Research on Millimeter-wave Radar Based Automotive Lateral Anti-collision Warning System

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Abstract. According to the reasons and features of car accidents happening in vehicles’ side areas, this paper designed and developed a kind of automotive lateral anti-collision warning system by frequency modulation continuous wave, based on the research on 24GHz linear frequency modulation continuous wave radar-probing system. The system designed in this paper will forecast the potential danger to drivers and avoid the accidents. The hardware structures, algorithm, program flows and working patterns of the warning system were introduced. Furthermore, pointing to the problem of false alarms, a kind of filtering method was presented creatively. This method improved the reliability of the warning system and the accuracy of the forecast. It filtered the disturbance coming from the side of the vehicles, and solved the difficult problem that prevented the millimeter-wave radar from being applied in automotive lateral anti-collision warning system. Finally, the experiment was designed and carried out. The result verified the rationality of the solution and the practicality of the system’s function.

Introduction

In recent years, with the number of traffic accidents gradually rising, automotive safety has become an increased focus that attracted people’s attention. In Europe, the United States and Japan there are already a number of famous motor corporations that invest heavily in the development of automotive driving assistant system [1]. Traffic accidents typically include rear-end collisions, the front and side collisions [2]. According to statistics, 30% incident is caused by the behavior, changing roads [3]. Therefore, a kind of device that is able to forecast the speed and distance of back vehicles is urgently needed. At present, there have been a lot of automobile front anti-collision systems based on millimeter wave radar. But the above radar is difficult to be used in lateral anti-collision system. The difficult problem that prevents the million-meter wave radar from being used in lateral anti-collision system is lateral disturbance (including the disturbance coming from cars on other roads rather than the side roads and the lateral obstacles). The above disturbance is hard to be filtered, which causes many false alarms. Based on the millimeter wave radar applied in front anti-collision system, this paper improved the algorithm, solved the problem of false alarm caused by lateral disturbance, applied the anti-collision system in vehicle driving assistant system. The above anti-collision system is able to detect the potential danger correctly and forecast the danger to drivers in time, thus avoid accidents.

Principle of Millimeter Wave Radar

At present, there are three categories of intelligent distance detecting. There are ultrasonic ranging radar, laser range-finder radar and millimeter wave radar [4]. Ultrasonic ranging radar is only able to measure little distance, thus this kind of radars are mainly applied as backing-up radar. Laser range-finder radar strictly rely on the weather conditions and other external environment, which makes the
laser range-finder radar difficult to be used in anti-collision system. The millimeter wave radar is hard to be affected by weather and external environment [5]. It has suitable detecting distance and high resolution [6]. These features are suitable to be used to detect the lateral vehicles. Therefore, millimeter wave radar is used to measure speed and long distance in this paper. There are two working patterns of millimeter wave radar, Pulse and Frequency Modulation Continuous Wave (FMCW). The pattern Pulse can only receive the wave after sending. There is minimal detecting distance. However, the FMCW pattern is not constrained. Therefore, the millimeter wave radar working on the pattern, FMCW is applied in lateral anti-collision system in this paper. The distance and speed formula of FMCW are shown below [7]:

\[ R = (f\textsubscript{m} + f\textsubscript{c}) \cdot C \cdot T / 4 \cdot B \]  
\[ v = (f\textsubscript{m} - f\textsubscript{c}) \cdot C / 4 \cdot f\textsubscript{0} \]  

Where \( B \) is emission signal bandwidth; \( T \) is cycle of modulating triangular wave; \( C \) is propagation velocity of electromagnetic waves; \( R \) is distance between target and radar; \( v \) is velocity of target relative to the radar; \( f\textsubscript{0} \) is center frequency of transmitting signal.

**Radar Sensors**

24GHz sensor is used as radar sensor in this paper. Table 1 shows some feature parameters of radar sensor. After receiving the echo waves, radar receiver mixes the echo waves and local oscillator signal, then outputs intermediate-frequency signal by low noise amplifier. The voltage ranges from 0-5V, and the output impedance is 100Ω.

| Parameters               | Index       |
|--------------------------|-------------|
| Operating Frequency      | 24GHz       |
| Modulation Waveform      | Triangular Wave |
| Maximum Power            | 20dbm       |
| Operating Distance       | 100M        |
| Horizontal Angle         | 6°          |
| Output Impedance         | 100Ω        |

**Hardware Design of the system**

The hardware in this paper utilizes Serial 5000 DSP [8] (Digital Signal Processor) of Texas Instrument Co., Ltd. and Serial CycloneII FPGA (Field Programmable Gate Array) of Altera Co., Ltd., which compose the dual-controller architecture of the hardware system. DSP TMS320VC5509A has fast processor, low power consumption, and 200MHz changeable basic frequency. Furthermore, the DSP chip is integrated with USB port, which can make it possible to communicate with USB main devices. Based on its fast processing speed, this DSP is used to carry out digital signal filtering, FFT transform, and other complex algorithm. FPGA is mainly utilized to control A/D, VCO, logical relation, and communication with external data. The hardware system has RS232 port, CAN port, and USB port that can satisfy vehicles’ need. The structure of hardware system is shown in Fig. 1.
Because the voltage of on-board power supply is generally 12V, the system power supply is designed to be 12V. The voltage is changed to be 5V by switching voltage modules. The voltage is filtered to supply to the radar and is divided to three types of voltage: 3.3V, 1.6V, and 1.2V. These types of voltage are respectively used to supply DSP, FPGA, and other external modules.

