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Anti-jamming signal processing of automotive forward-looking radar

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Abstract

With the increasing application of automotive forward-looking anti-collision radar, the number of radars during road driving is also increasing year by year, making the interference between automotive anti-collision radars increasingly serious, and automotive anti-collision radars receive electromagnetic waves from multiple vehicles Interference, because the interference signal is similar to the echo signal, the signal processing part can easily regard the interference signal as an echo signal, which will cause the radar to issue a false warning, which affects the normal operation of the radar and the judgment of the motor vehicle driver. Aiming at the interference problem of automobile anti-collision radar, the LFM-OFDM combined waveform is introduced by analyzing the principle of cross interference. Based on this combined waveform, the method of adaptive digital beamforming is used to suppress the interference, and the simulation results are given.

Keywords

Forward-looking radar, signal processing, adaptive beamforming.

1. Introduction

The design of signal waveforms transmitted by automotive radars has an extremely important position. Generally speaking, the working environment of automotive radars is complex, and cross-interference between automotive radars often occurs. Even in such a high-density target environment, it still needs to get the distance and azimuth information of all targets in the front observation area, and it needs to be completed in a short measurement time, while maintaining high distance accuracy and resolution. A good automotive radar, first of all, should have strong anti-interference ability to transmit signals.Scholars have successively proposed some anti-cross-interference methods for waveform design. The simplest automotive radar waveform is a single-frequency continuous wave signal used in overspeed detection[1-2], which can only achieve speed detection of moving targets, but cannot achieve static Target detection and distance judgment; It is difficult to determine how many wavelengths the frequency shift keying signal has passed from the launch to the target echo, so it has no distance measurement and resolution capabilities; The difference frequency of the single chirp continuous wave signal contains the frequency offset caused by the target distance and the Doppler shift caused by the velocity, and the distance and velocity are deeply coupled and cannot be distinguished; The use of triangular frequency modulation continuous wave radar is an important method for automotive radar to eliminate distance Doppler coupling. It uses continuous periodic change of positive and negative slope linear frequency modulation signals, and uses the opposite characteristics of the up-frequency and down-frequency difference frequency signals to achieve accurate moving targets The distance-velocity joint estimation can solve the distance-velocity coupling problem in monotonic frequency continuous wave moving target detection[3]. In most application scenarios of automotive radar, multiple stationary and moving targets exist at the same time[4]. When multiple moving targets exist, the triangular frequency modulation radar will have false targets when detecting multiple moving targets; Variable slope-double triangle frequency modulation continuous wave can effectively deal with the parameter estimation problem of multiple moving targets, but each processing cycle needs to transmit 4 frequency sweep cycles, and the processing time is too long, which seriously affects the data rate; In order to avoid triangular wave FM false targets and data rate problems, FM continuous wave radars usually use burst mode[5]. This paper analyzes the LFM-OFDM signal model, uses adaptive digital beamforming to suppress interference based on LFM-OFDM, and simulates radar ranging and speed measurement.

2. LFM-OFDM signal model

As shown in Figure 2-1, the LFM-based spread spectrum multi-carrier (LFM-OFDM) communication system block diagram, through serial-to-parallel conversion of binary data, the system autonomously completes digital mapping, and then performs IFFT modulation through pilot insertion, and then LFM completes the spread spectrum of the system, thereby generating an LFM-OFDM symbol[8-11]. The difference between this system and the traditional OFDM system is that before and after IFFT/FFT, the signal is subjected to LFM spreading and despreading.(Figure 1 cited from reference [8])

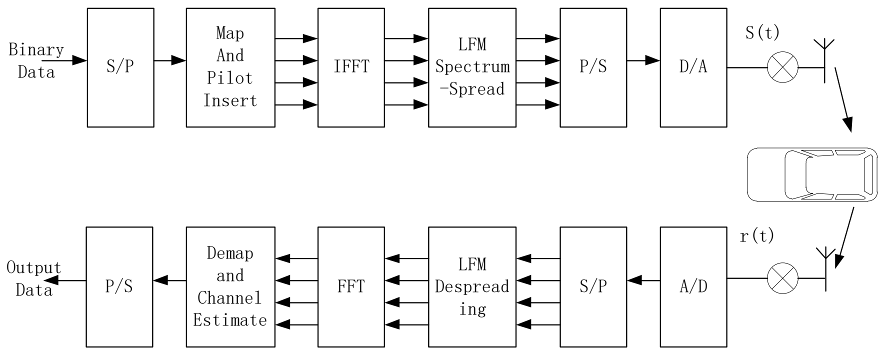

Figure 1:LFM-OFDM system block diagram[8]

2.1. Transmitting signal model

Since the LFM-OFDM signal is obtained from the OFDM signal through LFM spread spectrum, its signal model will have many similarities with the OFDM signal model[8-11]. The LFM signal is introduced into the OFDM signal, that is, each sub-pulse of the OFDM signal contains LFM signals of different carrier frequencies, and the resulting signal is called the LFM-OFDM signal. Among them K, Δf , T_G ,n they are the frequency modulation slope, adjacent sub-carrier spacing, CP time, and sub-carrier index value. $T_s = T + T_G$. T represents the effective integration time of IFFT, the time range T_s in the subcarrier expression represents the duration of a complete LFM-OFDM symbol, and it is known that the number of subcarriers in an LFM-OFDM symbol is N, and one frame of LFM-OFDM signal The number of LFM-OFDM symbols in is M[8].The modulation domain data of the nth subcarrier is X_n , and the rectangular pulse function is $g(t)$.

