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새로운 신호처리 알고리즘을 이용한 측방설치 차량감지용 레이다

(Side Looking Vehicle Detection Radar Using A Novel Signal Processing Algorithm)

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요 약

본 연구는 24GHz 측방설치 차량감지용 레이다를 개발하였다. 다차선에 존재하는 차량들의 속도 측정 및 차량 분류를 위해 24GHz 송수신 모듈을 개발하였고, 신호처리부에 새로운 신호처리 알고리즘을 적용하였다. 본 논문은 고정된 FMCW (Frequency Modulated Continuous Wave) 레이다 모듈로써, 동작원리 이론과 알고리즘에 대해 측정된 데이터를 나타내었다. 측정된 결과는, 가변 threshold 추출 방법을 이용하여 한 차선의 차량 속도에 대해 95%의 정확성과 두 차선에 대해서는 90%의 정확성을 보였다. 또한, 차량의 분류는 소형, 중형, 대형의 3종 분류로 약 89%의 정확성을 나타내었다.

Abstract

We have developed a 24GHz side-looking vehicle detection radar. A 24GHz front-end module and a novel signal processing algorithm have been 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. The data shows that measured velocity of the passing vehicle is within the accuracy of 95% in single lane and the velocity of the vehicles in two lanes is within the accuracy of 90% by using variable threshold estimation. The classification of vehicle size as small, medium and large has been measured with 89% accuracy.

Keywords :road vehicle radar, radar signal processing, object detection

I. Introduction

The objective of vehicle detection radar is to get some useful information of traffic flow, such as the speed and the length of vehicles passing on the road. The information is required for constructing intelligent transportation system. Loop detector is a widely accepted sensor to get such data, but it requires much cost of installation and maintenance.

Image detector with CCD camera has been developed for collecting vehicle information, but the operation is not satisfactory when it is raining or night. Both of the loop detector and the image detector are necessary to be installed at every lane for multiple lane vehicle detection. To overcome the disadvantages, the microwave radar technology has been developed to replace conventional traffic sensor[1-4]. This paper reports a vehicle detection

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microwave radar with 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.

2-1. FMCW Principle

In FMCW radar, beat frequency between transmitted and received signal can be described as 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[5].

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 information can be extracted out of the microwave spectrum and is independent of the aspect angle of a moving antenna toward ground[6]. The problem we are going to solve is different from the paper because antenna is fixed and target is moving. This paper describes a background theory for measuring speed and length of moving vehicles by using a fixed antenna of broad radiation pattern.

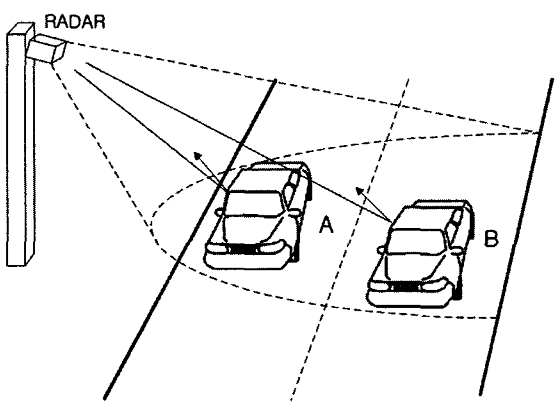

그림 1. 측방설치 차량감지 시스템
Fig. 1. Side-looking vehicle detection System.

2-2. Proposed Radar Operation

The antenna configuration is shown in Fig. 3. If the antenna has an omni-direction beam pattern, the received frequency fRx and power PRx depends on the vehicle velocity and the beam incident angle as equation (1) and (2).

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

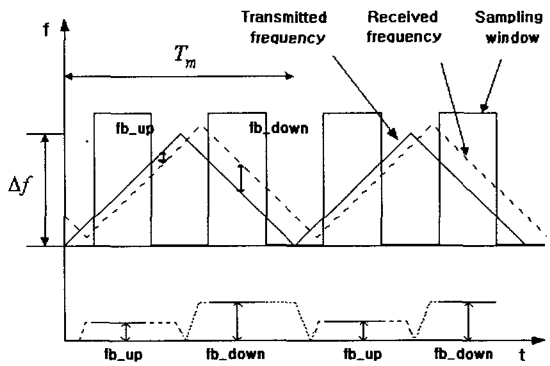

그림 2. FMCW레이다의 Frequency-time 다이아그램.
Fig. 2. Frequency-time diagram in FMCW radar.

