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Application of Sparse Array Technology in Vehicle Borne Millimeter Wave Radar

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ABSTRACT. *In recent years, with the continuous maturity of integrated circuit and antenna technology and the continuous reduction of component cost, automotive radar products are continuously developed and applied. As an important part of intelligent vehicle and intelligent transportation, the frequency of vehicle borne millimeter radar has been paid special attention by the national radio management department. The purpose of this study is to explore the mechanism and advantages of sparse array technology in vehicular millimeter wave radar. Based on the sparse array technology, the array structure is optimized, and the vehicle borne millimeter wave radar is simulated. The experimental results show that, compared with simulated annealing algorithm, the optimal and worst PSLL of sparse array algorithm are improved by 5dB and 2dB respectively, the optimal peak sidelobe level is - 15dB, the worst peak sidelobe level is - 14.5dB, and the corresponding aperture size of sparse array is 22 and 26, respectively.*

KEYWORDS: *Sparse Array Technology, Vehicular Radar, Millimeter Wave Radar, Optimized Array*

1. Introduction

Millimeter wave radar is a kind of radar which works in 30-300Ghz frequency band with the wavelength of 1-10mm. Millimeter wave has the advantages of microwave and far-infrared wave spectrum. It has the characteristics of long detection range, fast response speed and strong adaptability. Its detection range can reach more than 250m, the propagation speed is similar to the speed of light, and its modulation is simple. It is combined with high-speed signal processing system, it can quickly measure the distance, speed, angle and other information of the target [1-3]. Compared with other radars, millimeter wave radar has stronger penetration ability and can work in extreme weather such as rain, snow, fog, etc., and is not affected by color, temperature, illumination and other factors, so it has all-weather characteristics [4]. Under the background of the rapid development of intelligent connected vehicles, the on-board millimeter wave radar will play an important role

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in the realization of autonomous driving, and the prospect and market space of promotion and implementation will be very broad. [5].

Millimeter wave (MMW) radar is better than optical camera in robustness and ranging capability under different weather and illumination conditions. However, the characteristics of road features in millimeter wave radar images are quite different from those of optical images. Even physically continuous features, such as road edges, can also be represented as a group of bright spots or bright spots distributed on the roadside. Therefore, in the automotive imaging system, the recognition of radar features is very important. In order to solve this problem, Guo proposed a method called fringe Hough transform (HT), which can enhance the geometric feature extraction of road path. By comparing the extracted MMW image features with the actual road geometric features and the classical HT processing results, the effectiveness of the method is proved [6].

In this study, a signal processing algorithm for FMCW vehicle mounted millimeter wave radar based on space-time block code is designed. Compared with the virtual array algorithm based on time diversity, it can form a virtual array with the same antenna aperture and use the power gain brought by multiple antennas working at the same time to obtain higher system performance [7-8]. At the same time, aiming at the requirement of low cost of vehicle mounted millimeter wave radar system, a low complexity virtual array phase compensation algorithm suitable for coherent targets is designed. The simulation results verify the effectiveness of the algorithm [9-10].

2. Based on Sparse Array Algorithm

2.1 Sparse Array

In radar system, the elements of uniform array are arranged at fixed intervals, which are usually called periodic array or full array. Sparse array is a kind of sparse array, also known as periodic sparse array. It is formed by randomly removing elements from uniform array according to certain rules according to a given sparse distribution rate, or by making some selected elements in uniform array not working. Since the sparse array is extracted from the grid of uniform array, the spacing between elements is usually an integral multiple of grid spacing. Another kind of sparse array is that the array elements are randomly arranged on the same aperture as the full array. The spacing between the elements is usually not fixed and can be any value, which is also called random sparse array.

