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Spatial resolution cell based centralized target detection in multistatic radar

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A B S T R A C T

The problem of spatial resolution cell (SRC) based centralized target detection in multistatic radar is considered. Due to the fact that using the observation data from different radar sites can result in a much smaller uncertainty volume, the SRC of multistatic radar is usually an intersection of the overlapping range, azimuth and elevation resolution cells of all spatial diversity channels (SDCs). Then, the target detection problem in multistatic radar can be considered as deciding whether a target is present in each probed SRC. In this paper, a general scheme of the SRC based centralized target detection in multistatic radar is proposed. Considering that different neighboring SRCs of multistatic radar may correspond to the same range, azimuth and elevation resolution cell of one SDC, the desired signals or noises from these neighboring SRCs hence can be mutually dependent. Motivated by this, the symbiosis relationship of these neighboring SRCs in exceeding the test threshold during the process of centralized target detection is specifically studied. Furthermore, the performance of the peak search method to decide which SRC on earth contains the target of interest is accordingly analyzed.

1. Introduction

Multistatic radar is a comprehensive radar system including several spatially separated transmitting and receiving facilities where the observation data from different radar sites can be fused and jointly processed [1]. Each transmit-receive facility pair can be regarded as one spatial diversity channel (SDC). Multistatic radar with widely separated antennas can view a target from different angles. This system configuration enables multistatic radar to capture both diversity gain and geometry gain, so as to enhance the target detection performance and positioning accuracy [2,3]. More fundamental contents and applications of multistatic radar are revealed in recent publications and references therein [4–9].

Space registration is a prerequisite for multisensor signal fusion [10]. To be specific, the observation data to be fused in the signal fusion center should be that measured by each SDC with respect to the common surveillance region. It should be noted that the process of data collecting is all carried out by each individual SDC based on its own resolution, rather than the multisensor resolution. For monostatic radar (only one SDC), the volume of spatial resolution cell (SRC) is typically determined by the range, azimuth and elevation resolution. For simplicity, we consider only two dimensional (range and azimuth) case in this paper and the extension to three dimensional case is straightforward. Here, we can first summarize that the SRC of monostatic radar is actually equivalent to its range and azimuth cell (RARC), which can be represented as an error ellipse [11]. However, due to the fact that using the observation data from different radar sites can result in a much smaller uncertainty volume, the SRC of multistatic radar is usually an intersection of the overlapping RARCs of all SDCs [12]. Hence, the RARC of one SDC is commonly covered by several neighboring SRCs of multistatic radar. Therefore, the desired signals or noises from these neighboring SRCs can be mutually dependent.

Centralized target detection in multistatic radar means that the entire raw data observed by all SDCs are transmitted to the signal fusion center for joint processing [1]. Afterwards, the global test statistic is directly formed and compared with the test threshold, so as to make the decision whether a target is present in each probed SRC. It can be treated as an one-step target detection approach, being particularly useful for weak target detection since there is no local thresholding in each radar site, and hence no loss of the target information. By contrast, distributed (decentralized) target detection [13–15] can be viewed as a two-step method where each radar site processes its own observation data and transmits the local decision or statistic to the signal fusion

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center for further decision-making. This process is accompanied by the target information loss because of the local thresholding. Many centralized target detection algorithms have been appeared in open literatures [2,3,16–18]. These existing algorithms just focus on such a solitary probed SRC of multistatic radar and assume other neighboring SRCs contain only noise components. With these assumptions, the corresponding detection performances are usually further analyzed. However, as is normal in practice, different neighboring SRCs of multistatic radar in the common surveillance region may correspond to the same RARC of one SDC. Hence, they should share the same target response of that RARC in the signal fusion center. These neighboring SRCs have a kind of symbiosis relationship in exceeding the test threshold during the process of centralized target detection, which can cause a certain amount of false alarms in the radar surveillance region. This important feature is neglected in most open literatures of centralized target detection, which merits careful consideration in a more realistic situation.

The research of this paper mainly focuses on the SRC based centralized target detection in multistatic radar. There are several published literatures that are related to this work. Farina et al. [19] considered the problem of distributed target detection in multistatic radar, employing parallel decision fusion from collocated sensors with different resolutions. The proposed distributed fusion algorithm can yield the final decision with the highest available data resolution. Rago et al. [20] investigated the problem of data fusion from separated multiple sensors with resolution cells noncoincidence. They concluded that using this noncoincidence can somewhat improve the target detection performance in multistatic radar. Actually, the RARCs of any two SDCs are nearly always not coincident with each other because of the difference between their observation angles with respect to the common surveillance region. Under this situation, for centralized target detection, the reasonable minimum cell size for signal fusion should be the SRC of multistatic radar.

