Aerospace Science and Technology 40 (2015) 171–180

Contents lists available at ScienceDirect

Aerospace Science and Technology

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Spatial and temporal features selection for low-altitude target detection

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A R T I C L E I N F O

Article history:
Received 27 January 2014
Received in revised form 29 October 2014
Accepted 11 November 2014
Available online 25 November 2014

Keywords:
Target
Low-altitude airspace
Optimal classification plane
Background subtraction

A B S T R A C T

Target detection in plane position indicator (PPI) radar images aims at separating moving targets from complicated background image. Background subtraction is a powerful mechanism for such applications. Since there is still much clutter left in the foreground image after background subtraction, an optimal classification plane (OCP) should be constructed to distinguish targets from clutters. Due to the complexity and variability of the foreground and background images, the threshold value of each position of the OCP should be selected adaptively corresponding to each pixel of the foreground image. In this paper, a novel method is proposed to improve the classification results of the OCP with the spatial and temporal features from the PPI radar image sequence. Firstly, to select the thresholds in the OCP adaptively, a new formula is developed with the spatial features from two statistical models. The statistics from the foreground model reflect the aggregation degree of the concerned pixels, while those from the background model reflect their relative positions. Secondly, to further reduce the false alarm rate, a novel strategy based on the temporal features is incorporated to modify the OCP. Our method with the optimal parameter values is compared with the other successful techniques for target detection. Quantitative evaluations show that the proposed method provides better results.

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1. Introduction

With the development of general aviation industry, safety monitor for low-altitude airspace has become a significant task of air defense system, in order to ensure safety of important regions and sensitive targets, such as border and coastal areas, high-rise buildings and busy airports [15]. Therefore, an automatic surveillance technique is needed. Incoherent primary radar, which measures the azimuths and ranges of targets by detecting their echo signals, is applicable for security surveillance of low-altitude airspace, due to its low cost, wide coverage, easy installation, all-weather and all-time independent working ability. However, the incoherent radar has no function of target detection and tracking. Thus, digital plane position indicator (PPI) images are usually collected by a capture card, and then processed by the automatic target detection techniques, aiming at the separation of moving targets (called foreground) from the static parts of the scene (called background). In automated surveillance systems, cameras and other sensors are typically used to monitor interesting targets, collecting different kinds of image data, therefore, a large number of detection techniques have been developed for different data sources [18]. As a significant part of low-altitude airspace surveillance, this paper focuses on the detection techniques for PPI radar images collected by incoherent radar [5,20].

The appearance of background objects in PPI radar images often undergoes some changes over time, due to the unstable echoes caused by non-stationary objects such as wavering bushes or woods. Therefore, there is still much clutter left in the foreground image after background subtraction, especially on the edge of the stationary background, so the step of clutter rejection is required. Since the detection results are sensitive to threshold selection, specific threshold should be set for every pixel of the foreground image. Comparing the gray-scale of each pixel with the threshold, the pixels with higher gray-scale are always classified to targets and the ones with lower gray-scale to clutters. Therefore, a classification plane is constructed with specific threshold set for each pixel. Without any prior knowledge of the moving target, a simple and direct way is to set the thresholds with the same values for all the pixels, called the fixed threshold (FT) method. However, this method leads to false alarms if the gray-scale of clutter is higher than that of the small target. To improve the detection accuracy, the spatial and temporal features at each pixel can be utilized to construct an optimal classification plane (OCP). At present, most studies are concentrated on these two directions to improve the classification results of the OCP. (1) Various threshold

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http://dx.doi.org/10.1016/j.ast.2014.11.004
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adaptation methods based on spatial features have been proposed for the OCP construction. Among the most successful is the constant false alarm rate (CFAR) detector [21]. In Gaussian background, cell averaging CFAR (CA-CFAR) detector can give optimal detection performance, but its performance decreases in non-Gaussian background with multiple targets [14]. To improve the CFAR detector performance in non-Gaussian clutter, several improved CFAR detectors have been developed, such as the smallest-of (SO) CFAR [19], the greatest-of (GO) CFAR [12] and the ordered statistics CFAR (OS-CFAR) [8,11] detector, whose thresholds are determined by different samples from the ranking reference cells. For Weibull and lognormal distributed clutter, Guida proposed the CFAR detector based on best linear unbiased estimation (BLUE-CFAR) [9]. To improve the performance of CFAR detector in multi-target environment, the CFAR detector with cell selection was studied [13, 24]. With the consideration of the dynamic of sea clutter and the Doppler effect of target, the nonlinear algorithm based on artificial neural networks was introduced in sea clutter reduction, outperforming the CA-CFAR detector [22]. Morphological processing (MP) is usually used as the post-processing of CFAR, which could reject the small objects of a few pixels from the binary image provided by CFAR [23]. Unfortunately, the CFAR and MP methods are generally applied to detect targets on the sea when the PPI images contain little information of the still background objects, so these methods, which are not particularly designed for our scene of low-altitude airspace, only utilize the spatial features from the foreground model but ignore those from the background model. (2) Besides the spatial features, the classification results of the OCP could also be improved by the temporal features extracted from the image sequence, such as the track before detection (TBD) algorithm [6]. In TBD, the states of several targets are estimated through measurements. In many cases, some measurements might be due to clutter, thus one is forced to solve the problem of data association. The commonly used data association methods include nearest neighbor filter [3], joint probability data association [4] and multiple hypothesis tracking [1]. To increase the sensitivity of the radar, low detection thresholds are set, when the increased false alarms could be rejected by data association methods. Note that the TBD algorithms make the system work slow due to their high computational cost and memory requirements, which limits their applications in strong clutter environment. Some of the above techniques have been used in our preliminary work [7,16, 17]. In [17], the CA-CFAR detector was used for target detection in low-altitude airspace. In [7], the clutters were further rejected from the foreground image by the MP algorithm. In [16], a TBD algorithm based on particle filtering (PF) was proposed for target detection in cluttered environment.

