Signal Processing for Closing Vehicle Detection

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Abstract

The performance of automotive controller area network (CAN) for safety driving applications based on the radar sensors is tightly related to the target vehicle detection. The presented paper deals with introduction of appropriate signal detection and signal processing techniques for closing vehicle detection (CVD) based on FMCW radar.

Keywords: Closing Vehicle Detection (CVD), Constant False Alarm Rate (CFAR), Frequency Modulation Continuous Wave (FMCW) Radar Sensor.

1. Introduction

The basic problem of any radar sensor used in the radio technologies for intelligent transport systems and for safety of driving applications is to detect the target vehicle within the limits of scanning area and define the target vehicle range, azimuth angle, and relative velocity. The closing vehicle detection (CVD) is defined as a detection of closing vehicles in one or several rear zones of subject vehicle and warns a driver per the predefined requirements [1]. The closing speed of a target vehicle is defined as the difference between the target and subject vehicle speeds. The target vehicle detection would be an easy problem with statistically completely known noise and interference, but in real radar applications, the noise and interference are stochastic processes. In this paper, the 24 GHZ frequency modulation continuous wave (FMCW) radar sensor is proposed as a the main principle technology for CVD application [2], and an appropriate signal detection technique is presented to obtain the low probability of false alarm and high probability of detection based on the constant false alarm rate (CFAR) approach.

2. CFAR Detection Technique for CVD

The FMCW radar sensor with high duty cycle seems to be very sensitive to noise, so it is important to deal with the noise situation correctly and ensure the required detection performance. The probability of false alarm P_{FA} is defined as the probability that a sample from the target return signal $r(t)$ will exceed the threshold voltage V_T when only the noise is received by the radar system [3]:

$$P_{FA} = \exp\left(-\frac{V_T^2}{2\sigma_n^2}\right), \qquad (1)$$

where σ_n^2 is the noise variance. The threshold V_T can be defined based on a specific P_{FA} as given by

$$V_T = \sqrt{2\sigma_n^2 \ln\left(\frac{1}{P_{FA}}\right)}. \qquad (2)$$

It is important to note that P_{FA} is very sensitive to any small changes in the threshold value. Fig. 1 shows a relation between the normalized detection threshold ($V_T / \sqrt{2\sigma_n^2}$) and the probability of false alarm P_{FA} .

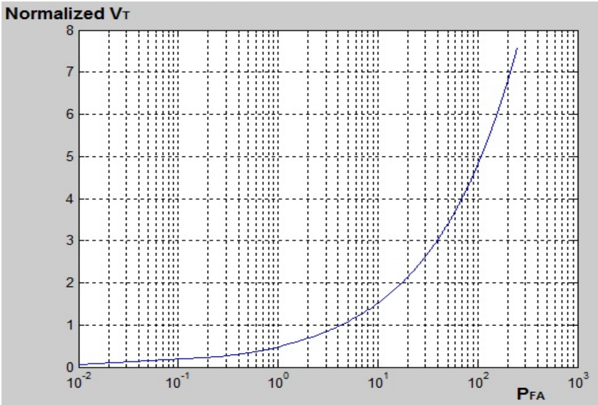

Figure.1: Normalized detection threshold versus P_{FA}.

If the noise variance σ_n^2 in (2) is assumed to be constant, then a fixed threshold can satisfy the threshold equation. However, owing to many reasons, this condition is not practical case and rarely is true. Thus, in order to maintain a constant probability of false alarm which is required in CVD application by tracking systems, the threshold value should be continuously updated or changed based on the noise variance (the background noise statistics are unknown and/or time-varying). The FMCW radar sensor input signal must exceed the threshold before a target return signal is recognized. The higher value for the threshold V_T, the lower detection probability and receiver sensitivity. There is a need to determine the detection threshold value in real time that complicates the threshold problem in detection and tracking systems. Under Neyman-Person criterion, we have to define, firstly, the error probabilities α and β that are used in the radar detection technique:

$$\alpha = P[d_1|m_0] = P_{FA},$$
$$\beta = P[d_0|m_1] = 1 - P_D = P_M, \quad (3)$$

where the event m_1 corresponds to a presence of target vehicles to be detected; the event m_0 indicates the absence of vehicle targets; and P_M is the probability of miss. It is desirable that the false alarm probability to be as low as possible, while the detection probability $P[d_1|m_1]$ should be high. A convenient strategy is to fix one of two probabilities at a given value, while the other one is optimized. This is precisely the Nyman-Pearson criterion that can be expressed more formally as follows: Fix $P[d_1|m_0]$ at a given value α_0 and then maximize $P[d_1|m_1]$. In the signal detection terminology: fix P_{FA}, then maximize P_D. The required signal detection scheme for CVD and tracking system should set the threshold adaptively based on the local information about the total noise power. This signal detection criterion is practically applied by constant false alarm rate (CFAR) systems. The threshold in CFAR detector using a sliding window technique is set on cell by cell basis to estimate the noise power by processing a group of reference cells surrounding the central cell (or cells) being investigated (test cell/cells). The available data in the reference cells is performed by a special algorithm to define the detection threshold. The first step is to estimate the average power Z of the noise by processing the reference cells. The second step is to multiply the estimated value Z by a scaling factor T that depends on the estimation procedure applied to estimate Z and the required false alarm rate. The resulting product is directly used as the threshold value, namely,

$$V_T = TZ. \quad (4)$$

Various CFAR algorithms are applicable in the FMCW radar sensor systems such as, the mean level CFAR schemes (cell averaging (CA-), greatest of (GO-), smallest of (SO-) CFAR), switching CFAR, and ordered statistic CFAR (OS-CFAR) [4]. In this paper we consider the CA-CFAR owing to a good performance in terms of probability of detection. The total noise power is estimated by a sum of N reference cells and given in the following form:

