Parameter Optimization of UWB Short Range Radar Detector for Velocity Measurement in Automobile Applications

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Abstract. For designing UWB-SRR detectors we must understand the required design parameters and specific algorithm for target detection. In this paper, we optimize the parameters such as the number of coherent integration, pulse repetition interval, Doppler frequency resolution and FFT measurement time of UWB Short Range Radars for measuring the relative velocity of the target in automobile applications. The proposed detector with optimized parameters can measure the target minimum relative velocity of about 6.99 km/hr in very short measurement time. The minimum number of FFT points required to process Doppler Frequency by Fast Fourier Transform (FFT) is 32 points. The detection is based on one transmitted pulse against a background of white Gaussian noise (WGN). The performance of the proposed detector with optimized parameters is analyzed and simulation has been done in order to verify.

Keywords: FFT, Velocity resolution, Coherent integration, UWB-SRR Detector, Doppler Frequency, Pulse Repetition Interval.

1 Introduction

In automobile industries, the vehicle safety has improved in the last decades with the increase in new safety technologies. The 24 GHz Short Range Radars are mainly used to give information such as range and velocity of the target to the driver and in some cases they are connected to a computer that performs some guiding actions to reduce collision and minimize the injuries. The source for target detection is the radar signals reflected by the target that is a mixture of noise and varied signals. The designed system must provide the optimal technique to obtain the desired target detections and to measure the relative velocity between the radar and target. The preferred detection can be determined by using specific algorithm for measuring the energy of the received signals. For this reason radar systems in 24 GHz have good performance in range and velocity measurement therefore they can be applied in different automobile applications like parking-aid, pre-crash detection [1].

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Previous works [4]-[5] has been focused on influence of increasing range resolution on detection ability of targets and also designed the algorithm with Fast Fourier Transform (FFT) method mainly. In this paper, we present the parameters optimization such as the number of coherent integration, the number of FFT points and the velocity resolution by using very narrow pulse width such as UWB signal. Our paper is made on the assumption of single moving target and shows the results by using the Monte Carlo simulation.

The organization of this paper is as follows. In Section 2, the system model is described. In Section 3, we propose the detector for velocity measure. In Section 4, the parameter optimization method is expressed. In Section 5, simulation result is shown. Finally, conclusion is presented in Section 6.

2 System Description

The block diagram of a UWB radar system as shown in figure 1 is split in to two parts, the transmitter part and the receiver part.

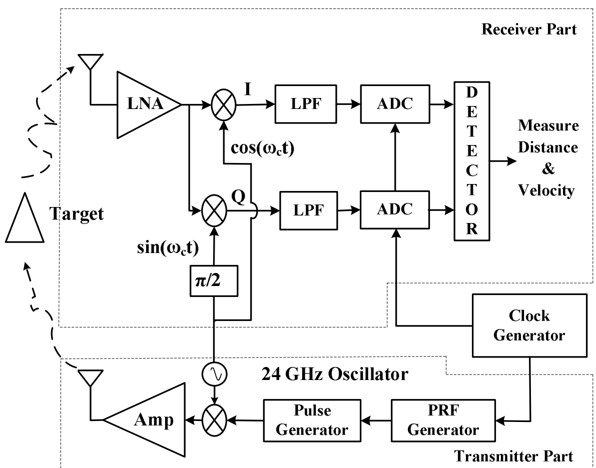

Fig. 1. Block diagram of UWB radar system

In the transmitter part, the pulses are initiated by the Pulse Repetition Frequency (PRF) generator which triggers the pulse generator which in turn generates Gaussian pulses with sub-nano second duration as shown in figure 2. The Pulse Repetition Interval (PRI) is controlled by the maximum range of the radar. The maximum range for unambiguous range depends on the pulse repetition frequency and can be written as follows

$$R_{\max} = \frac{c}{2 \cdot f_{PRF}} \tag{1}$$

where f_{PRF} is the pulse repetition frequency and c is the velocity of light. And the range resolution can be written as

$$\Delta R = \frac{c \cdot T_P}{2} \tag{2}$$

where T_p is the pulse width and c is the velocity of light. Then the transmitted signal can be written as follows

