Multi-Target Detection Algorithm for FMCW Radar

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***Abstract*—FMCW (Frequency Modulation Continuous Wave) radar has been a popular method for automotive applications. The typical FMCW radar, however, has serious problems in multi-target situations. That is, range-velocity processing gives rise to so-called ghost targets due to Doppler shift in the received beat-frequency. In this paper, we propose a new transmit wave and detection algorithm. In the proposed method, the rough range is detected in the first period, and the fine range and velocity are obtained in the second period.**

I. INTRODUCTION

The recent buzzwords of intelligent vehicles are safety and green. In particular, automotive safety systems are currently being designed to increase comfort and safety to protect drivers and minimize damage in the event of an accident. Figure 1 shows examples of driver safety systems [1]. Currently, many safety systems such as the Lane Departure Warning system, the Blind Spot Detection system, the Lane Change Assist system, and the Electronic Park Assist system, are based on camera sensors. However, camera sensors have limitations due to weather conditions and light conditions.

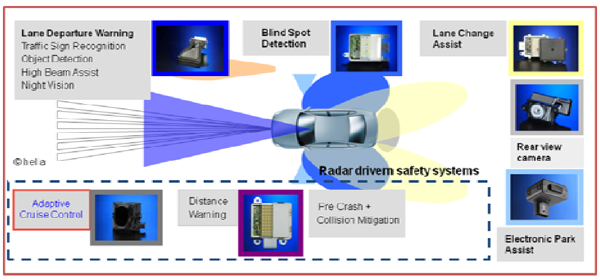

Figure 1. Driver safety system example

Recently, radar driven safety systems have attracted attention as a possible means of overcoming these limitations. Radar based safety systems include the ACC (Adaptive Cruise Control) system, the Distance Warning system, and the Pre-crash system.

FMCW radar has been used throughout the world as an effective automotive radar method. The FMCW transmit signal is a classical and well known waveform [2], as shown in figure 2. In this case, the modulation bandwidth and PRI (Pulse Repetition Interval) are described by B and T . The beat frequency, which is the difference between the frequencies of the transmitted and received signals, is shown in figure 1(b). The beat frequencies for the up-chirp and down-chirp are denoted as f_{bu} and f_{bd} , respectively. The target range R and the radial velocity V are delineated in equations (1) and (2), where c is the light velocity and f_c is the center frequency of transmitted signal.

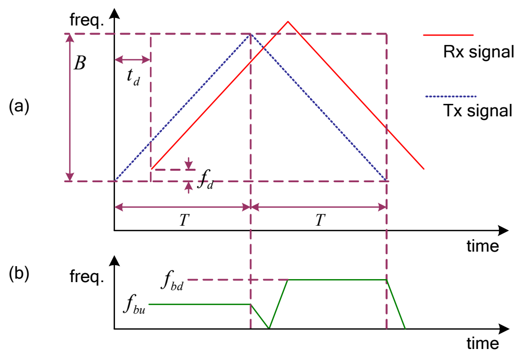

Figure 2. FMCW radar waveform princple for a single moving target (a) the transmitted and received signal, (b) the corresponding beat frequency

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$$R = \left(\frac{c \cdot T}{2 \cdot B}\right) \cdot \left(\frac{f_{bu} + f_{bd}}{2}\right) \quad (1)$$

$$V = \left(\frac{c}{2 \cdot f_c}\right) \cdot \left(\frac{f_{bu} - f_{bd}}{2}\right) \quad (2)$$

The FMCW radar is an effective method, but it yields range-velocity processing ambiguities in multi-target situations due to the following reasons [3].

- separation of ranges and velocities for each target with wide relative velocity
- identification of the correct combinations of beat frequencies for multiple targets is required.

In a multi-target situation, several up- and down-beat frequencies are detected. The combined processing of several beat-frequencies brings out so-called ‘ghost targets’ and degrades the radar performance.

To resolve these limitations, two methods are typically proposed [5][6][7].

The first approach is based on fast ramp trains[8], as shown in figure 3. In this method, a 2 step FFT (Fast Fourier Transform) is used to detect the target range and velocity. Since the movement duration measurement time is very short compared to the target distance, the detected Doppler shift of the detected beat-frequency can be neglected. Therefore, the range is detected in the 1st FFT at every PRI, and the Doppler spectrum is calculated at every beat-frequency. This method is very effective, but high computational effort is required due to the generation of many ramps.