However, the simple applications of these existing methods in our work are still far from satisfactory, which should be improved both in spatial and temporal domains. In this paper, a novel method is proposed to improve the classification results of the OCP with the spatial and temporal features from the PPI radar image sequence. Since the incoherent radar is operated on the land, the PPI radar images contain much information of the stationary objects. According to the authors' observation, it is worth noting that in the PPI images the clutters always appear on the edge of the stationary objects while the targets move in the airspace whose gray-scale value is almost zero. Although sometimes the absolute gray-scale value of the target is quite low, it is relatively stronger in comparison with its small neighborhood region. These characteristics inspire our work introducing more spatial information from the background model to enhance the detection capability of the OCP. Hence, the spatial statistics are firstly introduced from the foreground and background models into a Markov random field (MRF) model to calculate the threshold values in the OCP. The spatial statistics from the background model represents the relative

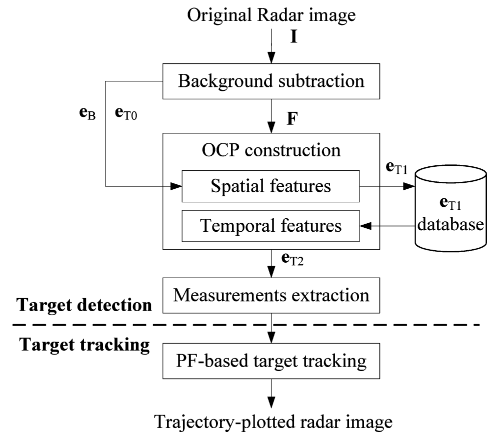

Fig. 1. Data processing scheme of the CAST-ASR system.

positions of the concerned pixels, while that from the foreground model represents their aggregation degree. Secondly, when analyzed temporally, it is also noticed that the clutters always appear at the same position in the image sequence, which could be utilized to modify the OCP with much higher computational efficiency than that of the data association in TBD.

The remaining part of the paper is organized as follows. Section 2 gives a brief introduction of the data processing scheme with the PPI radar images. Section 3 describes the method for the separation of the background and foreground model from the current frame. In Section 4, the OCP construction algorithm based on the spatial and temporal features is described. Section 5 presents the experimental results of the ground-truth data. Evaluations and comparisons with the existing methods are also included. The compared algorithms include four radar target detection algorithms and two state-of-the-art algorithms for video surveillance with cameras. Finally, some conclusions close the paper in Section 6.

2. Data processing scheme

Original PPI radar images are collected and processed by the in-house data processing scheme. Fig. 1 shows the data processing scheme of the Airspace Surveillance Radar system developed by China Academy of Civil Aviation Science and Technology (CAST-ASR), which is divided into two parts: target detection and target tracking. The detection part consists of three steps: background subtraction, OCP construction and measurements extraction.

(1) In the first step, the original radar image $\mathbf{I}$ is divided into the binary background model $\mathbf{e}_B$ and the binary foreground model $\mathbf{e}_{T0}$.

(2) In the second step, an adaptive OCP construction method for target detection and clutter rejection in PPI radar images is proposed. The background edge clutter is rejected from the foreground image using the spatial and temporal features. A new formula of the thresholding rule for target and clutter classification in the foreground image $\mathbf{F}$ is derived. Based on this formula, the threshold values in the OCP are adjusted by the spatial MRF model based on the statistics from $\mathbf{e}_B$ and $\mathbf{e}_{T0}$, and the binary map $\mathbf{e}_{T1}$ is obtained and stored in the database. Then, $\mathbf{e}_{T1}$ is further processed with the temporal features to generate the final detection map $\mathbf{e}_{T2}$.

(3) In the third step, the measurements are extracted from the binary image $\mathbf{e}_{T2}$ and provided for target tracking. Every connected area labeled 1 in $\mathbf{e}_{T2}$ is considered as a measurement, which may be due to target or false alarm. The information extracted from each measurement includes the central coordinates and the pixel number.

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