoidably corrupts the interferometric phase of the targets depending on its signal-to-clutter environment [14]. Consequently, the imaged moving targets will be displaced in azimuth according to its radial velocity.

There have been several studies on the clutter effects on the intended signals [15]. But there remain still many unresolved problems, e.g., how to reliably estimate the target's true interferometric phase from the clutter [16]. Moreover, in a non homogeneous terrain, the degree of physical overlap of the target with a bright stationary point clutter may also influence the estimation accuracy. In order to accurately estimate the target's true velocity, clutter contamination on the signal must be minimized [17]. Precise knowledge of the interferogram's phase and amplitude statistics is very important for distinguishing the moving targets from the clutter. A straightforward approach to clutter cancelation is the displaced phase center antenna (DPCA) technique [18]. For one two antenna DPCA system, the additional freedom provided by the second antenna can be used to cancel the clutter; however, it can no longer be used to estimate the moving targets' position information [19].

Target detection is the common research methodology, which is adversely developed in recent years due to the advancement in computer vision technology. Some of the commonly adopted sources for target detection are intelligent monitoring, intelligent transportation, military target detection, etc. [20]. Some of the optimization techniques, like particle swarm optimization (PSO) are used in the moving target detection [21]. The presence of the interfering stationary scatters during the detection and motion parameter estimation makes the task to be challenging. Comparatively, the studies of improving the GMTI capability of the single-antenna SAR system have more practical meanings. A low-cost approach has been presented as the subaperture approach [22]. However, weak targets cannot be detected in the image domain. Other algorithms, including the matched filter bank algorithm, the range cell migration (RCM) algorithm, and the symmetric defocusing algorithm, have also been investigated. It can be noted that all these algorithms are developed to detect the moving targets with certain motion features [23]. In real SAR data processing, the motion and numbers of the moving targets are unknown before the processing. In most existing GMTIm algorithms, the radar platform velocity is assumed to be constant during the data acquisition, and the motion of the moving target is modeled as with constant velocities or constant accelerations [24]. However, this model is unsuitable for the real data processing due to the existence of motion errors. In real applications, the motion errors come from both the platform and the moving target [25]. Therefore, it is not safe to solely use one of these GMTI algorithms, due to the fact that there may be multiple moving targets with different motion features.

IV. LITERATURE SURVEY

In 2011, Wen-Qin Wang [1] has presented a simplified fractional Fourier transform (SFrFT) for three-antenna-based SAR GMTI applications. This approach cancelled clutter with three-antenna-based methods and formed two-channel signals through which moving targets were detected and imaged. Next, the Doppler parameters of the moving targets were estimated with the SFrFT-based estimation algorithm. In this way, both target location and target velocity were acquired. Next, the moving targets were focused with one uniform imaging algorithm. The feasibility was validated by theory analysis and simulation results.

In 2015, Yang *et al.* [2] have proposed a novel moving target processing strategy with real SAR data, including a two-step ground moving target indication (GMTI) algorithm and a practical ground moving target imaging (GMTIm) algorithm with motion error compensation. The two-step GMTI algorithm has the ability of indicating multiple moving targets, particularly those submerged by the clutter; the practical GMTIm algorithm showed a robust performance in real data moving target imaging since the motion errors were estimated and compensated. Both simulated and real data processing results were provided to demonstrate the effectiveness of the proposed strategy.

In 2016, Li *et al.* [3] have proposed a new space-time adaptive processing framework for removing moving target artifacts in SAR images. In this new framework, the dynamic steering vector concept was proposed. In addition, this paper developed a moving target processing scheme for clutter suppression and moving target imaging and location for a high-resolution wide-swath SAR system. Finally, we located the well-focused moving targets at the stationary scene image without any disturbing artifacts. The simulated and real data were used to validate the effectiveness of the proposed method.

In 2015, Zhang *et al.* [4] have proposed an efficient Radon transform (RT) estimation to estimate the radial velocity of fast moving target by utilizing the geometry information, and much more geometry information was exploited to realize clutter cancellation, noise cancellation, and estimation error minimizing in the RT domain, which was not proposed by the others. With only two to four angles used to calculate rather than search for the radial velocity of moving targets, the proposed methods simplified the conventional range and angle (2-D) searching procedure into several time range (1-D) searching procedure efficiently. The theoretical and experimental analysis provided qualitative and quantitative evaluations into the effectiveness of the proposed methods. In the single-antenna SAR system, the proposed methods could estimate the radial velocity of fast moving target efficiently and accurately in high signal to clutter plus noise ratio scenarios.

In 2020, Tian *et al.* [5] have proposed a method based on the symmetric autocorrelation function and the proposed window Lv's transform (SAF-WLVT) for coherent integration and motion parameters estimation of maneuvering target, involving the range migration (RM) and Doppler frequency migration (DFM). Firstly, the SAF was utilized to correct the linear RM induced by target's radial velocity and range curvature caused by target's radial acceleration simultaneously. Then, the proposed WLVT was applied to eliminate the residual DFM caused by the target's radial acceleration, accumulated the target energy without introducing excess noise energy, and obtained the baseband velocity and acceleration estimations. Finally, the Doppler ambiguity number was estimated by matched filtering and 1-D parameter searching, and then the target's radial velocity was obtained. The proposed method has low computational complexity, and possessed favourable performance of target detection and parameter estimation in the high signal to noise (SNR) environment. The mathematical analysis and simulation results demonstrated the effectiveness of the proposed method.

