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Coherent Detection and 3D Tracking Stages of a DVB-T Based Passive Radar for Terrestrial Traffic Monitoring

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Abstract. This work tackles terrestrial traffic monitoring using a Passive Radar System (PRS) characterized by a surveillance channel processing composed of a Neyman-Pearson (NP) coherent detector and three-dimensional tracker implementation. The NP detector is a parametric approach that requires the prior knowledge of target and bistatic clutter statistical models at communication systems frequencies that fit with real data. The proposed tracker provides three-dimensional (range, azimuth and speed) trajectories declaration exploiting the capabilities of beamforming techniques based on a uniform linear array as surveillance antenna system. The considered solution is validated with real data acquired by a PRS in a semi-urban scenario.

1. Introduction

Non-collaborative target detection and tracking are a challenging problem of great interest. Bistatic Passive Radar Systems, PRS, are being extensively developed as an alternative solution to active ones, due to advantages such as low development, implementation and maintenance cost, small size, low weight, low probability of interception and avoidance electromagnetic compatibility or environment impact problems. All these features are a result of an opportunistic use of the transmissions of other non-cooperative radiocommunication services present in their surrounding area as Illuminators of Opportunity (IoO).

PRSs scheme is usually composed of two channels: the reference channel for acquiring IoO signal and the surveillance channel for capturing the target echoes. The two acquired signals are coherent processed in intervals (CPI, Coherent Processing Interval) consisting in the correlation of time delayed and Doppler-shifted copies of the selected reference signal with target echoes to generate Range-Doppler Surfaces (RDSs) using the Cross-Ambiguity Function. PRSs performances are strongly determined by the IoO properties and the radar scenario geometry.

The radar detector has to decide between target absence (null hypothesis, H_0) and target presence (alternative hypothesis, H_1). The most extended detector criterion in radar applications is the Neyman-Pearson (NP) detector, which maximizes the Probability of Detection (P_D) maintaining the Probability of False Alarm (P_{FA}) lower than or equal to a given value [1]. If $\tilde{\mathbf{z}}$ is the complex observation vector provided by the radar receiver and $f(\tilde{\mathbf{z}}|H_0)$ and $f(\tilde{\mathbf{z}}|H_1)$ are the detection problem likelihood functions under both hypotheses, a possible implementation of the NP detector consists in comparing the Likelihood Ratio (LR) to a detection threshold estimated according to P_{FA} requirements [2]. This approach requires a complete statistical characterization under both hypothesis and significant detection losses arise when the statistical properties of the observation vectors under both hypotheses vary from


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those assumed in the LR detector design [3]. There are not available too many studies of bistatic interference or clutter at communication systems frequencies in the literature. In [4], a two-dimensional (2D) LR detector is designed for a PRS based on Digital Video Broadcasting-Terrestrial (DVB-T) after proving that Gaussian and mixture of Gaussians statistical models fit with real data.

The three-dimensional (3D) passive radar detection and tracking consider target bistatic range, Doppler shift and azimuth information. Antenna array and digital beamforming techniques are required in the surveillance channel to provide the angular discrimination capability. The 3D-detector is usually based on two-stage processing scheme: the first one consists in a 2D-detector applied to the RDSs associated with each array element and a combination of the detection performances, and the second one is focused on Direction-of-Arrival (DoA) estimation techniques. In [5], Constant False Alarm Rate (CFAR) techniques (that can lead to suboptimal solutions) exploiting signals acquired by non-Uniform Linear Array (non-ULA), a 2D-tracker and a high resolution DoA estimator are proposed.

In this paper, an enhanced 3D-detector for IDEPAR (Improved Detection techniques for Passive Radars), a passive radar demonstrator, is proposed. IDEPAR is a multi-channel DVB-T PRS designed and developed for terrestrial targets [6], and its capabilities were evaluated in [4]–[7]. The antenna system of its surveillance channel is composed of an array of commercial antennas fulfilling the IDEPAR design requirement of using Commercial Off-The-Shelf (COTS) components to the largest possible extent. To improve the PRS performance, this work considers the LR detector implementation, a DoA estimator based on ULA and MUSIC algorithm [8], and 3D-tracker using all the target information to reduce anomalous trajectories.

