A Novel Signal Processing Technique for Vehicle Detection Radar

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Abstract — **We have developed a 24GHz side-looking vehicle detection radar. A novel signal processing algorithm is developed for speed measurement and size classification of vehicles in multiple lanes. The system has a fixed antenna and FMCW processing module. This paper presents the background theory of operation and shows some measured data using the algorithm.**

I. INTRODUCTION

The objective of vehicle detection radar is to get some information of traffic flow, such as speed and length of vehicle passing on the road. The loop detector is a widely accepted sensor to get such data, but it demands much maintenance cost. To overcome the disadvantage, the radar technology has been developed to replace conventional traffic sensor[1,2].

This paper proposes a novel signal processing algorithm for multiple vehicle detection in different lanes. The vehicle detection procedures are realized with high speed DSP and 24GHz FMCW front-end. We describe the algorithm to measure the speed and the size of the vehicle by using a fixed antenna module.

II. THEORY AND ALGORITHM

The radar detection module utilizes the side-looking transmitting to illuminate the vehicles in the multiple lanes. Fig.1 shows the side-looking circumstance encountered for multiple vehicle detection.

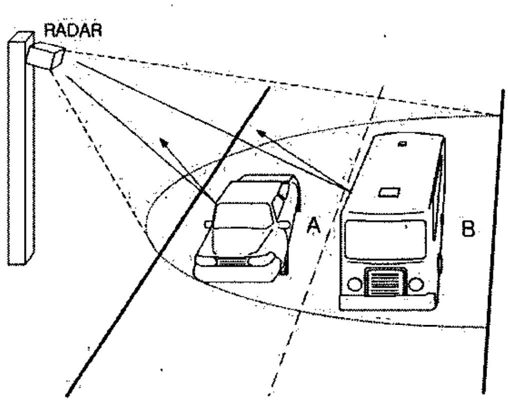

Fig. 1 Side-looking vehicle detection system

A. FMCW Principle

The FMCW principle and variables are shown in Fig.2. The FMCW radar is used widely to measure the distance and the speed of objects because it generates the modulation wave with comparatively ease and can transmit high power with broad bandwidth. The transmitted frequency is increasing and decreasing linearly with time. The information of velocity and distance of multiple targets can be obtained by using the frequency analysis for the beat signal[3]-[5].

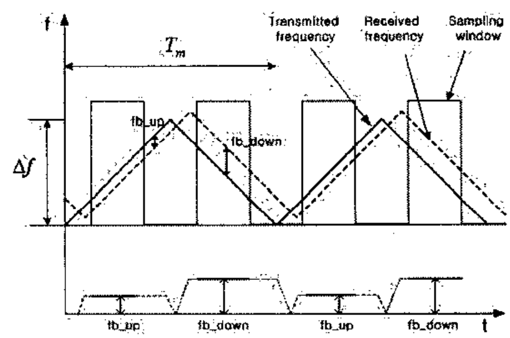

Fig.2 Frequency-time diagram in FMCW radar

Conventional radar systems usually have sharp radiation beam patterns to get the space resolution, but there was a paper which proposed a very broad aperture angle for ground speed measurement systems. That paper shows that a speed signal can be extracted out of the microwave spectrum and is independent of the aspect angle of a moving antenna toward ground[6].

This paper describes background theory for measuring speed and length of moving vehicles by using a fixed antenna of broad radiation pattern.

B. Proposed Radar Operation

1) CW source

The antenna configuration is shown in Fig.3. If the antenna has an omnidirection beam pattern, the received frequency f_{Rx} and power P_{Rx} depends on the vehicle velocity and the beam incident angle α as Eq(1) and (2).