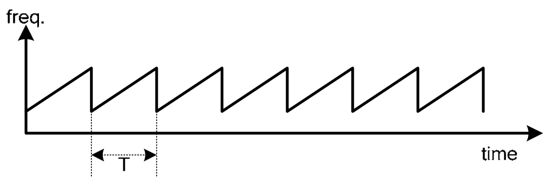

Figure 3. Fast ramp generation

The other method [9] uses slow ramps with different slopes, as shown in figure 4. In this approach, the computational effort is low compared to the above method. However, since this approach is an extended version of the typical FMCW method, an effective combined algorithm of beat frequencies and the ghost target cancellation technique is still required.

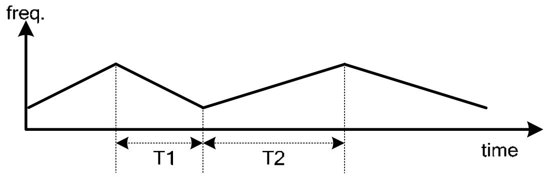

Figure 4. Ramp Generation with different slopes

In this paper, we propose a new multi-target detection algorithm for FMCW radar to reduce the ghost target.

II. The Proposed Method

Figure 5 shows the proposed waveform for FMCW radar.

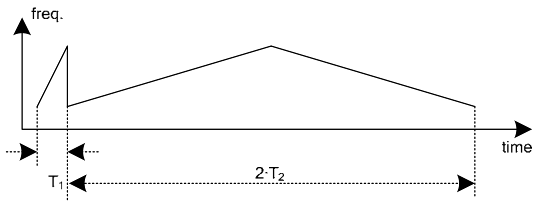

Figure 5. The proposed waveform

Since T1 is very short compared to T2, the Doppler shift of the beat-frequency is very low. In the T1 step, the approximate range can be detected with error due to the slight Doppler shift. Figure 6 shows the signal processing result in T1 period.

In this example, we assume that the number of detected targets is 3, where $f_{b1}(1)$, $f_{b1}(2)$, and $f_{b1}(3)$ are the detected beat-frequencies. We cannot ascertain the exact range of the targets due to the slight Doppler shift, but we can determine the bound of the target distance using the maximum Doppler shift information, as shown in the example presented in figure 6. In this case, the bound limitation is decided using radar system parameters such as PRI, ADC(Analog Digital Converter) sampling rate, FFT point, and so on.

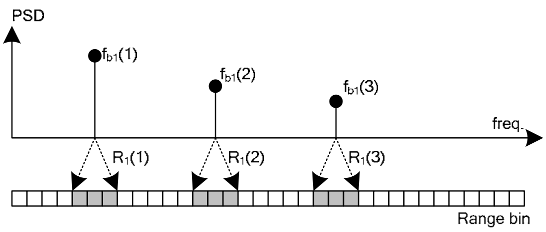

Figure 6. The range detection result in T1 step

Next, we can extract up- and down-beat frequencies in the T2 period. The detected frequencies consist of the range-beat frequency and Doppler shift. In this case, the Doppler shift cannot be neglected in order to obtain more accurate range and velocity.

Each detected frequency produces range and velocity pairs by combined processing, and we can then map the results into a R-V bin table, as presented in figure 7. In figure 7, we assume that the detected up- and down-beat frequency, respectively, is 3 such as fbu2(1)~ fbu2(3), and fbd2(1) ~ fbu2(3).

The number of mapped range and velocity pairs in the R-V bin table is thus 9, and they include 6 ghost targets. However, we can determine the range bound of the real target estimated by pre-processing in T1. Therefore, we can easily remove the ghost targets from the R-V bin table.