In 2013, Li *et al.* [6] have studied the application in ground moving target indication (GMTI) in wide-area surveillance radar system. MTI was the key task in wide-area surveillance radar system. Due to its great importance in future reconnaissance systems, it attracted great interest from scientists. In (Yan et al. in IEEE Geosci. Remote Sens. Lett., 10:617–621, 2013), the authors first introduced robust PCA to model the GMTI problem, and demonstrated promising simulation results to verify the advantages over other models. However, the robust PCA model could not fully describe the problem. As pointed out in (Yan et al. in IEEE Geosci. Remote Sens. Lett., 10:617–621, 2013), due to the special structure of the sparse matrix (which included the moving target information), there would be difficulties for the exact extraction of moving targets. This motivated the work in this paper where we would detail the GMTI problem, explored the mathematical properties and discussed how to set up better models to solve the problem. We proposed two models, the structured RPCA model and the row-modulus RPCA model, both of which would better fit the problem and took more use of the special structure of the sparse matrix. Simulation results confirmed the improvement of the proposed models over the one in (Yan et al. in IEEE Geosci. Remote Sens. Lett., 10:617–621, 2013).

In 2017, Li *et al.* [7] have showed that the decomposition has a unique solution under reasonable assumptions. We proposed a phase-based model to fully describe the special sparse structure. An alternating direction method of multipliers was implemented to solve the resulting nonconvex complex matrix problem. Simulation results verified the superior efficiency and the improvement of the new model.

In 2020, Kumar and Kumar [8] have proposed the moving target detection in SAR using decision fusion method. The newly developed scheme was named Bayesian fusion for moving target detection (BF-MTD) as the scheme utilized the Bayesian model for identifying the target location. Initially, the received signals from the SAR were fed through the short-time Fourier transform (STFT) and the matching filters for identifying the target location. Then, the results were fused together by the Bayesian fusion strategy for finding the actual target. For the fusion, the Naive Bayes classifier was used for determining the optimal parameter for the target detection. The simulation of the proposed BF-MTD model was evaluated by varying target, iteration; pulse repetition level and antenna turn velocity of the SAR. Simulation results revealed that the proposed BF-MTD has achieved significant performance for a detection time, missed target rate, and mean square error, respectively.

V. FEATURES AND CHALLENGES OF TRADITION GMTI METHODS

Author [citation]	**Methodology**	**Features**	**Challenges**
Wen-Qin Wang [1]	SFrFT	• It is not based on the Doppler shift or across-track velocity component of target. • It permits the estimation of true azimuth position of target in a direct manner from its	• The detection time is not accurately measured.

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		measured position.	
Yang *et al.* [2]	GMTIm	• It enhances the imaging resolution that is associated with the moving target. • It is efficient in processing distinct forms of moving targets.	• It does not assess the minimum detectable velocity figures.
Li *et al.* [3]	Space-time adaptive processing framework	• The SCNR of the coarsely focused outcomes are enhanced for the moving target detection. • The complexity of the system is enormously minimized.	• It does not consider the sensitivity of strong clutter and weak targets.
Zhang *et al.* [4]	RT	• The heavy computation load is minimized. • It can be used for the real-time estimation with high SCNR scenarios.	• It does not concentrate on estimating the effective motion parameter for multiple moving targets.
Tian *et al.* [5]	SAF-WLVT	• It attains better parameters estimation accuracy and performance of the target detection. • It contains lower computational complexity.	• It does not establish the equivalent outcome among the relaxed convex optimization and the original problem.
Li *et al.* [6]	Robust PCA	• The usage of the row-sparsity information is considered for the sparse matrix. • The row-modulus and structured RPCA model fits the problem in a better manner.	• It does not consider the entire usage of the information for extracting the moving target information.
Li *et al.* [7]	Phase-based model	• It completely describes the entire sparse features of the moving target matrix. • The nonconvex complex matrix problem is solved by the alternating direction multipliers method.	• It does not propose conditions for guaranteeing a unique decomposition in the availability of noise.
Kumar and Kumar [8]	BF-MTD	• Better performance is achieved in terms of detection time. • The target positions from the matching filter and STFT are recognized via the maximum energy.	• The sensitivity associated with the weak target is not considered.

VI. CONCLUSION

Target detection is one of the important subfields in the research of Synthetic Aperture Radar (SAR). It faces many challenges, due to the stationary objects, leading to the presence of a scatter signal. Many researchers have been done on target detection, and most of them prefer filter-based techniques. In wide-area surveillance radar systems, ground moving target indication is the main task. The underlying mathematical problem is to decompose a complexmatrix into a low rank matrix and a structured sparse matrix. Ground moving target indication (GMTI) is of great important for surveillance and reconnaissance, but it is not an easy job. One technique is the along-track interferometry (ATI) synthetic aperture radar (SAR), which was initially proposed for estimating the radial velocity of ground moving targets. However, the measured differential phase may be contaminated by overlapping stationary clutter, leading to errors in velocity and position estimates. The main intention of this proposal is to develop a novel adaptive Simplified Fractional Fourier Transform using the intelligent meta-heuristic improvement. This adaptive SFrFT will efficiently estimate the Doppler parameters of the moving targets. The improved Harris Hawks Optimization (HHO) will be used as the meta-heuristic algorithm that enhances the performance of the SFrFT-based target estimation.

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