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The maximum Doppler shift comes from the vehicle of α=0(at this frequency, there is no reflected power).

$$f_{Rx} = f_{Tx}(1+2v\cos\alpha/c) = f_{Tx} + f_d \qquad (1)$$

$$P_{Rx} = \frac{P_{Tx}\cdot\sigma(\alpha)\cdot G_A^{\,2}\cdot\lambda^2\cdot(\sin\alpha)^4}{(4\pi)^3\cdot r^4} \qquad (2)$$

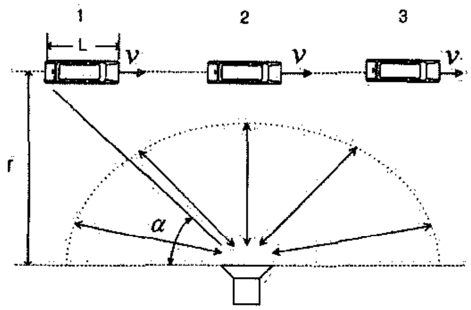


Fig.3 Moving vehicle and an omnidirectional antenna

The accurate received power depends on radar cross section $\sigma(\alpha)$ and antenna gain G_A, but normalized receiving power with these parameters can show rough approximation of incident angle dependence. Fig. 4 shows the normalized receiving power and Doppler frequency from a vehicle at a different point on the road.

According to the vehicle movement, the spectrum pattern of the received signal changes. When the vehicle is passing in the center of the radiation beam pattern, the maximum frequency bandwidth, BW_c can be obtained.

The length L and velocity v of the vehicle is given by

$$f_{d,\max} = \frac{2v}{c} f_{Tx} \qquad (3)$$

$$BW_c = \frac{L}{r}\times\frac{2v}{c} f_{Tx} = \frac{L}{r}\times f_{d,\max} \qquad (4)$$

where $f_{d,max}$ is the maximum Doppler shift.

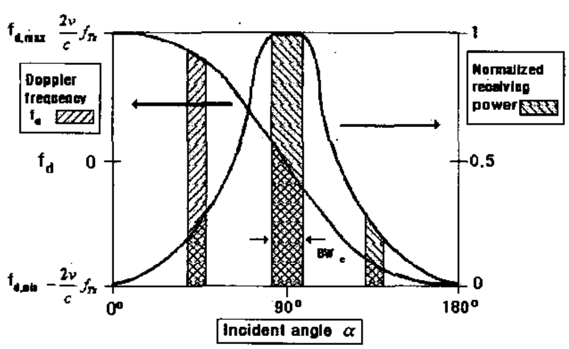


Fig. 4 Doppler shift and power with incident angle α for CW signal

2) FMCW source

With FMCW signal, the frequency of the received signal changes according to the velocity of the vehicle and the distance to it.

For FMCW case, the up or the down frequency range with time is to be sampled and processed. The received power has the similar pattern with CW source, and the received beat frequency sampled in the up frequency section is given by

$$f_b = f_{Rx} - f_{Tx} = f_d + f_r = \frac{2v}{c}\cos\alpha\cdot f_{Tx} + \frac{4\cdot\Delta f\cdot r}{c\cdot T_m}\cdot\frac{1}{\sin\alpha} \qquad (5)$$

where f_r is beat frequency with the distance to vehicle, Δf is the waveform bandwidth, and T_m is the modulation time.

If the reflected beam has finite angle bandwidth $\Delta\alpha$, due to the length of the vehicle as shown in Fig.4, the spectrum has finite frequency bandwidth. So, if the received signal has finite frequency bandwidth, the incident angle width $\Delta\alpha$ is obtained and the length of the vehicle can be calculated.

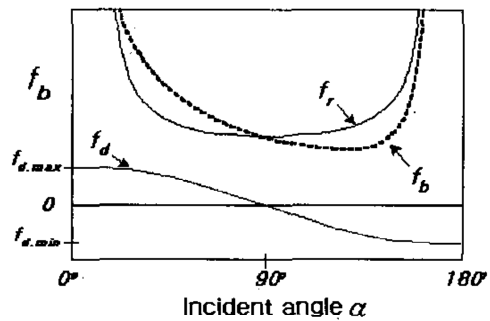


Fig.5 Beat frequency f_b as a sum of Doppler shift f_d and distance shift f_r with incident angle α for the FMCW signal

III. Experimental Results

The radar module is mounted on top of a pole by the road in order to make an elliptic footprint at a right angle to traffic lanes. The sliced footprint can provide two detection zones. The detection zone is divided into sector A and sector B as shown in Fig.1.

