Interference Mitigation in Automotive Radars

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Abstract

We study the mutual interference problem arising in the fast growing market of automotive radars. For the widely used frequency-modulated continuous waveform automotive radars, the major consequences of mutual interference are ghost targets and increased noise floor. The schemes of interference mitigation are then investigated, including adaptive signal processing in the time domain at receive side, modulation and beamforming techniques in the frequency and spatial domains at the transmit side, as well as multiple access and cooperation schemes with the help of a vehicle ad hoc network.

Index Terms

Automotive radar, FMCW, mutual interference, interference mitigation

I. INTRODUCTION

The automotive radars are key sensors for the advanced driving assistance systems (ADAS) and play a key role in obstacle detection for autonomous driving. The frequency-modulated continuous waveform (FMCW) radar technique is widely used in assistant automotive driving because of its good performance in measuring the range and speed simultaneously at a relative low cost. In the FMCW radar, the transmit frequency is linearly swept up and then down. During the up-chirp ramp, the difference frequency between the transmitted and received echo is called the up-chirp beat frequency. The down-chirp beat frequency is defined similarly. Range and speed information of targets can be retrieved when these two beat frequencies are obtained [1].

With the increasing of cars equipped radars running at the similar frequency band simultaneously, the mutual interference between automotive radars becomes a challenging problem. A simple scenario of mutual interference in automotive radars is shown in Fig. 1 [2], where an oncoming car interfering the radar directly. Another possible interference scenario is that a front car equipped with a rear radar sensor...
would generate interference to a car following it in a short distance. The interference from other FMCW radars would result in two major issues: 1) ghost targets and 2) increased noise level [2][3]. When the relative phase of an interference signal is within the round-trip time of FMCW radar, the generated beat frequency would result in ghost target. When the relative phase is out of the round-trip period, the beat frequency would increase noise floor. The ghost targets would trigger false alarm while the increased noise floor would degrade the radar detection sensitivity.

To anticipate the development of interference mitigation in automotive radars, the more safety for all by radar interference mitigation (MOSARIM) project was initialized by European Commission [4].

It should be pointed out that there is mutual interference between the ISM band and UWB automotive radar operating at 24 GHz frequency. In general, the coexistence between radar and wireless communication systems in the overlapped spectrum is an open research problem [5] and many methods have been proposed, such as projection based nulling [6]. By the European regulation, no new vehicle could be equipped with 24 GHz UWB sensors after 2013 [7]. In the year 2022, all the automotive radars operated at 22-29 GHz would shift to 77-81 GHz frequency range that is allocated only for vehicle radars [8]. With fulfillment of this shift, the coexistence problem between ISM band and automotive radar would be solved eventually. Thus, in the following we focus on mutual interference mitigation among automotive radars only.

### II. Mutual Interference Mitigation Techniques

In this section, we will study several methods to mitigate the mutual interference in automotive radars. These methods can be classified into working in the time domain, spatial domain, and frequency domain; they can also be classified into working at transmit (Tx) side or receive (Rx) side.

To identify the interference is the first step. In the mutual interference scenario considered in Fig. 1, a natural way is to use the averaged receive signal energy as a merit. When the averaged receive signal
energy is above a limit, the interference happens [9].

A. Frequency Hopping and Coding Methods at Tx Side

When the interference is detected, one can pause for a random duration between chirps. As indicated in [10], this method can suppress interference only a few dB. The ghost targets are mitigated at a cost of increasing noise floor.

If the chirp bandwidth of long range FMCW radar is narrow, there would be enough frequency bands in 77-81 GHz range. When adjacent automotive radars detect that the received noise level is above a threshold, frequency hopping idea from Bluetooth communications can be applied to make the probability of two neighbor automotive radars operating at the same frequency band extremely low. However, the relative narrow bandwidth would result in coarse range resolution. This method can remove most of the interference and its efficiency depends on the occupied bandwidth and available bandwidth.

To utilize the wide bandwidth, a frequency hopping random chirp (FHRC) method was proposed in [1] to design long range automotive FMCW radar to mitigate the ghost target due to the mutual interference. The parameters of FMCW radar, such as chirp bandwidth, interval, center frequency are configured in a pseudo-random fashion in each chirp cycle such that the probability of adjacent automotive radars with the same chirp pattern is quite low. The intuition is to reduce the correlation between the interference and desired signal and the make the interference noise-like. As a result of the proposal, the spurious tone of ghost target is removed at a cost of increased noise floor, which would degrade the radar detection sensitivity.