$$Z_{CA} = \frac{1}{N}\sum_{i-1}^{N} X_i. \quad (5)$$

The probability of detection can be presented in the following form:

$$P_D = [1 + T(1+S)]^{-N}, \quad (6)$$

where S is the average signal-to-noise ratio, N is the number of reference cells, and T is the scaling factor. The scaling factor is given by:

$$T = (P_{FA})^{-1/N} - 1. \quad (7)$$

3. Simulation Results

In order to find out the practical performance of proposed target vehicle detection technique, the practical probability of detection is defined after number of observations equal to M. This simulation method allows us to enhance the accuracy of making-decision about the presence of the target vehicle, and helps us to obtain a practical simulated detection performance as a function of the signal-to-noise ratio (SNR). In the case of noise only and when the number of realizations M is equal to 100, the results of simulation for noise and threshold are shown in Fig.2.

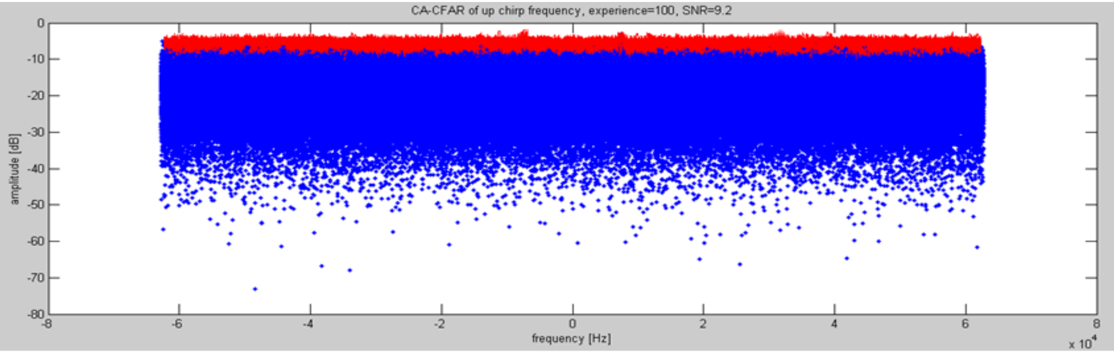

Figure.2: Noise (blue) and threshold (red) when there is no target return signal.

Figure.3 shows the upbeat frequency (the frequency difference between the transmitted and target return signals) for the up-sweep of the modulation signal in the case a “yes” target return signal at M=100.

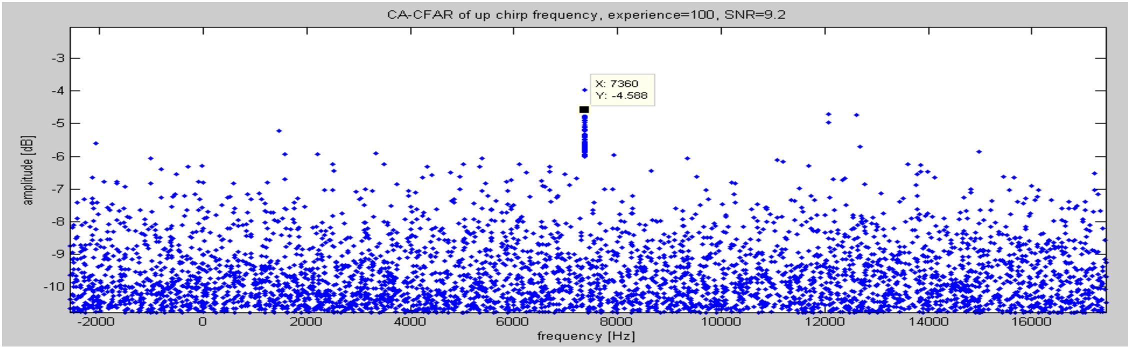

Figure.3: The simulation result in the presence of the target vehicle return signal.

P_D is defined as the ratio between the number of frequency components that exceed the threshold K and the total number of observations M:

$$P_D = \frac{K}{M}. \quad (8)$$

The detection performance at $P_{FA}=10^{-3}$ and M=100 is shown in Figure.4.

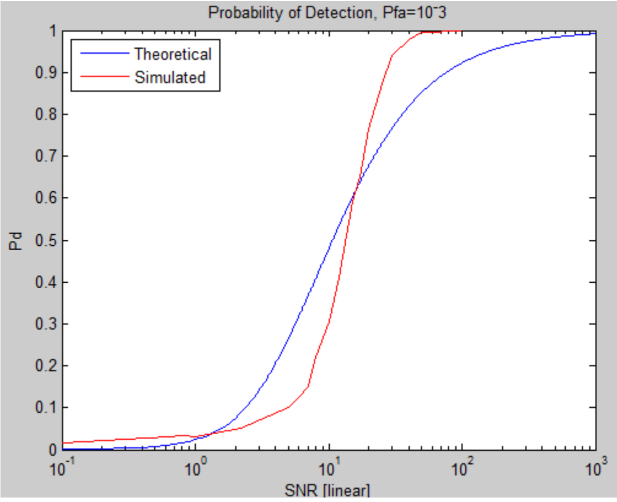

Figure.4: Detection Performance.

4. Conclusion

The implementation of signal detection technique with adaptive threshold in CVD application is very essential. The threshold should be determined in accordance with the locally observed noise and clutter for different values of the radar range under the condition when σ_n^2 is variable. The discussed signal detection procedure is very helpful to compare the theoretical probability of detection as a function of the signal-to-noise ratio (SNR) and the probability of detection obtained by simulation.

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Acknowledgments

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