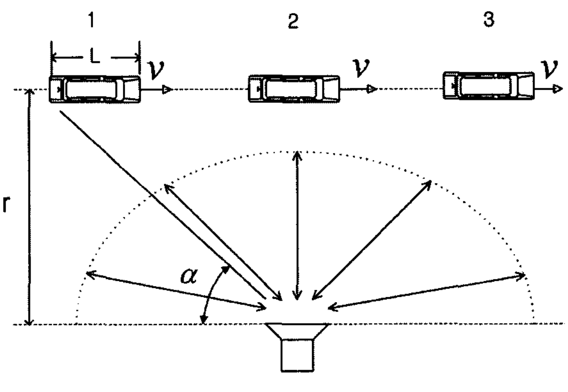

그림 3. 주행차량의 감지환경과 등방향서의 방사패턴.
Fig. 3. Moving vehicle and an omni- directional antenna.

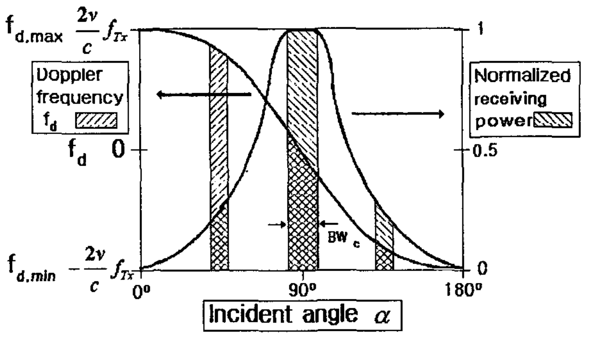

그림 4. 입사각(□)에 따른 수신된 도플러주파수와 수신전력.

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

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

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

The accurate received power depends on radar cross section σ and antenna gain GA, 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, BWC can be obtained. The length L and velocity of the vehicle is given by

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

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

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

III. Experimental Results

The frequency pattern can be simulated from equation (1)and (2). Fig. 5 shows frequency pattern when angle α is 90 degree between detector and vehicle. The RCS of the vehicle is modelled to be rectangular flat plate in order to predict the

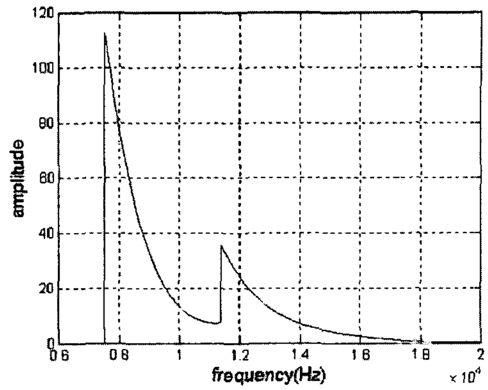

그림 5. 안테나로부터 거리 5.8m, 8.4m인 두 차선의 차량의 스펙트럼 시뮬레이션

Fig. 5. Simulated spectrum of vehicles in both lanes with 5.8m, 8.4m from antenna.

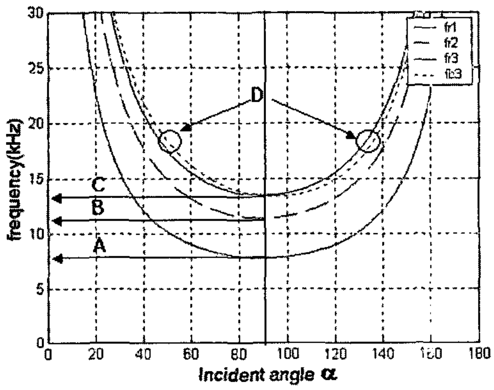

그림 6. 높이 3m인 1차선(A)와 2차선(B)의 비트주파수, 높이 4.5m인 2차선(C)의 비트주파수.

Fig. 6. Beat frequency from lane (1) and lane (2) from 3.5m and detector, and lane 2(C) from 4.5m detector height.

approximate reflected spectrum[7].

For the simulation, the antenna is fixed at the end of 3m or 4.5m high pole, and the distance between antenna and the first lane from the radar is assumed to be 5m. The reflected spectrum from ground is removed through calibration procedure. The simulated spectrum result is shown in Fig. 5 with two vehicles in the first lane and the second lane (i.e. section A and B as shown in Fig. 1). The reflected power from the first lane is larger than that of the second lane, and the beat frequency due to distance is higher from the second lane than that from the first lane. The Doppler shift changes by the velocity of vehicle, and beat frequency due to distance and velocity is shown in Fig. 6. Beat frequencies of two points D are due to distance and velocity of 30km/h approaching to the antenna or from the antenna, and are different from each other because Doppler frequency has different effect. The height of detector fix pole is 4.5m and the distance is 9m between detector and the first lane because of wide road side.