$$s(t) = A_T \cdot \cos(2\pi f_c t + \varphi_0) \cdot \sum_{n=-\infty}^{+\infty} p(t - n \cdot T_{PRI}) \tag{3}$$

where $p(t)$ is the Gaussian pulse as follows

$$p(t) = \exp\left[-2\pi\left(\frac{t}{\tau_p}\right)^2\right] \tag{4}$$

And the parameters employed in this UWB radar system are described as follows; A_T is the amplitude of single transmit pulse, φ_0 is the phase of the transmit signal, f_c is the carrier frequency, and T_{PRI} is the pulse repetition time.

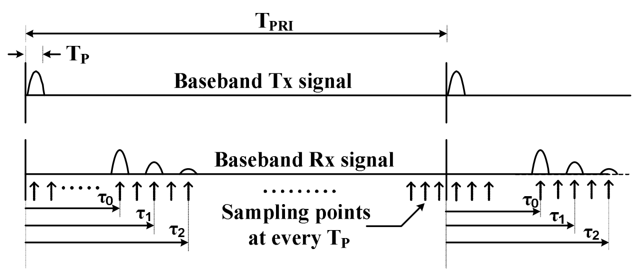

Fig. 2. Transmitted signal and received baseband signal

Since the range resolution of the UWB radar system is much less than the extent of the target, the echo signal is the summation of the time-spaced echoes from the individual scattering centers that constitute the target [3]. Therefore, in this paper, we can assume that the target has L independent reflecting cells. The target model is written as

$$h(t) = \sum_{l=0}^{L-1} \alpha_l \cdot \delta(t - \tau_l) \tag{5}$$

where the number of scatters L, the amplitude of the scatters α_l, and the time delays of the scatters τ_l are all unknown. If the target is moving with relative velocity v [km/hr] between the radar and the target, then the baseband complex received signal $r(t)$ is written as

$$r(t) = A_T \sum_{n=-\infty}^{+\infty} \sum_{l=0}^{L-1} \alpha_l \cdot e^{j\theta_l} p(t - nT_{PRI} - \tau_l) + n(t) \tag{6}$$

where $n(t)$ is the complex additive white Gaussian noise (AWGN) with two-sided power spectral density $N_0/2$ and θ_l is the arbitrary phase of l-th scatter that can be written as $\theta_l = -2\pi f_c \tau_l + \varphi_0$. The sampling rate is same to the pulse width and the wavelength λ is c/f_c and c is the velocity of light, the Doppler shift is denoted as $\omega_d = \pm 4\pi v/\lambda = \pm 4\pi v f_c/c$. In the Doppler shift, the positive sign (+) indicates the closing target and the negative sign (-) means the receding target.

3 Proposed Detector

In this section, we propose the algorithm for measuring the relative velocity of the target. First, as shown in Figure 3, we can detect the relative velocity of the target by performing DFT. Typically DFTs are performed with Fast Fourier Transform (FFT). The proposed detector consists of coherent integration, Discrete Fourier Transform (DFT) algorithm and square law detector. The sampling frequency is set depending on the pulse width, the baseband received signal is sampled in an in phase (I) and quadrature (Q) channel at every T_p, and the sampling rate T_p is same to the pulse width of 2ns and the range resolution can be 30cm from (2) and also it is assumed that the maximum target range can be 20m by using (1). From the above mentioned range resolution and maximum target range, the range gates of atleast 67 are required to detect the target range and velocity. Therefore the range gates are equal to the number of memory in the coherent integration. The sampled valued at every T_P is applied to switch I and Q of the coherent integration. The switch I is shifted at every T_p sample, i.e., the range gate. It takes $N \cdot T_{PRI}$ to coherently integrate and dump for all range gates. The coherent integration for the i-th range gate in I branch can be expressed as follows

$$X^I(i) = \frac{1}{N_c} \sum_{n=1}^{N_c} \mathrm{Re}\{r_n(iT_P)\} \tag{7}$$

where

$$r_n(iT_P) = A_T \sum_{l=0}^{L-1} \alpha_l \cdot e^{j\theta_l} p((nT_{PRI} + iT_P) - nT_{PRI} - \tau_l) + n'(nT_{PRI} + iT_P) \tag{8}$$

The DFT formed for a range cell provides a direct measure of the Doppler frequency. The result for one complete measurement cycle is a matrix of range gates and Doppler frequencies. Detection statistics (such as square law detection statistic) are performed for DFT outputs according to the prescribed detection strategy.