In radar system, the use of sparse array antenna array can greatly reduce the number of array antenna subarray and corresponding transceiver units. It has been widely used in the working environment with high spatial resolution and many constraints on equipment volume and weight. The sparsity ratio is usually used to measure the sparsity degree of the sparse array antenna. The sparsity ratio refers to the ratio between the number of antenna elements Ne and the total number of array grids N. if the sparsity rate is ξ, then

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$$\xi = \frac{N_e}{N} \quad (1)$$

The smaller the value of the sparsity rate ξ is, the greater the sparsity is, and the working array units of the radar are also less. However, the sparsity ratio should not be too low, otherwise the gain of the antenna will be too small to meet the working requirements. Usually, a fixed sparsity ratio is specified in the antenna design process to ensure that the antenna can maintain a certain gain.

2.2 Overview of Optimization Model

It is assumed that the number of elements in the optimized linear array model is 2N, the array aperture is 2L, and the array element spacing is dc. Considering the symmetry of the array, the excitation amplitude of N elements is taken as the optimization parameter. The purpose of optimization is to reduce the sidelobe level of linear array as much as possible. The design fitness function is as follows:

$$fitness = \max\{|\frac{F(\theta^{+})}{F_{\max}}|\} \quad (2)$$

Fmax is the maximum value of the level, and the above formula shows that the electric field value is normalized. θ + represents the value space of θ direction except the main lobe region. The fitness function can be understood as calculating the maximum side lobe level of the linear array pattern.

3. Collision Simulation of Millimeter Wave Radar

3.1 Simulation Model

Radar mainly includes: radar bottom shell, signal processing board, radar shell, connector, antenna board and radar mask, totaling six parts. From the perspective of collision simulation, the fixed relationship between components is analyzed. Among them, the connector placed on the outer side of the short side of the radar shell is fixed with screws, which belongs to rigid connection; the antenna board is placed on the side of the large side of the radar shell and fixed with screws, which belongs to rigid connection; the signal processing board is placed on the large side of the radar shell and is fixed with screws for another time, which belongs to rigid connection; the radar mask and the radar shell are bonded with rubber glue, belonging to elastic connection; The radar bottom shell and the radar shell are bonded with rubber glue, belonging to elastic connection. Due to the limited simulation time, the strength of glue is not checked.

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3.2 Simulation

In the drop test, the samples were dropped on the cement floor at the height of 1m (plus or minus 0.05m). The number of times of drop was 2 times in each axial direction and 6 times in three directions. This simulation project takes the test drop test as a reference, and also assumes that the product falls from LM height, assuming that the cement floor is a rigid object, then the impact speed can be calculated as follows:

$$v = \sqrt{2gh} = 4.42(m/s) \tag{3}$$

3.3 Material of Model

The material of each component is shown in Table 1:

Table 1 Component material list

Component name	Material model	Density (kg/m2)	Poisson's ratio	Yield strength
Connector	Pa6-gf48	3800	1.48e+09	0.27
Radar shell	Adc10	2900	5.00e+04	0.31
Circuit board	Pcba	1080	2.73e+09	0.29
Upper and lower covers	Pbt-gf25	1200	4.87e+08	0.41

4. Simulation Experiment Based on Sparse Array Technology

4.1 Collision Velocity Curve

The impact force is affected by many factors. It mainly includes the mass of the colliding object, the velocity of the colliding object, the rigidity of the colliding surface, the geometry of the colliding surface, and the material properties of the colliding object. The figure shows that the maximum impact force is about 0.4 ms, and the force amplitude is about 2.8 kn. The speed curve of output connector and radar shell is shown in Figure 1.

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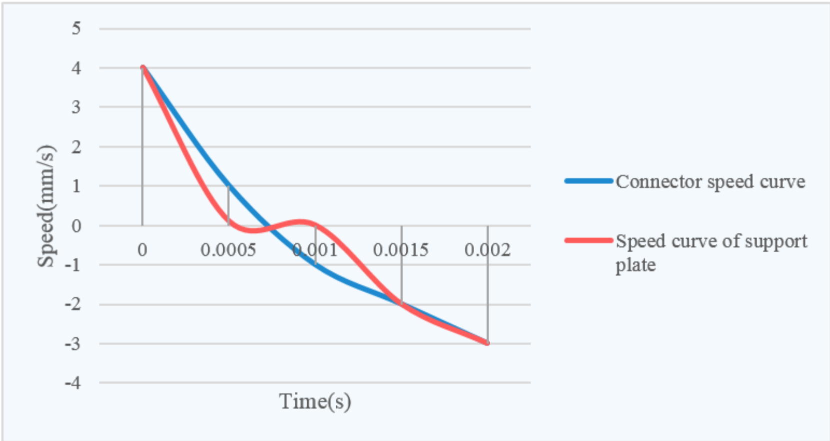