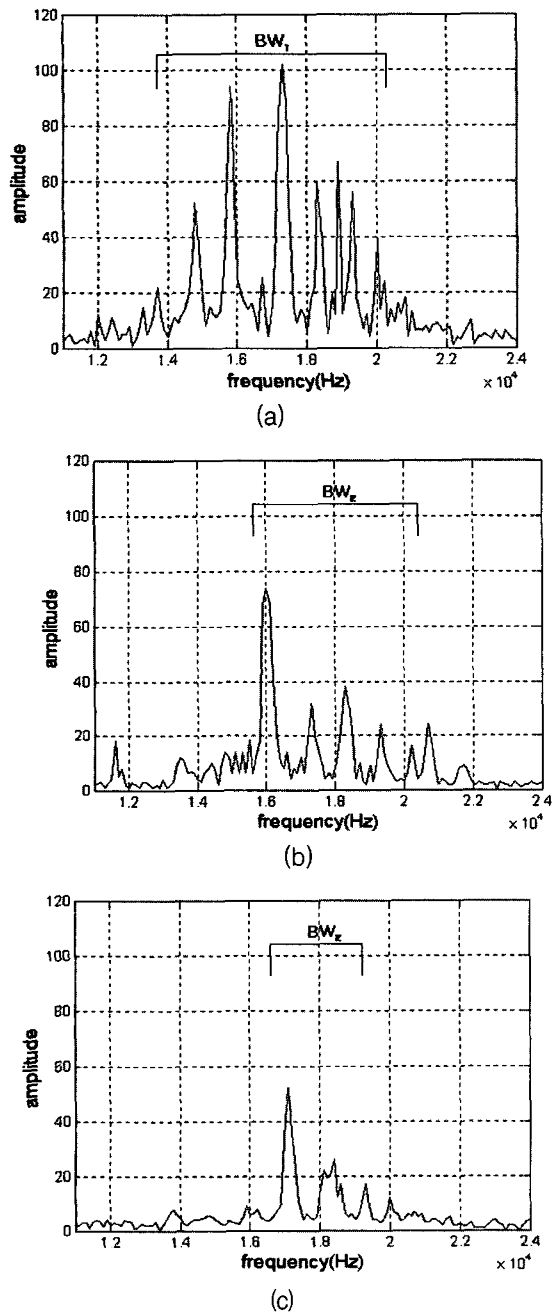

그림 7. 2차선에서의 차량의 수신 스펙트럼 (a) 대형차 (b)중형차 (c)소형차.

Fig. 7. Received signal of a vehicle in the second lane (a) large size (b) medium size (c) small size vehicle.

Fig. 7(a) shows the measured spectrum with the center of 17.3kHz and bandwidth of 7.8kHz for the large size vehicle(i.e. truck). Fig. 7(b) and (c) show the reflected frequency spectrum from the medium size and the small size vehicle with the bandwidth of 4.5kHz and 3.5kHz.For the case of incident angle 90 degree between radar and vehicle, the distance is about 10m and the beat frequency due to distance to the vehicle is 13.4kHz. The similar center frequency and bandwidth can be coming from the different incident angle and velocity, but the detector can calculate the incident angle and the velocity by using the information of vehicle approaching to the radar or going far from the radar. In the case of Fig. 7(b), two points for the vehicle can generate the measured spectrum, i.e. before passing or after passing the beam center(i.e. 90° incident angle). The same bandwidth can be occurred when vehicle passing center point is before 3.9m and after 5.9m. And an angle between detector and vehicle can be acquired, because detector has beat frequency with the distance to vehicle from center of lane. The angle is 68.8, the latter is 120.4 depending on the vehicle position. Measured data of vehicle is similar to the calculated value at point D in Fig. 6.

Simulation circumstance for inspecting proposed signal process is realized using National Instrument (NI), DAQ 6062E, LabVIEW, and the developed 24GHz FMCW front-end.

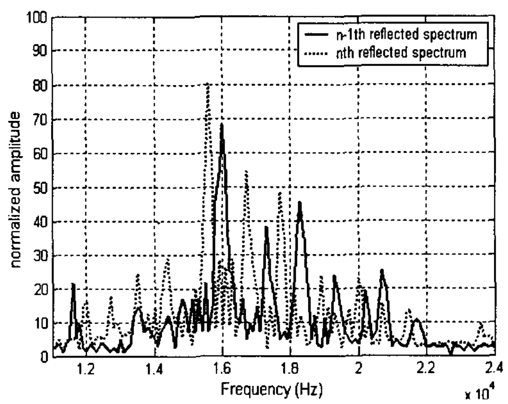

그림 8. 차량으로 돌아오는 신호의 스펙트럼에서 n-1번째 신호와 n번째 신호의 스펙트럼.

Fig. 8. Reflected spectrum of *n*th and *n-1*th in samples from vehicle.

