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Target Velocity Estimation using FFT Method

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Abstract

This paper studied a method of estimating target information using a radar in wireless communication. Position information on the target can be estimated angle, distance and velocity. The velocity information can be estimated since the Doppler frequency is changed in the moving target. The signal incident on the receiving array antenna is multiplied by the delay time and the reference signal to represent the output signal. This output signal is estimated by applying FFT (Fast Fourier Transform) after calculating signal correlation through correlation integrator. Since the output signal must be calculated within the correlator, it should be processed with the Dwell time. The correlation signal of the correlation integrator outside this Dwell time is indicated by the velocity measurement error. The FFT is applied to the signal that has passed through the correlated integrator in order to estimate the distance of the signal. The Doppler resolution must be improved because the FFT estimates target information using the Doppler information. The Doppler resolution decreases with increasing the integration time. The velocity information estimation should have no spread of the velocity. As a result of the simulation, there was no spread of the target velocity in this study.

Keywords: *FFT, Correlation Integrator, Delay time, Doppler frequency, Target velocity*

1. Introduction

The target estimation method is to find a position by analyzing a signal incident on a receiver. The target position estimation uses GPS, a mobile communication network, and an arrival direction estimation methods. The direction of arrival method estimates the desired target by removing interference and noise signals. The MUSIC and ESPRIT algorithms are used as the direction of arrival method because they have good target estimation capabilities. The MUSIC algorithm estimates the direction of arrival by finding the peak of the array response vector in the eigenvectors spectrum of the noise subspace to separate the signal space and noise space from the received signal [1-2]. The ability of the estimation method is limited to the number of elements in the sub array. The ESPRIT direction of arrive estimation method estimates the target by the rotation matrix [3]. The problem with these estimation methods is that it is very important to extract different signals from the estimator and compare the analyzed data model with other data. The target direction estimation methods have been used in radar, sonar, and wireless communication. The radar target estimation methods has been studied a lot. The radar is a system that estimates the distance, phase, and altitude of the target using a reflected received signal by radiating radio waves in spatial. The radar has been mainly used for military purpose for the search

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and tracking targets in the sky, ground, and sea. Since its opening to the public, it has had a significant impact on the development of the ground and the satellite high frequency communications, ship navigation systems, and weather observation systems.

The target estimation using radio wave reflection was studied by R. Appleton [4]. G. Brate and M.A.Tubes studied the method to detect the target with being reflected in the ionosphere by estimated the reflected wave of the ionosphere using pulsed waves. This is the first pulse radar to successfully track a target [5]. The multipath null method and the mechanical beam steering method were studied as the initial application techniques for target estimation [6-7].

An adaptive array antenna is used for target estimation. The adaptive array antenna increase the directivity of a radiation pattern in a desired direction by regularly arranging a plurality of antenna so that power radiated from each antenna causes reinforce interference in a specific direction and cancels interference in other directions. The adaptive array antenna is a system that removes unwanted interference signals such as jamming and clutter through spatial filtering of signals received using array antenna elements and obtains only desired signals. It is a system that can receive only the desired signal by forming a null pattern and keeping it constant for the incident direction of the interference signal [8-9]. The array antenna samples electromagnetic waves at many locations on the antenna's aperture surface, converts the signals from each receiving element into complex digital numbers and transmits them to a high-speed digital processor. The final result of this process is a set of beams having different directions in space [10]. It is not affected by the amplitude and phase errors in the antenna element and receiver channel since the null depth of the radiation pattern can be compensated by the calibration technique implemented in digital beamforming. There are two types of multi-beam formation: a systolic array method and a fast Fourier transform method. The fast Fourier transform method can implement hardware in a small circuit compared to the single-axis array method.

This study obtains the correlation between tow signals by multiplying the signal incident on the receiving antenna and the reference signal, and extracts the velocity of the target by applying FFT to the correlation between the two signals. The rest of this paper is organized as follows. Section2 represent the analysis of the receive signal. Section 3 describes the velocity algorithm proposal. Section 4 shows simulation results of the proposed algorithm, and section 5 draws the conclusion.

2. Analysis of the receive signal

2.1 Distance information estimation

The transmitted signal $x_t(t)$ is reflected by the target and enters the receiver. At this time, the transmission signal and the receive signal are delayed, so the receive signal $x_r(t)$ and the delayed reference signal $x_d(t)$ are represented as follows [11].

$$x_r(t) = x_t(t - \tau_r) \tag{1}$$

$$x_d(t) = x_t(t - \tau_d) \tag{2}$$

Where τ_r and τ_d are the receiver`s delay time and the reference delay time, respectively. The correlation value of the two signals is expressed by the following correlation function for the delay time difference ($\tau = \tau_r - \tau_d$).

$$R(\tau) = \frac{1}{T}\int_0^T x_d^*(t) \quad x_t(t) \quad d = \frac{1}{T}\int_0^T x_t^*(t) \quad x_t(t-\tau) \quad \mathrm{d}t \tag{3}$$