Among them $X_{m,n}$, m, are respectively the modulation domain data and symbol index on the nth subcarrier of the mth LFM-OFDM symbol. One frame of LFM-OFDM baseband complex envelope signal at the sender is $T_I(t)$.

The signal at the transmitting end is formed by linear superposition of multiple modulated sub-carriers[6], Assuming that f_c is the carrier frequency, the transmitted signal is as follows[8-11]:

$$\begin{aligned} T(t) &= \mathrm{Re}[T_I(t)\exp(j2\pi f_c t)] \\ &= \mathrm{Re}[\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} X_{m,n}\exp(j2\pi(n\Delta f(t-T_G)+\frac{K}{2}(t-T_G)^2+f_c t))g(t-mT_s)] \end{aligned} \tag{1}$$

2.2. Received signal model

Figure 2-2 shows a simplified LFM-OFDM radar receiving block diagram. The signal transmitted by the transmitting end needs to be scattered many times before returning to the receiving antenna. After being sent to the RF module, it performs low-noise amplification, down-conversion, etc. After the column operation[8-11], it is followed by analog-to-digital conversion and input to the radar processing module for speed and distance calculations[7]. (Figure 2 cited from reference [8])

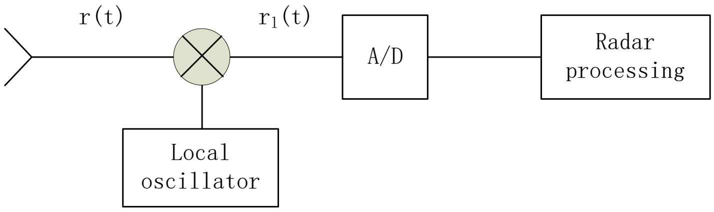

Figure 2:LFM-OFDM system receiving block diagram[8]

f_d, τ_p, p are Pule frequency, time delay, number of scattered targets, Where c and λ_n are the electromagnetic wave velocity and the wavelength of the nth subcarrier respectively. A_p is the amplitude and phase attenuation on the pth transmission path[8].

The received signal expression is[8-11]:

$$r(t) = \sum_{p=1}^{P} A_p \exp(j2\pi f_d(t-\tau_p))T_I(t-\tau_p) \tag{2}$$

3. Simulation analysis

Various simulation parameters

Carrier center frequency: f_c =77GHz;

Transmitting power: $P_t = 1.5mw$;

Number of sub-carriers: N=1024;

Subcarrier spacing: Δf = 90.909KHz;

Original symbol time: $T = 6.4\times10^{-6}$ s;

Cyclic prefix time: $T_G = 1.6\times10^{-6}$ s;

Symbol total time: $T_s = 8\times10^{-6}$ s;

Number of symbols: M=256;

Total signal bandwidth: B=186×10^{6} Hz;

Frequency modulation slope: K=7.5, frequency modulation slope unit MHz/us;

Number of array elements: 8;

Snapshots: 512

Interfering signal carrier center frequency, number of sub-carriers, sub-carrier spacing, original symbol time, cyclic prefix time, total symbol time, number of symbols, total signal bandwidth, frequency modulation slope does not change, add the transmit signal of the interference car, the interference car and The self-vehicle distance is 150m, the speed is 10m/s, and the simulation is performed, and the following figure is obtained:

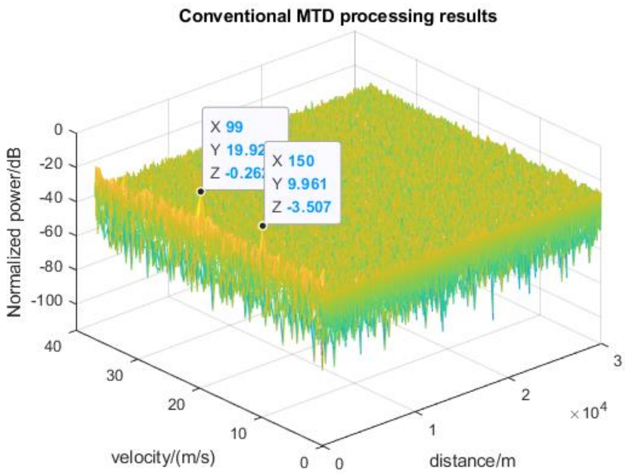

Figure 3: Conventional MTD processing results

The above picture is a simulation diagram after adding interference signals. When the distance is equal to 99m, it is the target signal, and when the distance is equal to 150m, it is the interference signal. Because the existence of the interference signal will affect the detection of the target signal, it will lead to misjudgment. The interference signal is judged as Target signal, causing danger.