2. 3D Passive Radar Detector and Tracker

For the formulation of the LR detector (1), where *i* denotes the *i*th-element of the surveillance antenna array composed of *N* elements, RDSs provided by each array element are used as the observation space and $f(\tilde{\mathbf{z}}|H_0)$ is defined by the ground clutter models proposed in [4] for the different areas of the RDSs. These models present small variations along time that can be characterized. A Gaussian target is assumed for $f(\tilde{\mathbf{z}}|H_1)$. The threshold ($\eta_{LR}$) is fixed attending to a given P_{FA}.

$$\Lambda^{\mathrm{i}}(\tilde{\mathbf{z}}) = \frac{f(\tilde{\mathbf{z}}|H_1)}{f(\tilde{\mathbf{z}}|H_0)} \underset{H_0}{\overset{H_1}{\gtrless}} \eta_{LR}^{i}\ (P_{FA}) \qquad i = 1, \dots, N \tag{1}$$

The *N* LR detector outputs are proposed to be combined by an OR-logic operation resulting a detection matrix indicating the range-Doppler cells where targets can be present, so this stage provides target 2D-dimensional parametrization. As η_{LR}^{i} is fixed to fulfill the P_{FA} requirements of only the *i*th-antenna, an increase of the final P_{FA} after the OR-logic combination is expected. However, once a target detection is loss in this step, it will never be considered in following steps. In addition, P_{FA} performance can be improved in the tracking stage.

The use of beamforming techniques provides the third dimension of the target characteristics space estimating its azimuth. MUSIC algorithm is applied to the range-Doppler cells where targets are declared, using *N*-dimension frequency domain snapshots composed of the corresponding samples of the RDSs generated for each array element. MUSIC estimator is widely used because this solution is computationally simpler than the Maximum Likelihood estimator providing good performance capability [8]. MUSIC algorithm finds the directions vectors that are orthogonal to a noise subspace exploiting the information of the eigenvalues and eigenvectors of the spatial covariance matrix.

The association of the temporal detections from the same target is carried out by a 3D-tracker based on a 3D Kalman filter. The considered solution is an updated version of the 2D-tracker presented in [5]. The target manoeuvres in the domain under study are described by equations (2-3) of dynamic model. The target movement in the bistatic range dimension follows a basic accelerate movement where the acceleration variation is modelled as white noise, $\omega_R(k)$. The instantaneous bistatic range position of the target is denoted as $R_b(k)$, and its velocity and acceleration as v_{Rb} and a_{Rb} respectively. The azimuth displacement, $\phi(k)$, is modelled as a lineal movement with additive white noise to represent the azimuth

rate variations, $\omega_\phi(k)$. v_ϕ represents the change rate in this dimension. In both equations, the time of the CPI is denoted as T_{int}.

$$R_b(k) = R_b(k-1) + v_{Rb}(k-1)\cdot T_{int} + \frac{T_{int}^2}{2a_{Rb}(k-1)} + \omega_R(k); \quad (2)$$

$$\phi(k) = \phi(k-1) + v_\phi(k-1)\cdot T_{int} + \omega_\phi(k) \quad (3)$$

3. Evaluation with IDEPAR data

A real radar scenario, in the nearby area of the Polytechnic School of University of Alcalá (Spain), is considered. IDEPAR (Figure 2), DVB-T based PRS, is located at the rooftop terrace of the Polytechnic School. This semi-urban scenario is described in [4]-[7]. The considered 3D radar signal processing scheme of IDEPAR is depicted in Figure 2.



Figure 1. IDEPAR PRS

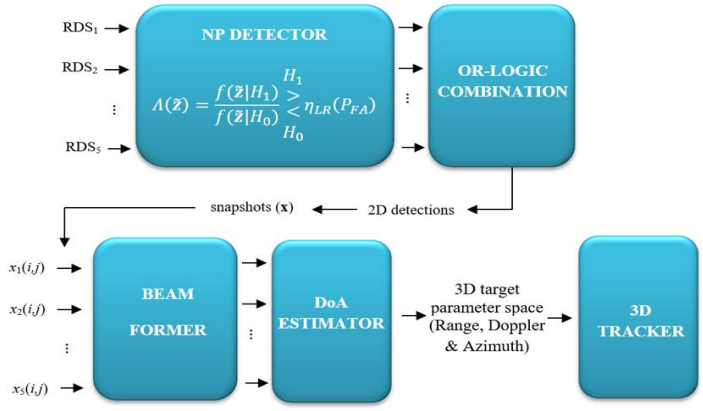


Figure 2. 3D passive radar detector and tracker scheme

The acquisition parameters are:58-th DVB-T channel (f_c=770 MHz); Signal bandwidth of 8 MHz; Coherent processing interval of T_{int}=250 ms; RDS size of 1000 range bins (corresponding to a coverage distance of 9.45 km) and 401 Doppler shifts (f_{DOP} = [-799.744, …,799.744] Hz); An acquisition of 20 seconds was recorded and 80 RDSs are generated. IDEPAR surveillance antenna system is a ULA of Televés 4G NOVA antennas (Figure 3): a commercial UHF log-periodic antenna designed in microstrip technology covering IDEPAR frequency band with a 3dB azimuth beamwidth of approximately 60º and a directivity of 7.98 dBi for 770 MHz. The inter-element spacing of ULA is 315 mm, so beam patterns for steering angles ∈ [-13.7º, 13.7º] will not present grating lobes (Figure 4).