Where T represents the period and $(\ )^*$ is a complex conjugate. The signal power spectrum $S(f)$ and the delay time correlation function can be written as follows.

$$R(\tau) = \int_{\infty}^{-\infty} S(f)\ e^{j\omega\tau}\ \ df \tag{4}$$

Where ω represents an angular frequency. The correlation integral of the radar can be written as follows.

$$C(\tau) = \int_{0}^{T_{int}} x_t^*(t)\ \ x_t(t-\tau)\ dt \tag{5}$$

If $\tau_d = \tau_r$ is adjusted to satisfy τ_d, the maximum correlation value can be represented. On the other hand, it does not correlate with any other random signal that exists and occurs independently of the transmitted signal. Even in the case of a dependent random signal, if the time delay difference is greater than the inverse of the signal bandwidth, there is no theoretical correlation. Therefore, the maximum correlation value is adjusted while artificially changing the delay time, and the maximum correlation value is adjusted while the delay time is changed to a distance. The distance information of the target can be extracted by converting the delay time into a distance. The important variables that determine the correlation are the bandwidth of the transmission signal and the correlation integration time. The correlation function $R(\tau)$ of the random signal in the baseband is expressed as follows.

$$R(\tau) = A\int_{B}^{-B} e^{j\omega\tau}\ \ d\tau = R_0\ \ sinc\ \ (B) \tag{6}$$

Where B represents bandwidth. In equation (6), the first null is represented by $\tau = 1/B$, and the 3dB delay time width (Δ_r) and the distance resolution (ΔR) of the radar signal are expressed as follows.

$$\Delta\tau = \frac{1}{B} \qquad\qquad \Delta R = \frac{c\Delta\tau}{2} \tag{7}$$

Where c is the propagation speed in free space. In order to improve the distance resolution, it is necessary to increase the signal bandwidth.

2.2 Velocity information estimation

The baseband signal is multiplied by the center frequency (f_0) and then up-converted to the high frequency band before transmitting the signal. The receiver calculates a correlation function $R(\tau)$ for the signal that is down-converted the delay reference signal and the received signal $X_b(f)$ to the baseband. When the transmission signal $X_t(f)$ is expressed in the frequency domain as a baseband signal, it is represented as follows.

$$X_t(f) = X_b(f - f_0) \tag{8}$$

The correlation function is expressed as follows.

$$R(\tau) = \int_{-\infty}^{\infty} |X_t(f)|^2\ \ e^{j\omega\tau}\ \ df\ \ = R_b(\tau)e^{-j\omega_o\tau} \tag{9}$$

Where $R_b = \int_{-\infty}^{\infty}|X_b(f)|^2\ \ e^{j\omega\tau}df$. The time of baseband correlation function is 0 in case of fixed target in the equation (9). The correlation function of the fixed target is added to the phase in the time. The delay time of a moving target approaching at the velocity (v) from the initial target distance can be expressed as follows.

$$\tau(t) = \frac{2\ R(t)}{c} = \tau_0 - \frac{2v}{c}\ t \tag{10}$$

The correlation function of moving target is as follows.

$$R(\tau(t)) = \ \left[R_b(\tau)e^{-j\omega_0\tau_0}\right]\ e^{j2\pi f_d t} \tag{11}$$

Here, $f_d = \frac{2v}{c}f_0$ is Doppler frequency. The I/Q component of the equation (11) can be expressed as follows.

$$R_I(\tau) = \ R_b(\tau)\ cos(\omega_d\ \ t) \tag{12}$$

$$R_Q(\tau) = \ -R_b(\tau)\ sin(\omega_d\ \ t) \tag{13}$$

The equation (12) and the equation (13) show the baseband correlation function as an amplitude and a function filled with the Doppler signal. The velocity information can be obtained by FFT the correlation data. Therefore, the Doppler resolution (Δf_d) is expressed as follows.

$$\Delta f_d = \frac{1}{T_i} \tag{14}$$

Here T_i is an integral time. The Doppler resolution is improved by increasing the integration time. The distance information extraction must be processed within the Dwell time. The Dwell time is expressed as follows.

$$T_{Dw} = \frac{\Delta\mathrm{R}}{V_{max}} = \frac{c}{2\ B\ V_{max}} \tag{15}$$

3. The velocity algorithm proposal

The Doppler resolution is the convolution of two signals because the integral function is multiplied by the sampling signal. The spreading characteristics of the Doppler resolution can be expressed as follows.

$$\Delta f_d = \frac{1}{T_i} + \frac{2\ v}{c}\ \ B \tag{16}$$

The Doppler resolution increases the spreading characteristics of the velocity resolution as the target velocity and bandwidth increase. In order to increase the bandwidth for improving the resolution, the spreading characteristic of the velocity resolution is increased, and if the bandwidth is decreased to improve the spreading characteristic of the velocity resolution, the distance resolution is reduced and the accuracy is reduced.