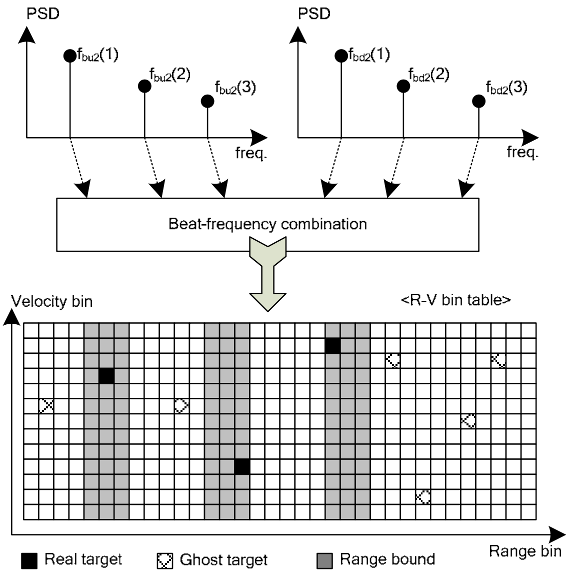

Figure 7. The range-velocity detection result in T2 step

III. SIMULATION RESULTS

The proposed algorithm is simulated using Matlab. The transmitted bandwidth is 300 MHz, and the center frequency is 76.5 GHz. We assume the system performance of the FMCW radar employed in this simulation is as given in Table I, where R_{max} is the maximum range, V_{max} is the minimum range, $\triangle R$ is the minimum range step, and $\triangle V$ is the minimum velocity step.

TABLE I. RADAR REQUIREMENT EXAMPLE

T	R_{max}	V_{max}	$\triangle R$	$\triangle V$
	200m	200km/h	1m	7.2km/h
0.1ms	2.667MHz	13.33KHz	13.33KHz	1.02KHz
1ms	266.67KHz		1.333KHz	

We also select two PRI, T1 and T2, as 0.1ms and 1ms. While the Doppler frequency is not related with PRI, the range beat-frequency is inversely proportional to the PRI. We can see the beat-frequency in T2 is 10 times higher than the beat-frequency in T1.

We also design the system parameters to meet the radar requirements of Table I.

First, we select the ADC sampling rate based on Nyquist theory as 6MHz (≥2.667MHz x 2) and 1MHz (266.67kHz x 2) in each PRI. We also choose the FFT point as 512 in T1 to detect the minimum range and 1024 in T2 in order to meet a sufficient range step and velocity step.

Therefore, the range step and velocity step in T1 are 0.879m and 82.722km/h, respectively. This means the rough target range has errors of ±3 step due to Doppler shift. In T2, we can obtain the fine range step and velocity step as 0.733m and 6.896km/h. In this simulation, however, the target SNR (Signal to Noise Ratio) is not considered in detail.

In order to simulate the proposed method, we assume the ranges and relative velocities of objects on a road as shown in figure 8. Four vehicles are moving away from the radar system, three cars are approaching the radar equipped car on the road, and three targets (a vehicle and a road sign) are stationary at the side of the road. The range and velocity of each target are provided in Table II.

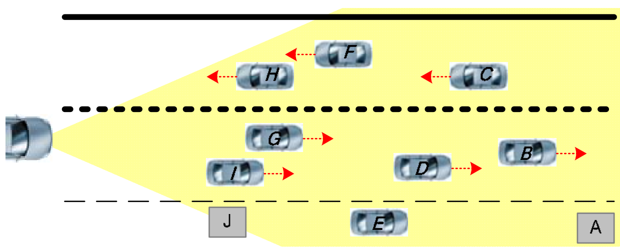

Figure 8. Simulation example of the proposed method

TABLE II. RANGE AND VELOCITY OF TARGETS IN EXAMPLE OF FIGURE 8

		Range (m)	Velocity (km/h)
Target A	Stationary	180	0
Target B	Moving	150	160
Target C	Moving	130	-99
Target D	Moving	110	120
Target E	Stationary	90	0
Target F	Moving	80	-90
Target G	Moving	75	150
Target H	Moving	50	-190
Target I	Moving	30	90
Target J	Stationary	20	0

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In period T1, we can obtain the rough ranges from target A to J as 20m, 29m, 52, 74m, 81m, 90m, 109m, 131m, 148m, and 180m. In this case, the maximum range error is about 2m due to Doppler shift in the range-beat frequency.

Using these results, the bound of range is generated and the beat-frequency combined processing is applied to suppress the ghost targets.

Figure 9(a) shows the combination results using up- and down-beat frequencies detected in T2. The horizontal axis is the range and the vertical pole is the velocity. We can see the number of targets is 30 including 20 ghost targets. Therefore, the miss-detection rate is 20/30, that is, 67%.

