Experimental Study of Infrastructure Radar Modulation for Vehicle and Pedestrian Detection

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ABSTRACT

Currently, radars installed on vehicles have been widely put into practical use [1]. Moreover, radars will be attached to road-side-units for safety systems in the near future. The purpose of our research is to show that 2FCW (Two-Frequency Continuous Wave) modulation is suitable as an infrastructure sensor. First, we indicate that 2FCW modulation is less affected by static objects by comparing FMCW (Frequency Modulated Continuous Wave) modulation, which is often used in radars installed on vehicles. Further, we demonstrate the performance of detecting vehicles and pedestrians by radars using 2FCW modulation. Second, we show 2FICW modulation based on 2FCW can solve a principled problem that 2FCW modulation has.

Keywords: Safety system, Infrastructure sensor, Radar

1. INTRODUCTION

In recent years, safety systems, for example driving safety support systems to avoid traffic accidents, are examined in partnership with industry, government, and university. These systems absolutely need infrastructure sensors that can detect the position and the velocity of vehicles and pedestrians.

Radar sensors are thought to be appropriate in this safety system because radar using electromagnetic waves such as microwave and millimeter wave can be used without performance loss even at night and/or under bad weather conditions. However, because the infrastructure radar is set on roadside and transmits radio waves toward a wide area, the radar receives many clutters from roads and other static objects. Consequently, the SN ratio is deficient, and the detecting

1

performance loss of the radar is a problem.

Here, the selection of cost effective radar modulation is a crucial factor in designing radar. In general, FMCW modulation and 2FCW modulation can provide high range resolution at low cost. In this paper, we select 2FCW modulation, which is thought to be insusceptible to clutter from static objects, and evaluate the detecting performance of 2FCW radar as infrastructure radar.

First, we demonstrate the superiority of 2FCW modulation as an infrastructure sensor. Further, we estimate the performance of 2FCW radar by detecting a vehicle or a pedestrian on public roads. Second, we show the effectiveness of 2FICW modulation in solving a principled problem of 2FCW modulation.

2. EXPERIMENTAL EVALUATION OF 2FCW

2-1. 2FCW modulation and FMCW modulation

2FCW modulation provides high range resolution with narrow band width. The transmission frequency sequence is shown in Fig.1. Two signals, whose frequency is slightly different, are transmitted alternately. The received wave is mixed with the transmitting wave (f_1 or f_2), and each sampling data is converted to Doppler spectrum with FFT (Fast Fourier Transform). The Doppler frequency is calculated from the frequency more than the threshold in the Doppler spectrum. The velocity is calculated from the Doppler frequency. The position is calculated from the phase difference of the f_1 Doppler signal and the f_2 Doppler signal.

FMCW modulation provides a high range resolution with fewer signals processing complexity. The transmission frequency sequence is shown in Fig.1. The received wave is mixed with transmitting wave, and each sampling data is converted to the beat signal spectrum with FFT. The velocity and position is calculated from the beat signal spectrum of the up-chirp and the beat signal spectrum of the down-chirp.
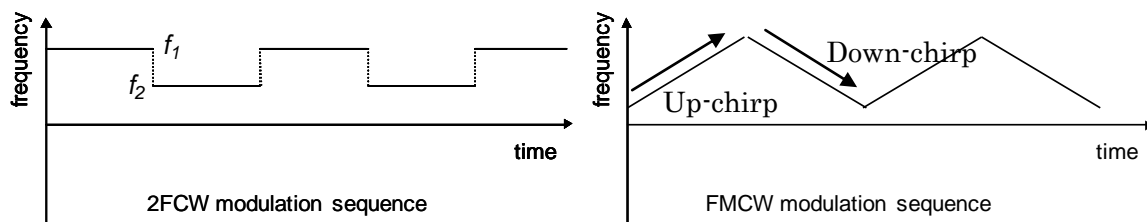

Figure.1 Transmission frequency sequence

2-2. Experimental radar equipment and radar parameters

We have developed experimental equipment that generates each signal, 2FCW and FMCW. Fig.2 shows the experimental radar equipment. The radar employs the radar parameters in Table.1.

Figure.2 Outline view of experimental radar equipment

Table.1 Radar parameters

Modulation	2FCW	FMCW
Transmission Frequency	24.15GHz	24.15GHz
Transmission band width	1.5MHz	100MHz
Antenna beam width	±30°(horizontal) ±8°(Vertical)	±30°(horizontal) ±8°(Vertical)
Maximum detection range	100m	100m

We set the experimental radar antenna at 6m height, aimed toward a road. We compared the 2FCW signal spectrum (Doppler spectrum) we received with the FMCW spectrum (beat signal spectrum) in order to show the superiority of 2FCW with clutter from the road and other static objects.

Moreover, we conducted experiments on public roads in order to estimate the performance of detecting vehicles or pedestrians.