Figure 1. Collision velocity curve

It can be seen from the velocity curve that since the connector is the first to contact the ground, the speed mutation is obvious, and then the deformation absorbs part of the energy, making the speed gradually stable and negative. In the process of collision, the connector is equivalent to a buffer element, so the collision speed of radar shell changes relatively slowly. The overall rebound velocity is about 2.4 meters per second, which is lower than the initial collision speed, which is related to the energy loss in the collision process.

4.2 Optimize Array Structure

Considering that the array structure to be optimized is a sparse array with the largest aperture, the array in this study is optimized. The simulated annealing method is used to optimize the array element position and excitation distribution simultaneously when the array aperture is 32 and the number of array elements is n = 23. In order to compare the performance of other algorithms, the same conditions are selected when the proposed method is used to optimize the array, that is, the maximum array aperture is 32, the number of array elements is n = 23, and the minimum array element spacing is half wavelength. At the same time, the initial parameters of genetic algorithm are set as follows: the initial population size is equal to 20, the maximum number of iterations is 80, and the crossover probability is 0.5. The optimal peak sidelobe level is - 15dB and the worst peak sidelobe level is - 14.5db. The corresponding aperture sizes of sparse array are 22 and 26 respectively. Compared with simulated annealing algorithm, the optimal and worst psll of sparse array algorithm are improved by 5dB and 2dB respectively. The optimal, worst and average convergence curves of three independent tests are carried out, as shown in Figure 2.

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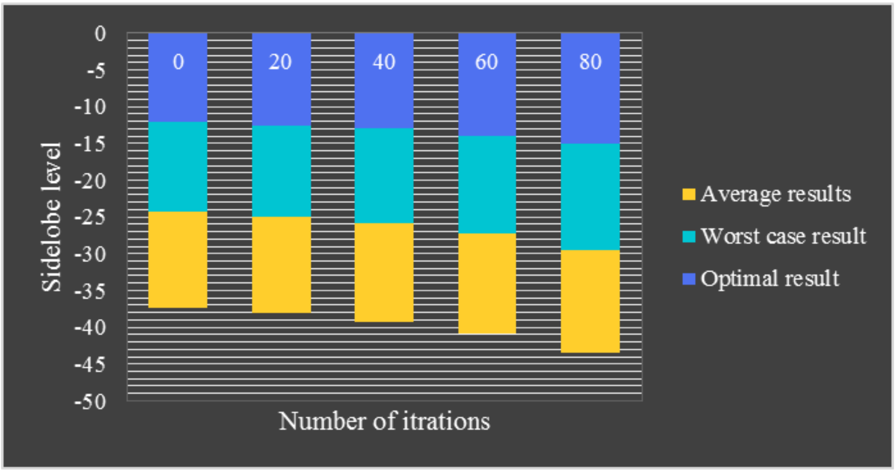

Figure 2. Peak value of side lobe level

In order to evaluate the performance of the array, it is very important to evaluate the performance of the array with the minimum peak value. The minimum sum of peak sidelobe levels is introduced into the random sparse array configuration to reflect the performance of array design more effectively.