In this paper, we provide a deep insight into the SRC based centralized target detection in multistatic radar. The main contributions of this paper include the following aspects. First, we address the problem of centralized target detection using radar data from several locations in a more realistic situation. Given the difference between monostatic and multistatic resolutions, we propose a general scheme of the SRC based centralized target detection in multistatic radar, which gives the definitions of space mapping from the common coordinate reference system to the local radar sites and specifies the rules of target response in each probed SRC of multistatic radar. Then, we apply the proposed general scheme to a specific non-coherent integration (NCI) detector. Considering that different neighboring SRCs of multistatic radar may correspond to the same RARC of one SDC, the desired signals or noises from these neighboring SRCs hence can be mutually dependent. Theoretical analysis of the probability of these neighboring SRCs in exceeding the test threshold during the process of centralized target detection is provided. This is really an important matter that needs attention when implementing the proposed signal fusion architecture in practice. Furthermore, we investigate the performance of the peak search method to decide which SRC on earth contains the target of interest. This can be viewed as a process of finding the target final position from a group of detected SRCs that actually correspond to one common target.

The remainder of this paper is organized as follows. In Section 2, a general scheme of the SRC based centralized target detection is proposed. In Section 3, a case study of the NCI detector is taken. The symbiosis effect and dominant capability with respect to the target-present SRC are specifically studied. Experiment results are presented in Section 4. Finally, conclusions are drawn in Section 5.

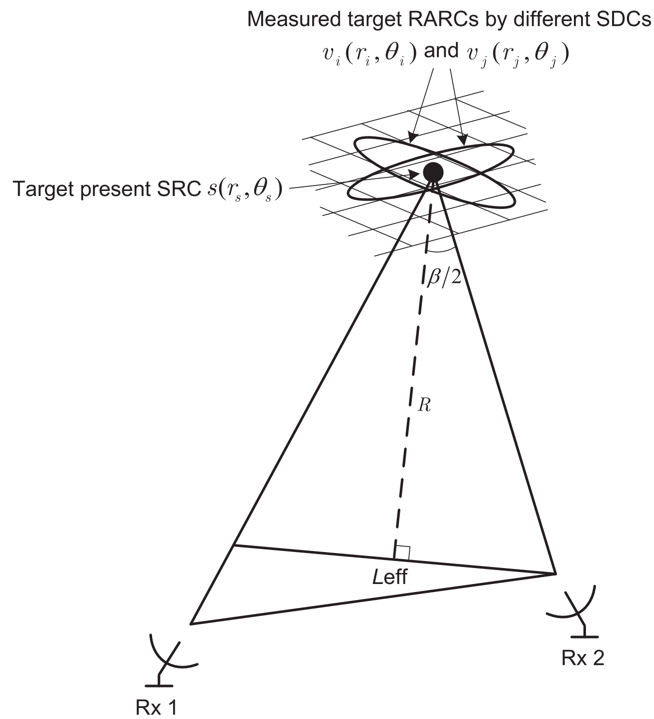

Fig. 1. Common surveillance region with many diamond-shaped SRCs of multistatic radar.

2. General scheme of the spatial resolution cell based centralized target detection

The common surveillance region of multistatic radar can be partitioned into many SRCs for subsequent signal fusion. Then, the target detection problem in multistatic radar can be considered as deciding whether a target is present in each probed SRC. Fig. 1 illustrates a two-dimensional surveillance region with many diamond-shaped SRCs. For the sake of brevity, the figure conceptually demonstrates a multistatic radar system with only two SDCs. The RARC of each transmit-receive facility pair can be regarded as an ellipse that comprises several SRCs in the two-dimensional space. The specific SRC where the target lies is denoted by a filled circle dot.

2.1. Monostatic and multistatic resolution

The definition of radar resolution is the degree to which two targets can be separated in one or more dimensions, such as range, angle and doppler [21]. For monostatic radar, the resolution cell geometry can be easily obtained. Conventionally, range resolution is taken to be $\Delta r_{\rm m} = c/2\Delta f_s$, where c is the speed of light and Δf_s is the signal bandwidth. Meanwhile, angle resolution is taken as $\Delta\theta_{\rm m} \approx \lambda_c/L_{\rm m}$, the 3dB antenna beamwidth, where λ_c is the signal wavelength and $L_{\rm m}$ is the antenna aperture. Hence, the size of one RARC of monostatic radar at a fixed target range R can be approximately given by

$$Q_{\rm m} \approx \Delta r_{\rm m} \times R\Delta\theta_{\rm m}. \tag{1}$$

For multistatic radar, the resolution cell geometry can be quite complex since the number of variables relating to the geometry is very large. Here, we simply take considerations of only two SDCs. Under this situation, range resolution can be taken at a level of $\Delta r_{\rm b} = \Delta r_{\rm m}/\cos(\beta/2)$, where β is the bistatic angle. Meanwhile, angle resolution is usually taken as $\Delta\theta_{\rm b} \approx c/L_{\rm eff}\Delta f_s$ [1], where $L_{\rm eff}$ is the effective length of baseline between radar stations. Hence,