2-3. Measurement results

2-3-1. Comparison of received signal spectrum

The Doppler spectrum in 2FCW modulation and the beat signal spectrum in FMCW modulation are shown in Figure.3.

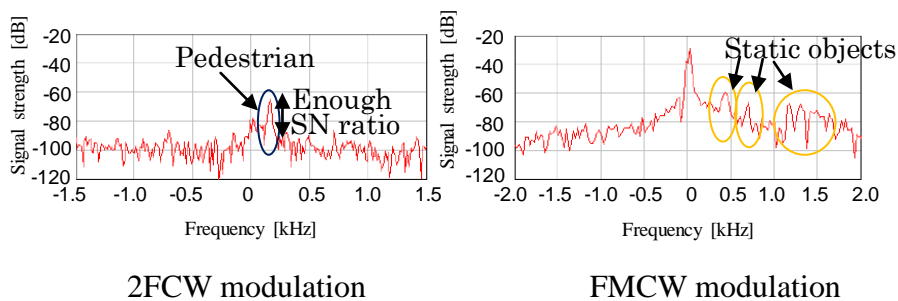

2FCW modulation   FMCW modulation

Figure.3 Comparison of received signal spectrum

In FMCW modulation, because the   beat signal spectrum depends on both the velocity and position of the targets, reflected waves are observed simultaneously from all ranges of the

3

beat signal spectrum. Consequently, the SN ratio of the targets tends to decrease.

On the other hand, in 2FCW modulation, the Doppler spectrum, which is the signal after FFT, depends only on the velocity of the targets. Consequently, the Doppler frequency of clutter from static objects (velocity:0) all concentrate at 0Hz in the Doppler spectrum, and so SN ration can be ensured.

As seen in the experiment results, the noise level is comparatively high in spectrum in the FMCW modulation, and strong signals from static objects are observed. On the other hand, in 2FCW modulation, the SN ratio from a pedestrian is about 20dB.

In this way, detection by 2FCW modulation is less influenced by clutter from static objects than FMCW modulation. From this perspective, because 2FCW modulation can be used under all kinds of circumstances, 2FCW modulation is more suitable as an infrastructure sensor.

2-3-2. Detection performance of vehicles and pedestrians

As shown in Fig.4 and Fig.6, the radar is set on a pedestrian overpass 8.4m above a road.
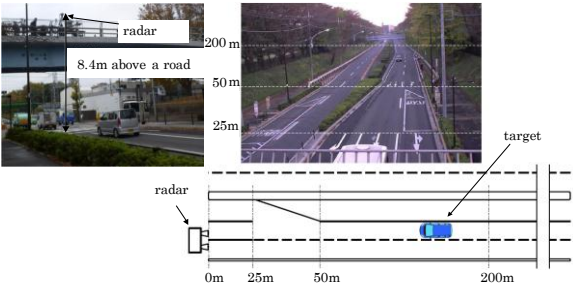

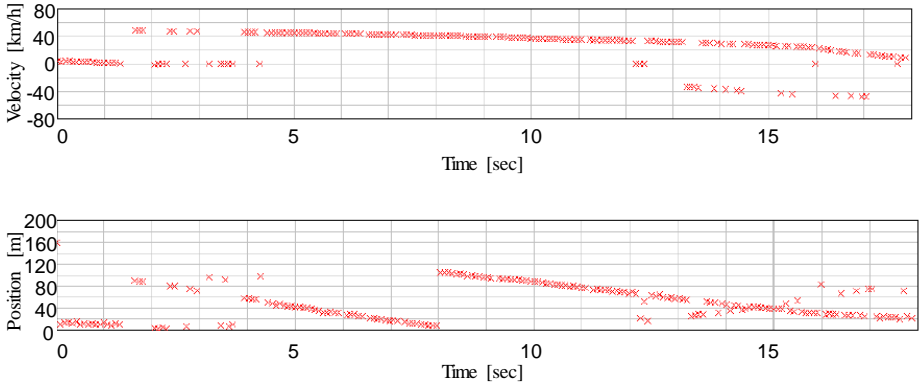Fig.4 Experiment to detect the vehicle

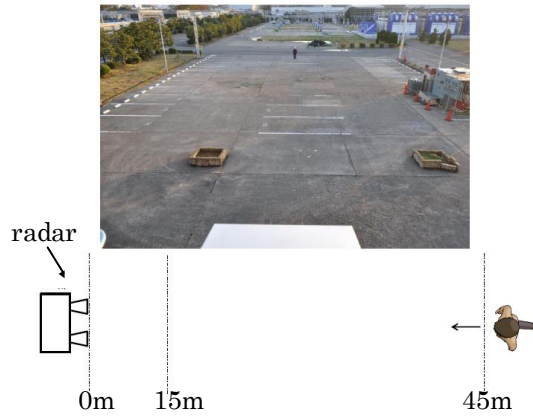Fig.5 Measurement results of detecting vehicle

