Resolution enhancement for FMCW radar system using fine offset estimation

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Abstract. The frequency modulated continuous-wave (FMCW) radar system measures the frequency spectrum of received beat signal in order to estimate the speed and the distance of moving objects. Its resolution and accuracy are determined by the sampling frequency and the number of samples used in the system. In this paper, the frequency offset estimation is applied to enhance the resolution. The simpler algorithm finding beat frequency is developed based on kernel function analysis. The more accurate information of the target can be obtained by using the proposed method without any change of system parameters.

Keywords: FMCW, Doppler radar, automotive application, kernel function, fine estimation.

1 Introduction

The frequency modulated continuous-wave (FMCW) radar is effectively used to measure the distance and the velocity of moving objects. The 77GHz millimeter wave band provides the good performance for automotive applications[1], and many countries adopt this band through ITU recommendations[2].

The FMCW radar system uses a linear frequency modulation (LFM). Typical FMCW system is divided into two parts, which are target detection and parameter estimation. The target existence is determined by constant false alarm rate (CFAR) algorithms[3, 4], and the distance and the speed of relatively moving target are estimated by using beat frequency detector[5]. Since the most FMCW radar systems use discrete Fourier transform (DFT) to obtain the beat frequency, the frequency offset is inevitably included in discrete beat frequency, and hence their resolutions are determined by the sampling frequency and the number of samples[6]. The bandwidth extrapolation (BWE) method[7], relaxation (RELAX) method[8] and compressive sensing (CS) estimation[9] are proposed to improve the accuracy, which need to change the system parameters. In order to enhance the system resolution, the fine frequency estimation methods are proposed such as two sample method[10] and three sample method[11]. Although these methods improve the resolution without any change of system parameter, they need a large computational complexity.

Here, we propose a simple offset estimation algorithm, which are developed from kernel function analysis described in [12] for the automotive application system. The proposed method can estimate the beat frequency which is approximated to its exact value without any change of the system parameter.

This paper is organized as follows. The signal modeling for FMCW system introduced in section 2. The simple frequency offset estimation method is proposed with the kernel function analysis in section 3. In section 4, the performance of proposed method is evaluated by the computer simulations. The conclusive remarks are in section 5.

2 FMCW radar system

The beat signal is obtained from received signal after removing the reference signal, which are classified as up chirp and down chirp signals. The beat signal can be derived as followings[13]

$$Sbeat,up(t) = exp\{j2v((f_d — 2ar)t + (ar — f_c — f_d)t)\} \quad (1)$$

$$Sbeat,dn(t) = expti27((fd+2a* — (err + f_c + IF + f_d)r)\} \quad (2)$$

where the frequency sweep rate, Doppler shift, carrier frequency and time delay are denoted by a, f_a, f_c and T, respectively. The Hamming window is applied to beat signal in order to improve CFAR performance for automotive applications[13]. The beat frequencies of the up chirp and down chirp signals can be obtained by DFT, which are represented by

$$fbeat,up = f_d-2ar \quad (3)$$

$$fbeat,dn = fd+2ar \quad (4)$$

Now, the distance and relative speed can be computed from above two beat frequencies. The resolution is directly proportional to the maximum offset error written by

$$Qf= mss \quad (5)$$

where f, and N are the sampling frequency and number of samples, which are the key system parameters of FMCW radar.

3 Frequency offset estimation method

The beat frequency error is defined by

$$err_{bf} = \frac{N \cdot (if^{\circ} - fbl)}{27r}, \quad 0 \; err_{bf} \; 0.5 \tag{6}$$

where f_o and f_b are the discrete beat frequency and exact beat frequency. In case of FMCW system for automotive application, the frequency offset can be approximated by kernel function of applied window[4]. Figure 1 shows the frequency distribution of sampled beat signal from the rectangular window. In the case of rectangular window, the kernel function is derived from a sine function. If P_o is biggest magnitude and $/3_{-1}$ is larger then p_i, the magnitudes P_o and p_i are described by

$$Po = Amax \, ' \, sinc(err_{bf}) \tag{7}$$

$$Pi = Pina, \cdot sinc(err_{bf} - 1) \tag{8}$$

Here, p_{max} is the maximum magnitude at the exact beat frequency. The ratio of p_i and p_b is written by following equation

$$Prate = \frac{p_i}{Po} = \frac{sinc(err_{bf} - 1)}{sinc(errbf)} \; \backslash = \frac{-err_{bf}}{err_{bf} - 1} \tag{9}$$

and hence the beat frequency error can be derived by

$$err_{bf} = \frac{Prate}{Prate + 1} \tag{10}$$

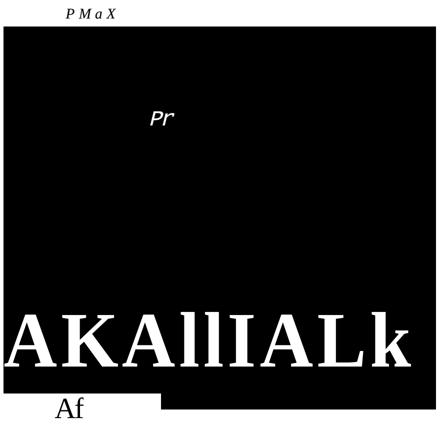


Figure 1. Ideal frequency spectrum plot by rectangular window

Now, we can obtain the estimated beat frequency by the following equation

$$fp \quad fb \quad \frac{2ir \cdot err_{bf}}{N}$$

The windowing performed prior to DFT improves CFAR performance. However, all other windowing techniques except the rectangular windowing require the large computational complexity for the inverse operation of kernel function. To reduce the complexity of the windowing process, we propose the filtering method which is applied after the beat frequency estimation. The filter coefficients are derived from kernel function of window. Figure 2 shows the estimated offset error when the proposed method is applied for the cases of Hamming window and rectangular window. These are simulated for SNR is equal to 0 dB, and LUT of size 10,000 is used for Hamming window method.