The important parameters to get the vehicle information are the threshold and the frequency range of detection. The threshold for detection is established considering the reflection level causing from the ground and fixed obstacles. The received signal, which is higher than the threshold and found in the beat frequency range of detection zone, is regarded as a real vehicle signal and processed to get the vehicle information. The frequency range of detection zone is important as well as the threshold, and need to be tuned from initial calibration process. And, if the occupied time of a received signal in detection zone is less than the minimum duration which vehicle can cross the detection zone, it is ignored as an invalid signal.

The classification of the vehicle is obtained by using those equations of the magnitude and the spectrum pattern of the received power which is related to the vehicle size.

The velocity is estimated by using the appearance duration of the reflected signal and the length of detection zone and Doppler shift.

The radar module designed to detect the vehicle is shown in Fig.6. It consists of 24GHz microwave module in waveguide and DSP board. The DSP board conducts signal sampling, analog to digital conversion, 512 points FFT and some data manipulation.

Fig.7 shows the received signal for a vehicle in the first lane and the second lane measured with the radar system, respectively. Fig.7(c) shows a signal for the vehicles in both lanes.

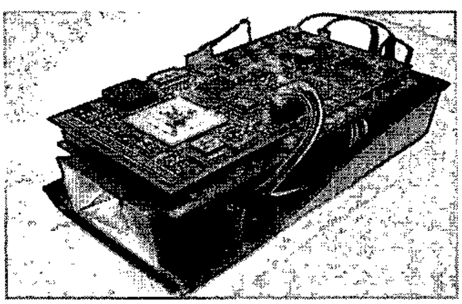
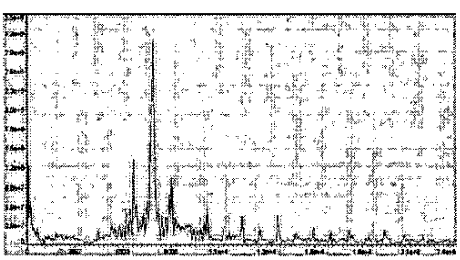
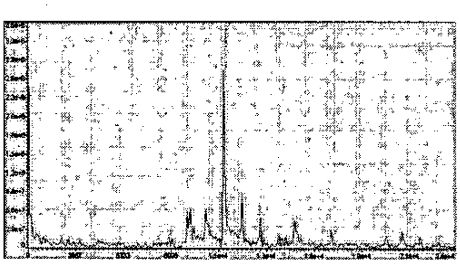


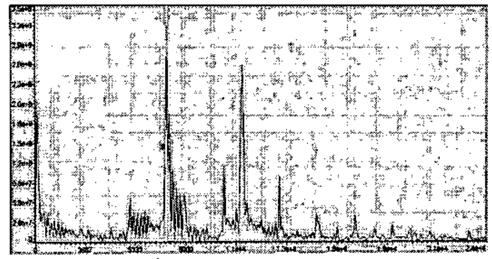
Fig.6 DSP board and RF module mounted in horn antenna



(a)



(b)



(c)

Fig.7 Received spectrum of vehicles (a) a vehicle in the first lane (b) a vehicle in the second lane (c) vehicles in both lanes

A. Velocity Measurement

If a vehicle is detected in a lane, the velocity is calculated from occupied time which belongs to the effective range of detection. If a pre-determined threshold is applied when two vehicles are detected simultaneously in both lanes, the velocity for the second lane is inaccurate