4

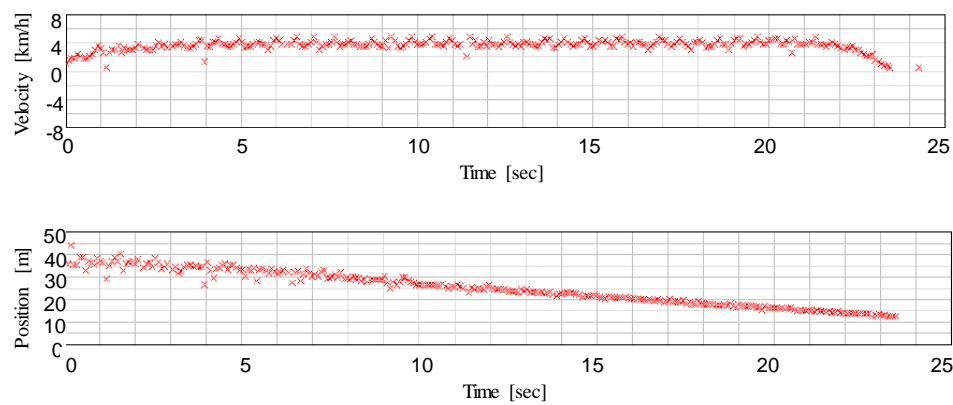Fig.6 Experiment to detect the pedestrian

Fig.7 Measurement results of detecting pedestrian

2FCW modulation can estimate the velocity and position both in vehicle detection and in pedestrian detection.

Fig.5 and Fig.7 show that 2FCW modulation is able to detect a vehicle more than 100m away from the radar, and a pedestrian more than 20m away from the radar. A wide detection range will be needed for infrastructure sensors in safety systems, but we expect 2FCW radar will be able to achieve this detection range.

3. EXPERIMENT EVALUATION OF 2FICW

3-1. Principle problem of 2FCW modulation

In case the detection target is the only target, 2FCW radar is able to detect the target as seen in the second chapter.

However, if there are multiple targets that have the same velocity, 2FCW cannot detect the targets separately, because the Doppler frequency of the targets is the same.

Since some vehicles and pedestrians often have the same velocity in the infrastructure detection area, solving this problem becomes a key issue.

We suggest 2FICW (Two-Frequency Interrupted Continuous Wave) modulation, and show the efficiency of 2FICW modulation through the experiment conducted on public roads.

3-2. 2FICW modulation

Since the 2FICW signal is pulsed, how long it takes for the transmitted pulse to return after reflecting off a target tells the position range of the target. Therefore, even if there are multiple targets at the same velocity, 2FICW radar can detect those targets separately by analyzing each signal that is received at a different time. Also, 2FICW is able to offset the position correctly when called position ambiguity occurs.

The transmitting sequence of 2FICW modulation is seen as Fig.8. Each Frequency f_1 and f_2 pulse is transmitted for pulse-transmitting-time T_p at pulse-repeat-intervals T_{pri}. This is repeated M times for observation-time T_{opi}. The received wave is mixed with transmitting frequency (f_1 or f_2). Signals received at the same position range are converted with FFT, and a frequency that is over the threshold is detected, and the target velocity is calculated from the detected frequency. Further, the target position is calculated by the phase difference between the detected frequency in f_1 and detected frequency in f_2.
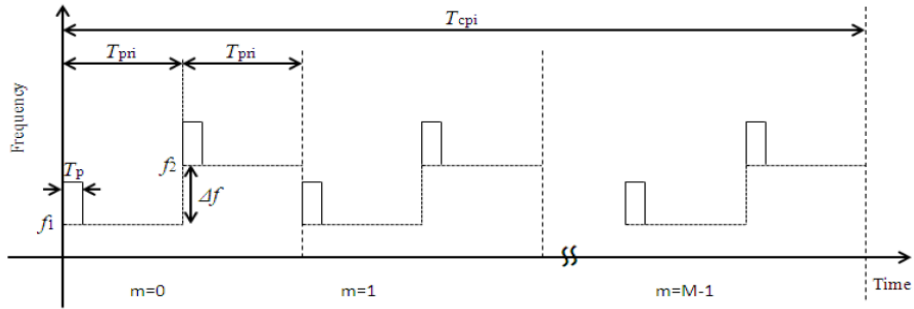

Fig.8 Transmitting sequence of 2FICW modulation

3-3. Experimental parameter

We compare 2FICW with 2FCW by detecting two vehicles that run in tandem in different lanes.

The parameters of 2FICW radar are seen in Table.2.