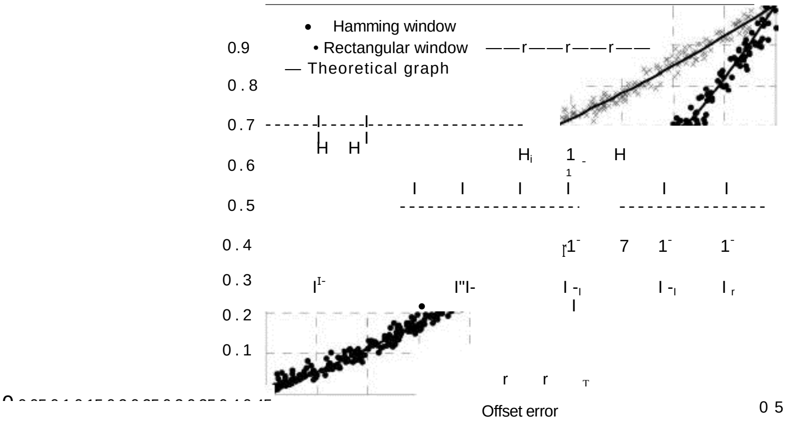


Figure 2. Offset error estimation comparison of Hamming and rectangular window

4 Performance evaluation

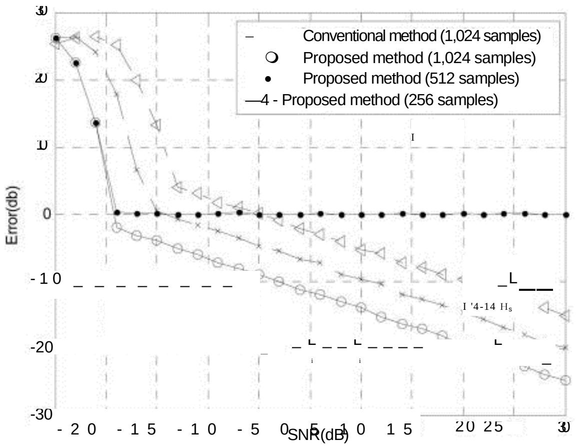
The performance of proposed method is evaluated by computer simulations for automotive application environment[2]. The system parameters for simulations are summarized in Table 1.

Table 1. FMCW radar system parameters

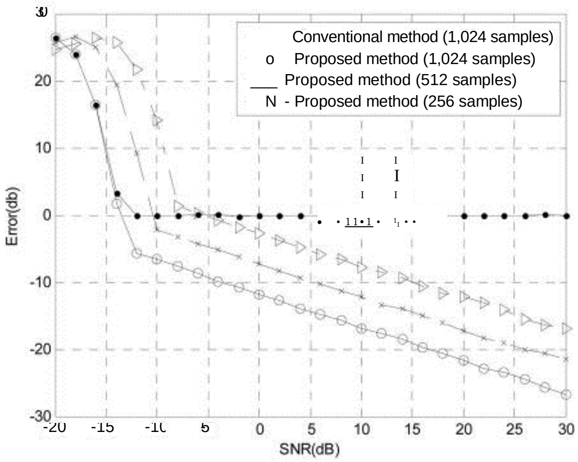
Parameter	Value
Carrier frequency (f_c)	Carrier freq : 77 GHz
Sweep time	3 msec
Sampling frequency	369 khz
Bandwidth	150 MHz
the frequency sweep rate *(a)*	**5 x** 10^{10}
FFT size (N)	1,024

Figure 3 shows the average error of measured values with respect to SNR for the conventional method and proposed method with respect to the various DFT size. The conventional system has same accuracy regardless of SNR when it is larger than -

15dB, but proposed method can improve the accuracy in proportion to the SNR. For the case when the number of samples is 1,024 and SNR is 5dB, the average error of measured error is reduced from 0dB to -12dB and -14dB for rectangular and Hamming window cases, respectively. Also it shows that the proposed method can obtain the desired accuracy even with the smaller number of samples, which means that proposed method can reduce total computation complexity of FMCW radar system.



(a) Rectangular window



(b) Hamming window

Figure 3. The mean error of measured relative speed and distance for moving targets

5 Conclusion

The simpler frequency offset estimation is proposed for the FMCW radar system. The proposed method obtains the accurate beat frequency approximated to its exact value, and hence it enhances the system resolution with the reduced computational complexity. The proposed method can be applied to various radar systems based on Doppler processing.

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