In [7], the coherent detection stage is evaluated. The implementation of the LR detector clearly reduces the interference. In Figure 6, the superimposition of the detections declared at the output of the OR-logic combinatory in the whole acquisition time is presented. The false detections associated with the neighborhood metal buildings will be removed by the 3D tracker because is not being able to establish any correspondence with any terrestrial target movement dynamics. The trajectories declared by the 3D tracker (Figure 10) confirm the suitability of the considered solution.

4. Conclusions

A coherent detection and 3D tracking solutions are proposed for terrestrial traffic monitoring using PRS based on DVB-T as IoO. A two-stage processing scheme is designed: the first stage consists in implementing a LR coherent detector to each surveillance acquisition channels and a combination of the outputs with an OR-logic operation; in the second stage a DoA estimator based on digital beamforming techniques and MUSIC algorithm is performed. UHF terrestrial bistatic clutter models are considered for approximating the NP detector and providing the best detection capability. Surveillance ULA completes the 3D target features extraction and allows the 3D tracking. Real data acquired by IDEPAR (DVB-T PRS) in a semi-urban scenario are used to confirm the suitability of the presented radar processing approach.

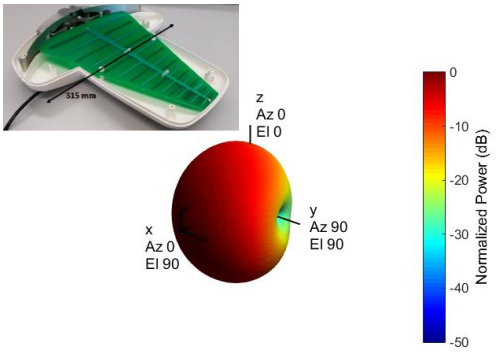


Figure 3. Televes 4G NOVA radiation pattern

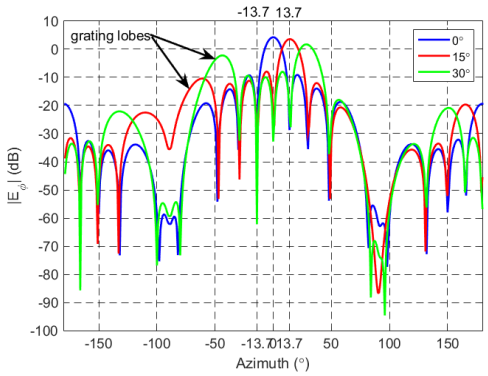


Figure 4. ULA radiation pattern synthesis

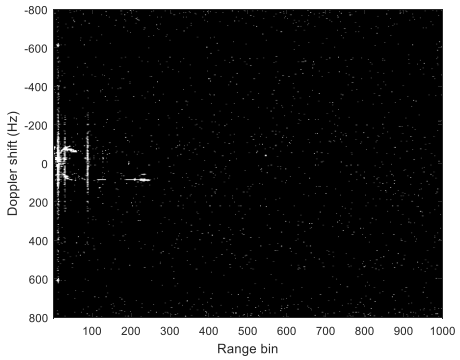


Figure 5. Superimpositon of 2D detections



Figure 6. Terrestrial Target Tracking Performance

5. References

[1] Neyman J and Pearson E 1933 On the problem of the most efficient test of statistical hypotheses *Philosophical Trans. of the Royal Society of London* vol A 231 no 9 pp 289–337
[2] Trees H V 2013 *Detection, estimation, and modulation theory* (Wiley)
[3] di Vito A. and Naldi M. 1999 Robustness of the likelihood ratio detector for moderately fluctuating radar targets *IEE Proceedings on Radar, Sonar and Navigation* vol 146 no 2 pp 107–112
[4] del-Rey-Maestre Net all 2018 Machine Learning Techniques for Coherent CFAR Detection Based on Statistical Modeling of UHF Passive Ground Clutter *IEEE J. of Selected Topics in Signal Processing* vol 12 no 1 pp 104-118
[5] del-Rey-Maestre N et all 2017 Passive Radar Array Processing with Non-Uniform Linear Arrays for Ground Target's Detection and Localization *Remote sensing* vol 9 no 7 pp 1-29.
[6] Jarabo-Amores M P et all 2016 IDEPAR: a multichannel digital video broadcasting-terrestrial passive radar technological demonstrator in terrestrial radar scenarios *IET* Radar, Sonar and Navigation pp 1–9
[7] Gómez-del-Hoyo P J et all 2018 Terrestrial Targets Tracking with Passive Radar System Using Neyman-Pearson Detector *2018 IEEE Radio and Antenna Days of the Indian Ocean* pp 1-2
[8] Yu T and Hansen J H L 2010 Automatic beamforming for blind extraction of speech from music environment using variance of spectral flux-inspired criterion *IEEE Journal of Selected Topics in Signal Processing* vol 4 no 5 pp 785–797

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