Based on LFM-OFDM, an adaptive digital beamforming method is proposed to suppress interference. The array output selects an appropriate weighting vector to compensate for the propagation delay of each array element, so that the array output can be superimposed in the same direction in a certain desired direction, so that the array produces a main lobe beam in that direction, and in a certain direction A certain degree of interference is suppressed in the direction. Adaptive beamforming is to realize the optimization of the weight set through an adaptive algorithm under a certain optimal criterion. The adaptive beamforming can adapt to various environmental changes and adjust the weight set to near the optimal position in real time. In simple terms, adaptive beamforming is to suppress interference through beamforming, and form a null in the interference direction to filter out the interference signal. In this paper, the capon algorithm is used for adaptive beamforming, and a null is formed at the interference to achieve the purpose of anti-interference. The figure below shows the pattern of adaptive beamforming.

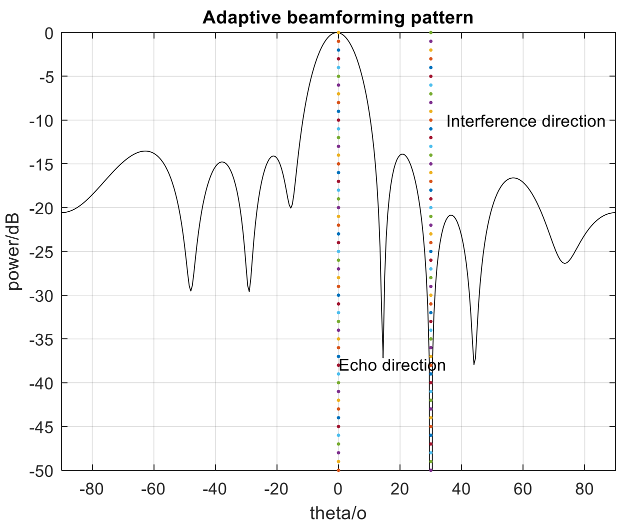

Figure 4:Adaptive beamforming pattern

The abscissa is the angle and the ordinate is the power. The angle of the target vehicle relative to the self-vehicle set in the simulation is 0 degrees, that is, the angle of the interfering vehicle

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relative to the self-vehicle is 30 degrees in the same direction. It can be seen that there is a null in the direction of 30 degrees, thereby suppressing interference signals.

The following figure is a simulation diagram of suppressing interference signals.

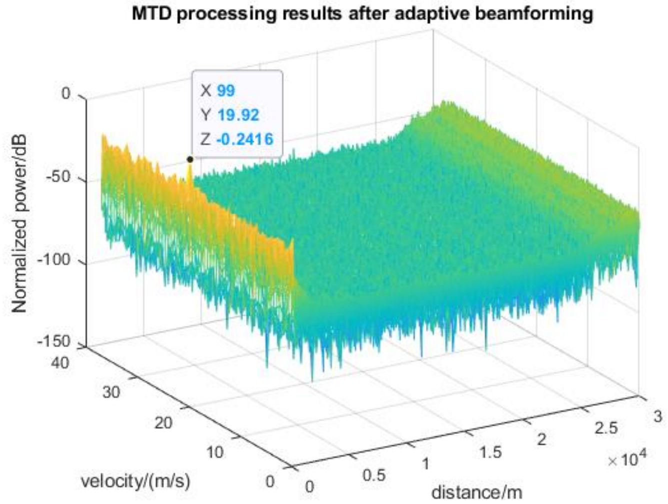

Figure 5:MTD processing results after adaptive beamforming

It can be seen from the figure that the interference signal at a distance of 150m is filtered out, and the target signal can be obtained for range and speed measurement.

4. Conclusion

This article introduces the LFM-OFDM combined waveform, and analyzes its transmitted signal model, received signal model and the principle of distance measurement and speed measurement. Through the analysis, several sets of distance measurement and speed measurement are compared. The simulation results show that the measured distance and speed are similar Then, on the basis of ranging and speed measurement, interference signals from other vehicles are added, and simulation experiments are carried out. It is concluded that the interference does exist. Based on this combined waveform, the method of adaptive digital beamforming is used to suppress the interference, and the capon algorithm is used for adaptation. Beam forming, forming a null at the interference to achieve the purpose of anti-interference, obtain the target vehicle signal, and improve the measurement accuracy of the automotive radar.

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