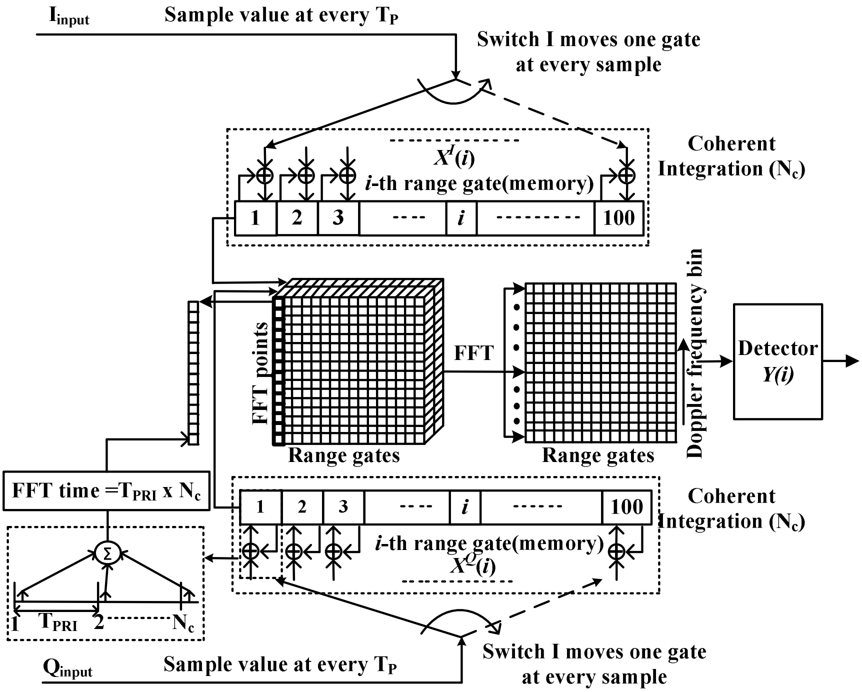

Fig. 3. Block Diagram of the proposed detector

The DFT algorithm performed by FFT operates at every $N \cdot T_{PRI}$ and the 32 point output of the DFT algorithm is a complex output which is squared and added can be represented as

$$Y(i) = \frac{1}{N}\sum_{n=1}^{N}\left\{X^{I}(i)e^{-j\Omega n}\right\}^{2} + \left\{X^{Q}(i)e^{-j\Omega n}\right\}^{2} \tag{9}$$

4 Parameter Optimization Method

The detector of UWB radar must determine that a signal of interest is present or absent, and then the UWB radar processes it for some useful purpose such as range determination and velocity measure.

In this paper, we propose the importance of optimizing various design parameters such as the number of coherent integration, sampling time, velocity resolution, Doppler frequency resolution, FFT measurement time and the required FFT length.

The most important part of radar receiver is to understand how the ultra-short pulses are sampled in resolution (range-Doppler) cell. The required sampling frequency depends on the Doppler frequency range which corresponds to the relative velocity between the detector and the target. The minimum Doppler frequency resolution that can be achieved is given by

$$\Delta f_D = (1/T_{FFT})/N \tag{10}$$

where T_{FFT} is the sampling time of the FFT input which is the product of number of coherent integration (N_c) and pulse repetition interval (T_{PRI}). And N is the number of FFT points

$$T_{FFT} = N_c \times T_{PRI} \tag{11}$$

The relation between Doppler frequency and relative velocity is

$$f_D = -\frac{2vf_c}{c} \tag{12}$$

where v is the relative velocity and f_c is the transmitter frequency.