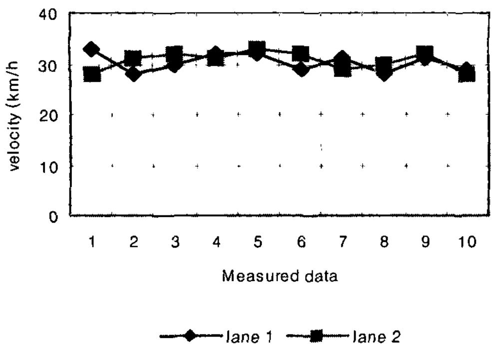

그림 9. 1차선과 2차선의 독립적으로 측정한 차량의 속도 측정결과 (30km/h).

Fig. 9. Measured velocity of a vehicle in lane 1 or 2 (30km/h).

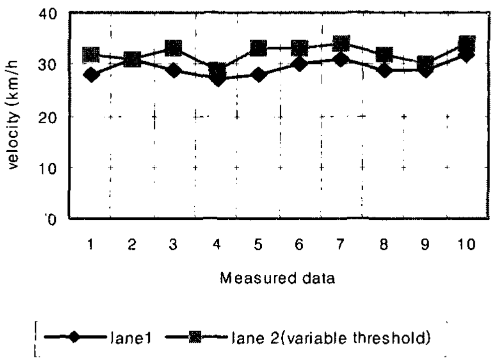

그림 10 두차선을 동시에 측정한 차량의 속도 측정결과 (30km/h).

Fig. 10. Measured velocity of a vehicle in lane 1 or 2 (30km/h).

In the simulation, the distance is calculated using the reflected spectrum, and the accuracy of vehicle velocity is high and vehicle size is low because antenna beam pattern has some directive characteri -stic. Fig.8 shows the reflected spectrum of the two sampled signal using the developed radar module when vehicle is coming into detection range. The spectrum shows that frequency is decreasing and received power is increasing. Frequency range of n-1th reflected spectrum is 15.75kHz to 18.4kHz. The size of vehicle is calculated 3.35m. And frequency range of nth reflected spectrum is 15.6kHz to 17.8kHz. The size of the vehicle is 3m. In this case, speed is calculated 50km/h, moving distance of 0.664m and system time of 47ms. This result shows good agreement with the information of the moving vehicle in the road.

3-1. 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 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. 9 shows the measured velocity of the passing vehicle (30km/h) in the first lane or in the second lane. Fig. 10 shows the measured velocity of the passing vehicles (30km/h) in both lanes. The speed error is less than 10% by using variable threshold.

3-2. 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 glass window. To improve 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. 7. 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. Fig. 11 shows one hundred typical experimental data which measure the received power and bandwidth of the vehicles for classification.

In X-axis, data number from 1 to 23 is for large size vehicle, 24 to 51 for medium size vehicle, and 52 to 100 for small size vehicle. The figure shows that

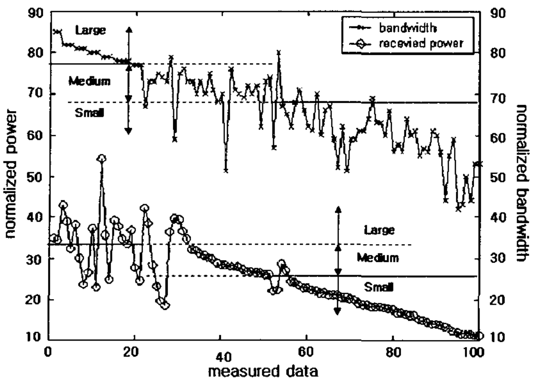

그림 11. 2차선에서의 차량의 반사전력과 대역폭 측정에 의한 차종 분류 데이타.

Fig. 11. Measured power and bandwidth of the vehicles in the road.

received power changes very much for large size vehicle but some maximum and minimum criterion window can be set up for medium and small size vehicle. Measured bandwidth can classify large size and other vehicle. So we can classify vehicle size more accurately by using both of the received power and bandwidth criterion.

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 have been used to classify the vehicles, and 89% of the classification is proved to be correct for road measurement test. The vehicle detection radar technology can be useful to get the traffic information for multiple vehicles in the multiple lanes by using single microwave detection radar.

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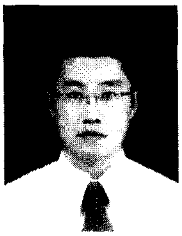

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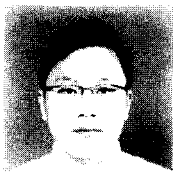

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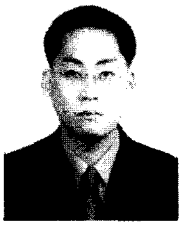

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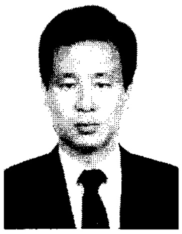

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