Table.2 Radar parameters of 2FICW

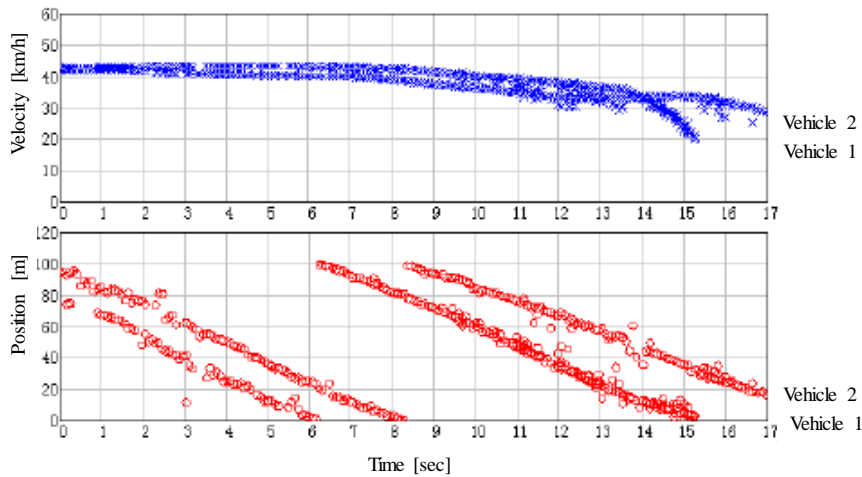|	2FICW modulation
Transmit frequency	24.15GHz
Transmit band width	5MHz
Antenna beam width	±30°(horizontal) ±8°(vertical)
Frequency change interval T_{pri}	2.4μs
A/D sampling frequency	10MHz
Pulse width T_p	0.2μs (position gate range 15m)
Observation time T_{opi}	100.8ms

3-4. Experimental results and considerations

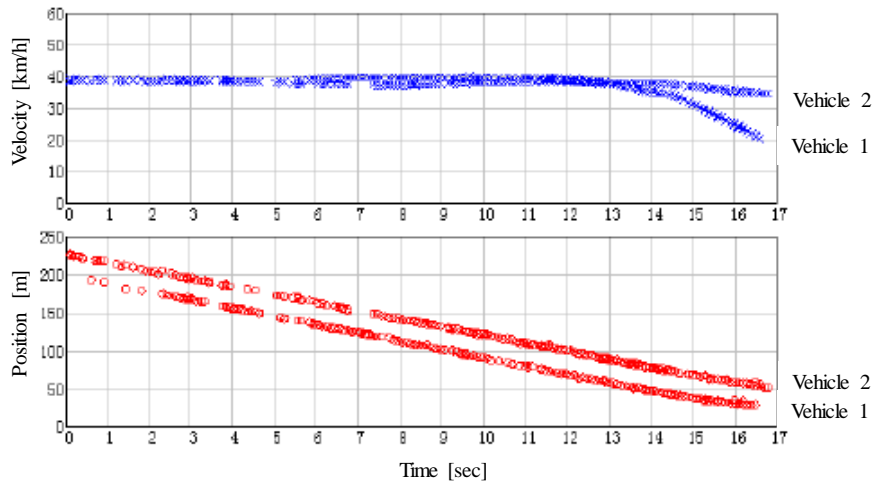Fig.9 Results of 2FCW modulation

Fig.10 Results of 2FICW modulation

For 6 seconds from 0[s] in the detection results for vehicle 1, and for 8 seconds from 0[s] in the detection results of vehicle 2 in Fig.9, though the actual position is 200m, the position shown is 100m because of position ambiguity. Considering this, both 2FCW and 2FICW can detect vehicles at more than 100m away. However, when the velocities of the two vehicles are the same, we think that 2FCW radar cannot estimate the position of the vehicles correctly. On the other hand, when the velocities of the two vehicles are the same, 2FICW radar can estimate the positions of the vehicles correctly as seen in Fig.10.

Covering 4 lanes with an antenna of $\pm 30°$ horizontal beam, 2FCW and 2FICW radars can detect vehicles at more than 100m away. Also, we show that 2FICW radar can detect vehicles of the same velocity separately. 2FICW radar can be applied to infrastructure sensors.

4. CONCLUSION

Assuming an infrastructure sensor detects vehicles and pedestrians, we have conducted experiments in the field. In case clutter from roads and other static objects is heavy, 2FCW modulation has enough SN ratio, and detects a vehicle at 100m away and a pedestrian at 30m away, accurately. Moreover, 2FICW radar can detect two vehicles of the same velocity separately.

We showed the possibility that 2FCW and 2FICW radars can be applied to infrastructure sensors for safety systems.

5. REFERENCES

[1] Takayuki Inaba, Tetsuo Kirimoto, "Automotive Millimeter Wave Radars", Vehicle Technology 64-2, Feb.2010.