In random sparse array, the position of array elements is randomly and sparsely arranged according to a certain distribution, and the energy of grating lobe is effectively pressed into the side lobe, which leads to the elevation of receiving array pattern sidelobe. Because the position of random sparse array is randomly distributed, only how to effectively eliminate the influence of grating lobe is considered, and the side lobe of pattern is not constrained. If the signal-to-noise ratio is low, high side lobe will lead to angle measurement error. Therefore, we will study the optimized sparse array, which not only eliminates the influence of gate lobe, but also suppresses the high side lobe. The optimization of sparse array configuration is mainly to select a cost function and use optimization algorithm to solve the optimal array element position or weighted value, so as to eliminate the grating lobe.

4.3 Simulation Results and Analysis

The simulation platform is built based on the system parameters of the actual vehicle mounted millimeter wave radar. The angle measurement performance and the motion phase calibration algorithm of the three schemes are compared by comparing the simulation time diversity scheme, space-time block code scheme and simultaneous transmission scheme. The simultaneous transmission scheme is that the transmitting lines work at the same time, and the receiving end does not do virtual array processing, and their corresponding equivalent phase modulation matrix. The horizontal axis is the CBF angle value, the vertical axis is the energy

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value, and the noise power is normalized to 1. The two simulation targets have the same radial distance, radial velocity and RCS, and the azimuth angles are 0 ° and 20 ° respectively. Both space block code and time diversity virtual array algorithm adopt the motion phase calibration algorithm based on velocity parameter estimation proposed in this paper. The space-time code scheme can obtain the same angular resolution as the time diversity scheme by phase calibration and decoupling of the target spectrum signals. Compared with the simultaneous transmission scheme, the angle resolution of the vehicle borne MMW radar is significantly improved through the virtual array algorithm. The system resolution simulation diagram shows the CBF simulation results of time diversity scheme based on different phase calibration algorithms in coherent target scene, in which the noise power is normalized to 1. The two simulation targets have the same radial distance, radial velocity and RCS, and the azimuth angles are 0 ° and 20 ° respectively. The phase calibration algorithm based on velocity parameter estimation can distinguish two coherent targets obviously. The difference phase calibration algorithm is not applicable in the scene of coherent targets, and can not accurately estimate the angle parameters of two targets, or even distinguish the number of coherent signal sources. It is the simulation of angle estimation accuracy and false alarm rate of time diversity scheme and space-time block code scheme. The performance of angle parameter estimation and false alarm rate based on space-time block code is better than that of time diversity millimeter wave radar system in the effective detection range of vehicle borne millimeter wave radar, especially in the scene with low signal-to-noise ratio in long-distance. Compared with time diversity, space-time block code (STBC) can obtain the power gain of multiple transmitting antennas under the condition of single transmission channel power limitation of vehicle borne MMW radar, so it has higher signal-to-noise ratio in beamforming and angle estimation. Simulation diagram of system angle estimation accuracy and conclusion of system false alarm rate simulation.

5. Conclusion

The principle of vehicle mounted millimeter wave radar is that the radar signal receiving module and transmitting module are built in. The millimeter wave signal should be transmitted outward through the integrated antenna. Once the signal reaches the target, the echo will be reflected. After receiving the requested sound in time, the receiving unit of radar system carries out FFT processing on the signal, and analyzes the receiving environment information, such as relative speed, relative distance, angle, motion direction and other objects with high precision. Computer system detection, classification, application target monitoring, safety inspection, etc. after the information processing unit matches the driving information of its own vehicle, the data is combined after mixing and filtering. Finally, the integrated central processing unit (ECU) makes decisions on driving information, and at the same time, it reminds and warns the driver through voice and light, or intervenes independently on the safety operation to improve the safety driving safety to avoid accidents. Advanced driving assistance and automatic driving technology are developing rapidly. As an environmental sensor, millimeter wave radar is the most important part of various auxiliary driving functions or automatic driving technology. The car's millimeter wave radar detects the target and carries out data processing. The processing of logical alarm will immediately send an alarm to the driver or send an alarm signal in the body control system, which is used to actively control the movement of the vehicle, so as to avoid accidents as much as possible. According to the operation requirements and material platform, the selection of route based or data processing and alarm algorithm can perform the function more efficiently and accurately.

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