Software and Algorithm

When changing roads, the driver mainly observes the vehicles on one side of driver’s car. Therefore, the warning system mostly detects side vehicles. The radar is fixed to keep 2.5° from the car. Thus, the detection range is from 4.8M outside to 0.4M inside with the distance 50M. The schematic diagram is shown in Fig. 2. The system can make it sure that all the objects approaching the car are able to be detected within the distance of 50M.

Because there are many complex obstacles on both sides of the car, the radar always receive the echo waves caused by isolation belts, electric line poles and other objects, which will make serious disturbance. To avoid the false alarms caused by the above disturbance, the echo waves are processed with complicated algorithm. The steps of processing are listed below in detail:

Step 1: Pretreat the signal in time domain, window the echo waves, and make fast fourier transform to the windowed echo waves,

\[ X(N) = \text{FFT}(x(n) \cdot w(n)) \]

then transform the signal from time domain to frequency domain [9]. The signals become complex and finally turned into form of modules,

\[ X(N) \].

Step 2: Since echo intensity is different at different distances, \( X(N) \) needs to be compensated to keep the same echo effect at different distances,

\[ Y(N) = X(N) \cdot C(N) \].

Step 3: Primarily detect the object. Time is very important for automotive safe. Thus, to detect vehicles situation of side road fast, data is not non-coherent integrated, while the frequency information \( Y(N) \) is divided into \( [Y_0, Y_m], [Y_1, Y_{m+1}], \ldots, [Y_{N-m}, Y_N] \), and calculate the average of each set, then assign weights to each average and calculate the primary threshold. These thresholds do not correspond to the actual number of frequencies one by one. Therefore, the same threshold value at the ends of the frequency set is given. The equation of low frequency is shown as below:
\[ TH_{m/2} = \left( r \cdot \sum_{i=0}^{m} Y_i \right) / m + b \]  

(3)

Where \( TH \) is threshold; \( r \) is weight value; \( b \) is offset value; first \( m/2 \) frequency data can use the above threshold. Other threshold can be calculated by Eq. 3. Similarly, the threshold in high frequency can be calculated in the same way.

Step 4: Agglomerate the possible effective frequency. Agglomerate all the frequency points around the possible effective frequency to make them turn to one frequency point. Agglomerate the frequency points outside the range of possible effective frequency to make sure the intensity of each frequency point. If the intensity is lower than the criteria, the agglomeration frequency point is false alarm, and will be cancelled. The equation of agglomeration is:

\[ FC_n = \sum_{m \in S_n} \left| Y(m) \right| / \sum_{m \in S} \left| Y(m) \right| \]  

(4)

Find the agglomeration frequency point with maximum power after compensation from these effective agglomeration frequency points:

\[ i \in S \quad Y = \max \{ Y_i \} \]  

(5)

Step 5: Find the solution of speed and distance, and verify the effectiveness. The speed and distance can be calculated with Eq. 1 and Eq. 2. Compare the speed and distance calculated with former data of speed and distance to make sure the object detected by radar is effective vehicle, and then track the vehicle. When the distance between the vehicle and our car is within 50M, meanwhile its speed is higher than our car’s, the system will warn the driver that changing road at this time will be dangerous. The warning system has CAN port, serial port, and I/O port. Therefore, the system can warn the driver in various ways.

Experiments

The system is tested on real road. The data is acquired and sent to computer with USB port, and is processed with MATLAB software. In Fig. 3, the ordinate is the distance between the object detected and our car, the abscissa is data collected that can be changed into time. The blue star line is effective distance calculated, and the black line is the data filtered by the algorithm. The figure clearly shows the distance when two vehicles exceed our car. The result shows that the system can effectively warn the drivers pointing to the vehicles on side of our car.

![Figure 3 Processing the data of experiment](image)

Fig. 4 shows the working condition of real device. By observing rear-view mirror of the vehicle and the screen of out device, we can clearly distinguish the vehicle coming from side road. If there is no vehicle on one side, as shown in Fig. 4-A, there is only one car in the screen, which represents our car fixed with radar. In Fig. 4-B, there are isolation belts and vehicles in opposite direction, but in the screen, there is no other car. This means that there is no false alarm. In Fig. 4-C and Fig. 4-D, there are vehicles on side road to exceed our car, and the screen shows these conditions and effectively warns the driver. The results above show that the device designed in this paper can effectively warn the potential dangers and can effectively avoid false alarms.
Conclusions

Pointing to the features of changing road aside, a kind of novel filter algorithm is presented, and the disturbance caused by obstacles (such as isolation belts, electric line poles) and vehicles that are not on both near side roads is effectively filtered. Based on the hardware and software introduced in this paper, vehicles on near side road can be correctly detected, meantime, the disturbance coming from both sides are effectively cancelled. The experiments on real roads present the reliability of hardware and stability of algorithm. The results show that the automotive lateral anti-collision warning system designed in this paper can sufficiently satisfy the need of vehicle driving assist.

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