Similar to idea of [1], pseudonoise (PN) code sequences were applied in [11] to modulate the FMCW radar waveforms. As a result, the ghost target is mitigated at a cost of increased noise floor.

The report [10] indicates that only a few dB interference suppression is expected using random sequence of chirp pattern.

B. Beamforming Techniques with Radar Array at Both Tx and Rx Sides

Equipped with a radar array, beamforming can be applied in both transmit and receive sides to suppress the interference by exploiting the spatial degree of freedom.

With the phased-array techniques, the radar sensor array mounted at the front side of a car can form a narrow beam to scan long/median/short range area in front of it cyclically. The goal of transmit beamforming is to control the side lobe of the scanning beam in order to suppress the power leakage/interference to cars running along adjacent lanes.
At the receive side, with a radar array, receive beamforming can be used to suppress the interference emitting from other automotive radars while allowing the signal from the interested directions pass without reduction. In [9], digital beamforming (DBF) is proposed for interference mitigation. To apply DBF, the covariance matrix of the receive signal needs to be known, which can be estimated via the samples. Usually the diagonal loading technique is applied in the receive beamforming. The DBF can be implemented via FPGA or DSP and its advantage is low cost, design flexibility and reliability.

The experimental data in [10] shows that the DBF could only achieve a few dB interference suppression. Actually, the suppression effect depends on the beamwidth. A large size array would provide more degree of freedom for spatial interference mitigation.

C. Pre-Processing in Time Domain at Rx Side

Considering pre-FFT processing in the time domain, replacing zeros for the received signal over the period of interference is a simple way to suppress a short duration interference [3]. The original signal in the short duration could be extrapolation from samples before the interference when signal-to-noise ratio (SNR) is high. If the interference is narrow band but has a long duration, an adaptive notching filter could be designed to suppress the interference frequency.

However, the above methods require the knowledge of interference in both time and frequency domain. Further, these methods could not remove all interference with relative wide bandwidth.

In [12], based on the received samples, the parameters of interference signal with chirp sequences or FMCW waveforms can be estimated in time domain. The idea is to estimate the amplitude and phase parameters of the interference signal using sufficient samples. The reconstructed interference is then subtracted from the raw samples. However, the procedure involves high computation and parameter estimation accuracy is related to the number of available samples.

It was shown in [10] that detection of interference and repairing the receive signals in the time domain could achieve around 20 dB in interference suppression.

D. Polarization

It is suggested in [10] that specific polarization following radar locations, e.g., frontal, rear and side could be exploited to suppress the interference. In the automatic cruise control (ACC) application, 45 degree slant polarization has been used, resulting in 15 dB interference reduction from oncoming radars.
E. Multiple Access Schemes at Tx Side

One idea is listen before talk, borrowed from wireless LAN, which can be reviewed as a scheme of carrier sensing multiple access (CSMA). The automotive radars first listen until the frequency band is valid and then transmit.

If the pulse radar technique is used in automotive, one can apply the pulse compression (PC) technique. The radar transmits a long PN sequence to allow multiple radars operating at the same frequency band simultaneously using the coding division multiple access (CDMA) [13]. The PC scheme could enhance the signal power and reserve the range resolution corresponding to single pulse.

F. Cooperative Among Automotive Radars

The cooperative method could be building a coordination scheme to assign separate frequency bands for the cars along the same driving direction in a spatial colocated area. This coordination scheme would be running on a vehicle-to-vehicle (V2V) communication network, also known as vehicular ad hoc network (VANET) [14]. The coordinate scheme should be adaptive as cars join and leave. Furthermore, the same frequency band could be reused for automotive radars when their distance is larger than a pre-defined range, a similar idea borrowed from 3G cellular networks. The advantage of cooperation using VANET is that it can provide the optimal wide bandwidth spectrum allocation among a group of radar sensors. One challenge of this proposal is to build a VANET across cars of different manufacture dates/types/vendors. However, there is still a potential probability of interference coming from crossing traffic vehicles which are not nodes of the VANET.

III. Conclusions

We have briefly reviewed the mutual interference problem arising in automotive radars and to suppress the interference, multiple solutions have been proposed, which can be classified into working in the time, frequency, spatial domains as well as working at transmit or receive side. By adaptively allocating separated frequency bands to adjacent automotive radars and reusing these frequency bands geometrically, such as frequency hopping or cooperation between radar sensors, good interference mitigation performance are expected. With the deployment of radar array, which can resolve closely located obstacles in the spatial domain, beamforming techniques are also good options for interference suppression at both transmit and receive sides. Among many proposals, performance and cost/complexity trade-off is a big concern when one considers implementation.
REFERENCES