Thus the velocity resolution that can be achieved from the minimum Doppler frequency is

$$\Delta v = -\frac{\Delta f_D \cdot c}{2 \cdot f_c} \tag{13}$$

The required FFT measurement time also depends on the velocity resolution as shown in the figure below, For a FFT length of 32 points the FFT measurement time is given by

$$T_{FFT\,measure} = N \times T_{FFT} \tag{14}$$

If the number of FFT points increases then the measurement time also increases correspondingly.

5 Computer Simulation Result

The purpose of the simulation is to find the relative velocity between the UWB detector and the target. In the simulation we assume that the total energy reflected from the target is 1 and the system parameters are used as mentioned in table I. The signal-to-noise ratio (SNR) is defined as $\bar{E}/N_0$, where $\bar{E}$ is the total average energy reflected from the target. Fig. 6 shows the simulation result of a single moving target in frequency domain against a background of additive white Gaussian noise (AWGN).

Fig. 7 shows the variance (dB) versus the Signal-to-noise ratio ($\bar{E}/N_0$) in time domain and frequency domain. A large enough number of trials are performed to obtain the variance at various $\bar{E}/N_0$. The number of trials is about 1000000 times. We can predict that the variance (which is proportional to noise power of AWGN) in frequency domain is less than the variance in the time domain, therefore the performance of the detector will be superior in frequency domain than compared to time domain.

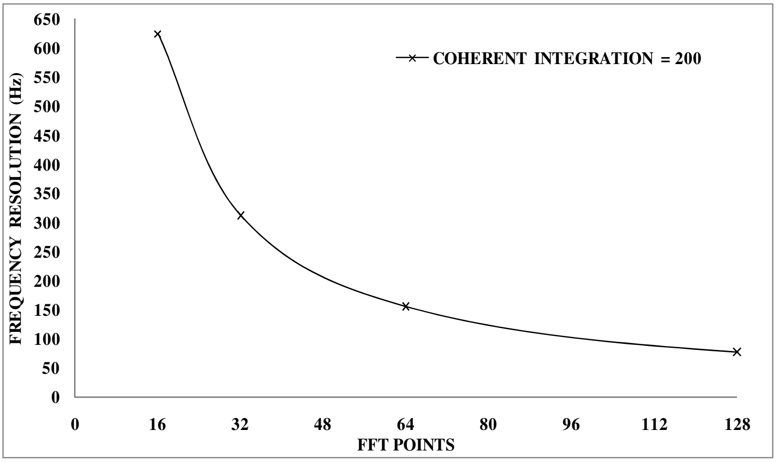

Fig. 4. FFT points Vs Doppler frequency resolution

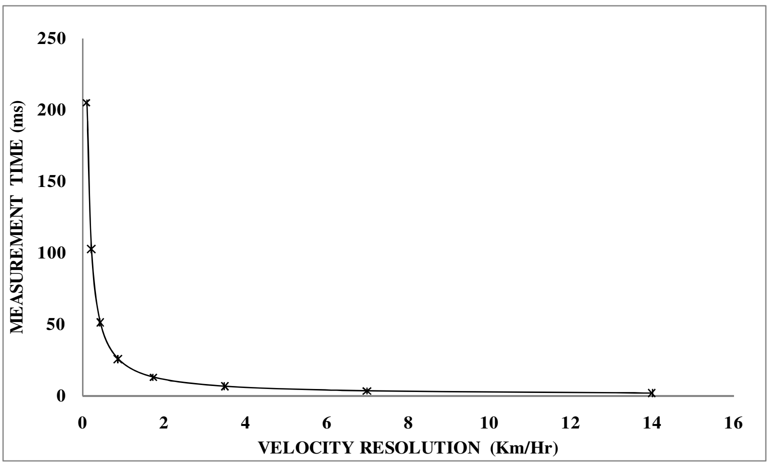

Fig. 5. Velocity resolution Vs measurement time

Table 1. System Parameters

Parameters	Notation	Value
Pulse Repetition Interval	T_{PRI}	500ns
Pulse Width	T_p	2ns
Maximum Target Range	R_{max}	20m
Range Resolution	ΔR	30cm
Number of Coherent Integration	N_c	200
Velocity Resolution	Δv	6.9948 km/hr
Number of FFT points	N	32