The ghost targets of figure 9(a) can be removed using the range bound generated by T1, as shown in figure 9(b). Most ghost targets are canceled and the miss-detection rate is 1/31, that is. 3%.

If the multi-ramp shown in figure 4 is employed instead of a single ramp in T2, the detection performance can be improved.

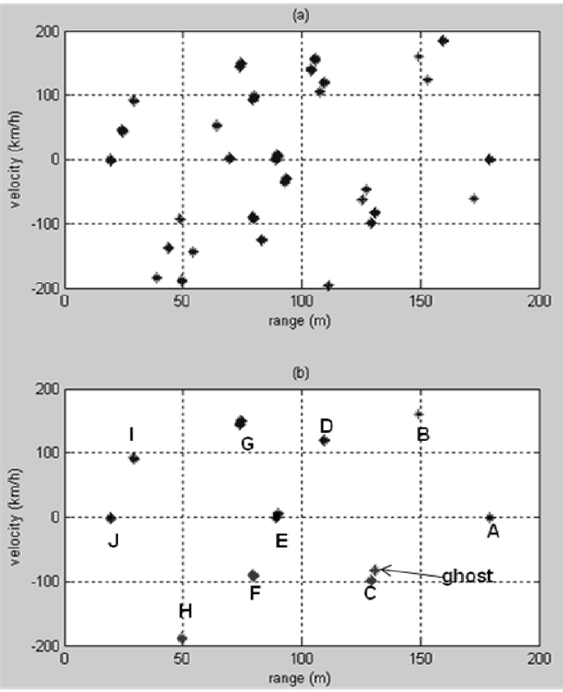

Figure 9. The beat-frequency combination resulst, (a) typical processing, (b) the proposed processing

IV. CONCLUSIONS

We have proposed a new method to effectively detect the range and velocity for automotive FMCW radar. First, using short ramp, the rough range is detected in the first period and the range bound, where the real target exists, is determined using the maximum Doppler shift. Next, in the second period, the up- and down-beat frequencies are extracted and the possible range-velocity combinations are determined. The ghost targets are neglected using the range bound generated by the first period. This method will be useful to improve the radar detection characteristics.

In the future, the simulation including the target SNR will be carried out in detail, and fields test will be conducted for detection of real targets. Also, a comparison of the characteristics of the proposed method with those of other with the other modulation methods will be carried out.

ACKNOWLEDGMENT

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REFERENCES

[1] www.hella.com

[2] Stove, A. G.. "Linear FMCW radar techniques", IEE Proceedings-F, Vol. 139, No. 5, Oct. 1992..

[3] Shunji Miyahara, "New Algorithm for Multiple Object Detection in FM-CW Radar", SAE Technical paper series, 2004-01-0177, March 2004

[4] Eugin Hyun, Jong-Hun Lee, "A Method for Multi-target Range and Velocity Detection in Automotive FMCW Radar", Proceedings of 12th International IEEE Conference on ITSC, pp. 7-11, Oct., 2009

[5] Winkler, V., "Range Doppler detection for automotive FMCW Radar", Proceedings of the 4th IEEE European Radar Conference, pp. 166-169, Oct.. 2007

[6] Eugin Hyun, Woojin Oh, Jong-Hun Lee, "Two-step Moving Target Detection Algorithm for Automotive 77GHz FMCW Radar", 2010 IEEE 72nd VTC Fall, Sept., 2010

[7] Eugin Hyun, San-Dong Kin, Yeong-Hwan Ju, Jong-Hun Lee, Euan-Noh You, Jeong-Hi Park, Dong-Jin Yeom, Sang-Hyun Park, Seung-Gak Kim, "FPGA Based Signal Processing Module Design and Implementation for FMCW Vehicle Radar Systems", Proceedings of 2011 IEEE CIE International Conference On Radar, pp. 273-275, Oct., 2011

[8] Wojtkiewicz, A., Misiurewicz, J., Nałe¸ M., Je¸ Drzejewski, K., Kulpa, K., "Two-dimensional signal processing in FMCW radars", http://staff.elka.pw.edu.pl/~jmisiure/esptr_2007 /lect_fmcw/kk97.pdf

[9] Rohling, H., Moller, C., "Radar waveform for automotive radar systems and applications", Radar Conference 2008, pp. 1-4, May 2008