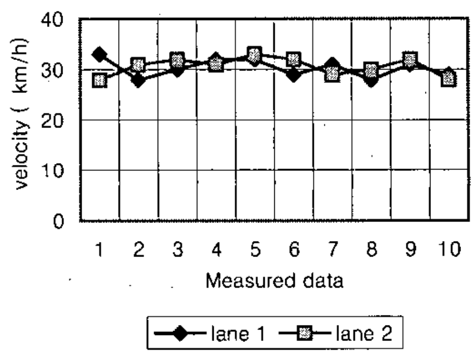


Fig.8 Measured velocity of a vehicle (30km/h) in lane 1 and lane 2

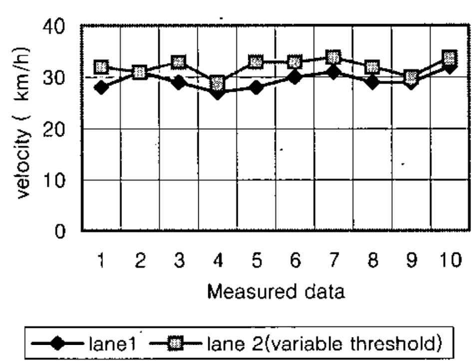


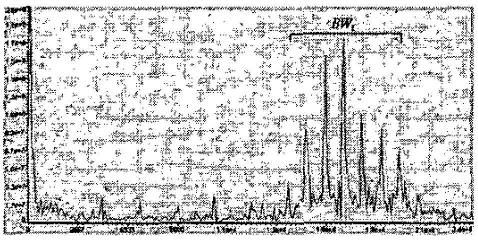
Fig.9 Measured velocity of vehicles (30km/h) in both lanes

because transmitted signal is not large enough to the vehicle in the second lane by interfering and blocking of the vehicle in the first lane. To solve this problem, a lower variable threshold for second lane is applied for the case.

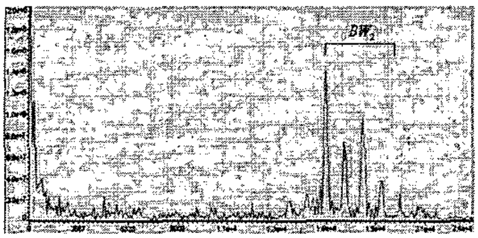
Fig.8 shows the measured velocity of the passing vehicle (30km/h) in the first lane or in the second lane. Fig.9 shows the measured velocity of the passing vehicles (30km/h) in both lanes. The speed error is less than 10% by using variable threshold.

B. *Vehicle Classification*

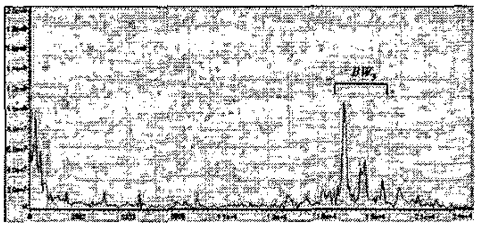
The classification of a vehicle, as large, medium or small size, is possible by processing received power and spectrum pattern which depends on the vehicle size. Received power is useful for the classification of vehicle in some extent, but it does not work properly to identify a bus as a large size vehicle because of much window glass. To improve the performance for the classification, the bandwidth(BW) of the reflected spectrum from the vehicle is used. BW is proportional to the vehicle size as shown in Fig.10. More than 90% accuracy of vehicle classification can be obtained by using the received power and BW together. The large-sized vehicle such as a bus is distinguished from the medium-sized and small-sized vehicle by using spectrum bandwidth criterion.



(a)



(b)



(c)

Fig.10 Received signal of a vehicle in the second lane (a) large size (b) medium size (c) small size vehicle

IV. Conclusion

In this paper, a novel algorithm of radar signal processing for multiple lane vehicle detection is proposed and realized by using DSP for real time processing. Measured velocity of the passing vehicle is obtained with the accuracy of 95% in a lane and simultaneously measured velocity of the vehicles in both lanes is with the accuracy of 90% by using variable threshold estimation. The received power and occupied BW is used to classify the vehicles, and 89% of the classification is proved to be correct for 200 measurement tests. We are looking forward to publish more experimental data in the near future.

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