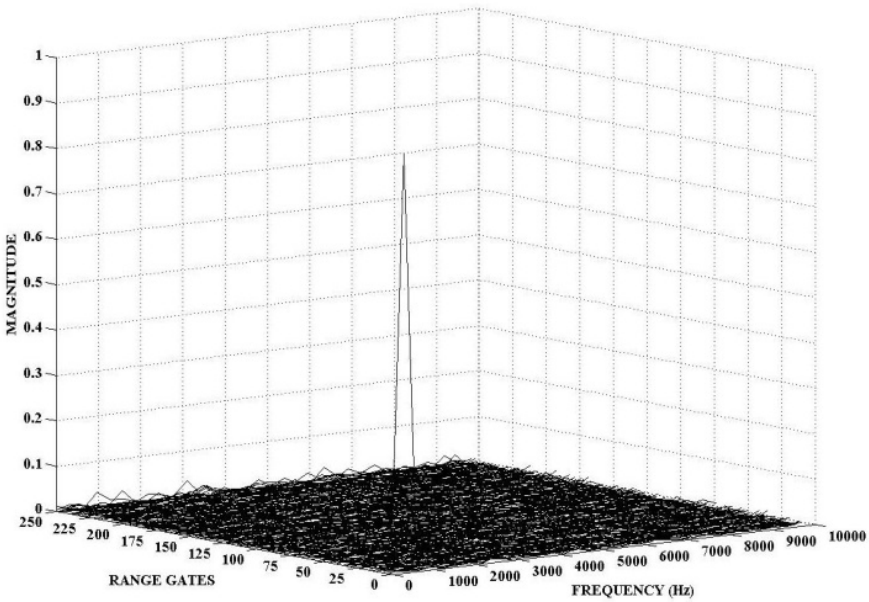

Fig. 6. 3D Graph of Detector output

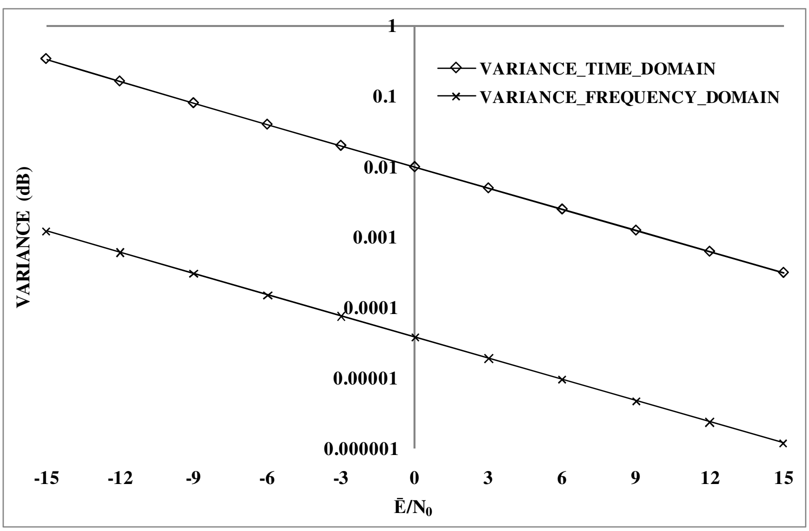

Fig. 7. $\bar{E}/N_0$ Vs Variance

6 Conclusion

In this paper, we have optimized the design parameters such as coherent integration, pulse repetition interval, target velocity resolution and the FFT measurement time of Ultra Wide Band Short Range Radar (UWB-SRR) detectors in Automobile applications. Thus the optimized parameters enhance the performance of the proposed detector, so that the target relative velocity of up to 6.9948 km/hr can be detected in very short FFT measurement time of about 3.2ms by using minimum FFT points of 32 efficiently. Finally, we show that the noise power is reduced in frequency domain when compared with the time domain thus increases the detection probability of the detector. Therefore the proposed detector is memory and time efficient detector for automobile applications which is the critical problem in conventional FFT method.

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