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Radar sensor network for target detection using Chernoff information and relative entropy

Ishrat Maherin *, Qilian Liang

Department of Electrical Engineering, University of Texas at Arlington, Arlington, TX 76019-0016, United States

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ABSTRACT

In this paper, we propose to apply information theory to Ultra wide band (UWB) radar sensor network (RSN) to detect target in foliage environment. Information theoretic algorithms such as Maximum entropy method (MEM) and mutual information are proven methods, that can be applied to data collected by various sensors. However, the complexity of the environment poses uncertainty in fusion center. Chernoff information provides the best error exponent of detection in Bayesian environment. In this paper, we consider the target detection as binary hypothesis testing and use Chernoff information as sensor selection criterion, which significantly reduces the processing load. Another strong information theoretic algorithm, method of types, is applicable to our MEM based target detection algorithm as entropy is dependent on the empirical distribution only. Method of types analyzes the probability of a sequence based on empirical distribution. Based on this, we can find the bound on probability of detection. We also propose to use Relative entropy based processing in the fusion center based on method of types and Chernoff Stein Lemma. We study the required quantization level and number of nodes in gaining the best error exponent. The performance of the algorithms were evaluated, based on real world data.

1. Introduction

Time varying and rich scattering complex environment of forest makes target detection through foliage an ongoing challenge. In Radar Sensor Network (RSN), multiple distributed radar sensors survey a large area and observe targets from different angles. We can formulate the target detection as a binary hypothesis testing. To apply the Bayesian detection, accurate statistical information is necessary for this decision making problem. However, in many situations of practical interest we do not know the statistics of the probability of the target present or it might be very small. Also the distribution of foliage clutter is important. But it was shown that the foliage clutter behaves dynamically and it is impulsive in nature [1]. The challenges that are unique for this study are:

- Foliage clutter is dynamic and impulsive.
- The prior statistical information about the target presence is unknown.
- UWB signal shape changes many times during radar viewing. So conventional matched filters or correlators are unsuitable for target detection [2].

To deal with these problems we performed the data analysis and introduced information based target detection. Radars used in our experiments were mono-static and acted independently. From the experimental data collected by Air Force, it has been found that echoes with target has more random phenomena than the region without target, [3]. This finding leads us to use Maximum entropy Method (MEM) and mutual information as the target detection tool [4]. In this paper, we explain the reason of using relative entropy based preprocessing in fusion center. This can be explained based on method of types and Chernoff Stein Lemma. Method of types is a strong procedure

* Corresponding author. Tel.: +1 9723526624.
E-mail addresses: ishrat.maherin@mavs.uta.edu, i_maherin@yahoo.com (I. Maherin), liang@uta.edu (Q. Liang).

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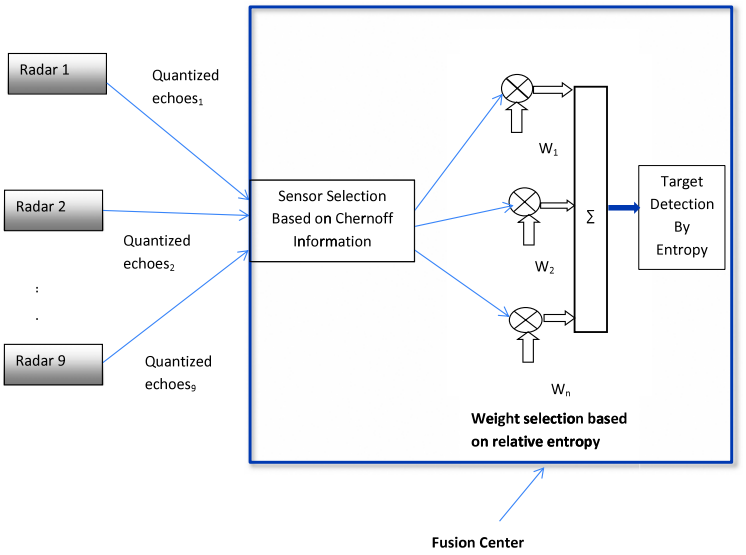

Fig. 1. Detailed block diagram for target detection through foliage.

that analyzes the sequences that have the same empirical distribution. This is applicable for our MEM based target detection algorithm, as entropy is dependent on the empirical distribution only. Based on this, we can find the bound on probability of detection. Also, the error probability associated with the detection is crucial in understanding the performance of the detection. Chernoff information gives the best error exponent in hypothesis testing, thus can be used as a sensor selection scheme in fusion center.

The potential of the method of types and Chernoff information is widely explored recently. A wide variety of information theoretic problems and communication problems deals with this new concept. Type based decentralized detection in wireless sensor network was investigated in [5]. A method of types approach was used for the acknowledgment reduction technique in multi-cast networking [6]. Chernoff information was used in optimization of sensor network in distributed detection [7]. Error exponents in target class detection was investigated in [8]. They were used in UWB [9] and also used in analysis of energy detectors of cognitive radio [10].

The rest of the paper is organized as follows: In Section 2, we describe the system model and block diagram. In Section 3, we explain the theory behind the method of types and Chernoff Information that are used in preprocessing and in sensor selection scheme. In Section 4, we present the simulation results. We conclude this paper and propose some future research in Section 5.

2. System model

RSN and rake structure that we employ in our work has nine different radars, each collected 35 readings as shown in Fig. 1. These radars are mono-static and independent. Since two radars will not experience deep fading at the same time, RSN provides better signal quality when they are spaced sufficiently far apart. Also the collections of the reading from different positions of the radar were not taken at the same time. This guarantees the time as well as spatial diversity in the proposed RSN.

Information collected by individual radars are quantized and sent to fusion center to combine by using the weighted average. But before the weighted average is applied, best sensors will be selected based on their Chernoff information. Also the weight will be applied based on relative entropy. Detailed analysis of these theorems are discussed in the Section 3. Finally, an information theoretic algorithm, Maximum entropy Method (MEM) is used to detect target [3]. Sensor selection and preprocessing have two fold advantages on target detection problem. By sensor selection, we reduce the computational load and take into account only the radars that are reliable. Preprocessing by relative entropy on the other hand significantly increases the performance.

3. Design and performance analysis

3.1. Method of types

Method of types is a powerful procedure in which we consider the sequences that has the same empirical distribution [11]. With this restriction, we can derive strong bounds on the number of sequences with a particular empirical distribution and the probability of each sequence in this set. It is then possible to derive strong error bounds in target detection problem, when Target detection is done using information theoretic method like entropy and mutual information, which depends only on empirical distribution.

Let $\mathbf{x}$ be a sequence of n symbols from an alphabet $X = \{a_1, a_2, \ldots, a_{|X|}\}$. The type $P_{\mathbf{x}}(a)$ (empirical probability distribution) of sequence is the relative proportion of occurrences of each symbol of X and can be written as [11],

$$P_{\mathbf{x}}(a) = N(a|\mathbf{x})/n, \quad \forall a \in X \tag{1}$$