Figure 1 shows the target distance and the velocity extraction process. After ADC the delay reference signal and the received signal, the delay reference signal pass through N delay elements. The delay reference signal corresponding to each distance bin is multiplied by the received signal. Accumulating about N sampling points and repeating this process M times, the FFT operation of M-point data can extract velocity information. If the Doppler Bin that satisfies the detection condition is checked from the acquired Doppler information, it is possible to know whether the target a specific velocity exists in the corresponding distance. By applying these calculations in parallel to all distance bins, the target distance and velocity information can be obtained. The sampling frequency is usually set at least twice the bandwidth when the sampling the received signal and the reference signal. The Doppler sampling frequency should also be set to at least twice the maximum Doppler frequency. Therefor both $\mathrm{T_i}$ and $\mathrm{T_c}$ is as follow.

$$N = \frac{T_i}{T_s} \quad (17)$$

$$N_c = \frac{T_c}{T_s} = \frac{B}{f_{d\_mas}} \quad (18)$$

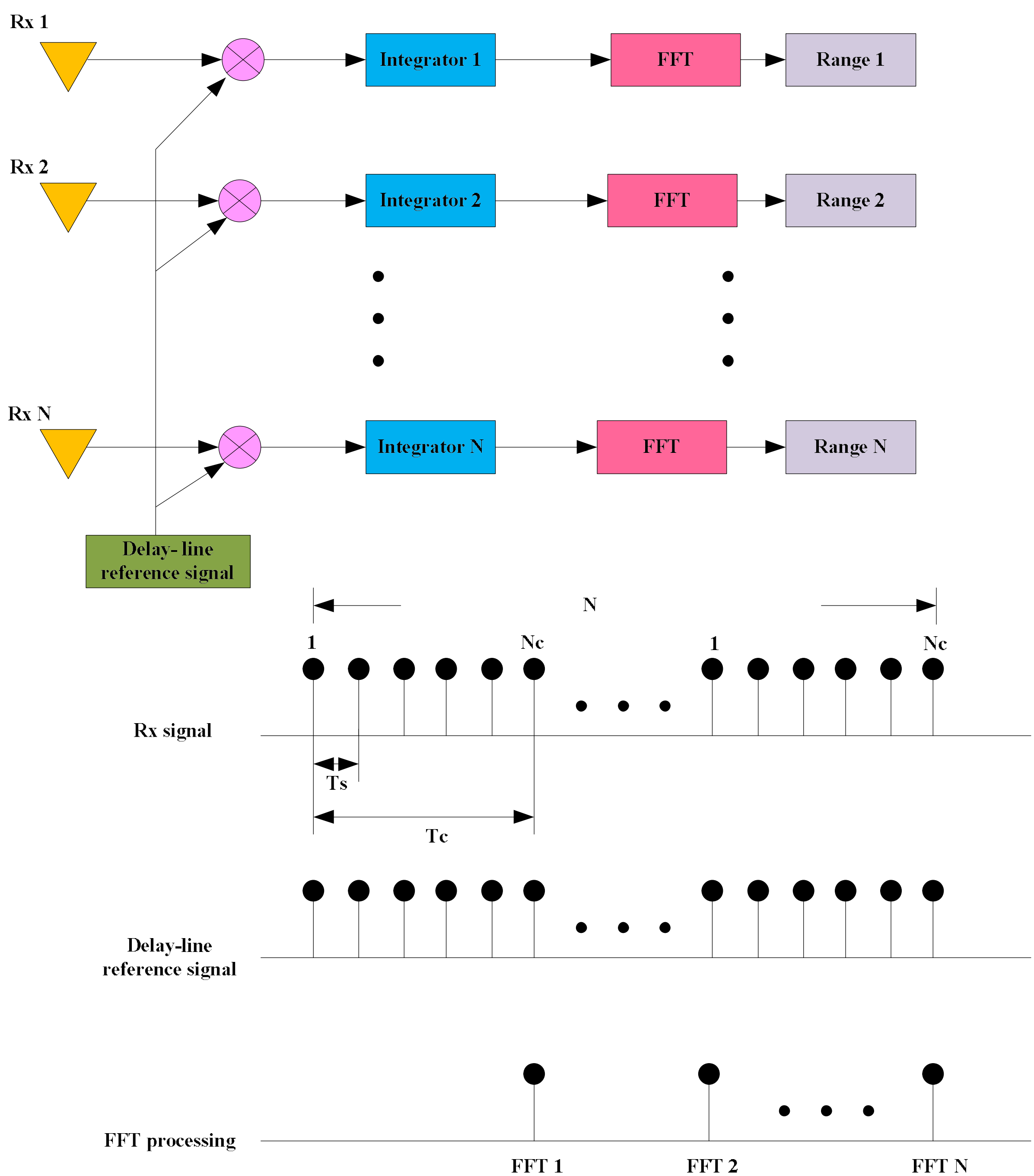

Figure 1. The velocity and the distance of FFT processing algorithm

If the correlation integration time for the base rental signal is too short, the number of AD sampling is small and the correlation gain value is too small. If the number of sampling is too large, the Doppler sampling period is too long, and the Doppler information may be lost. The distance resolution (ΔR) and the velocity resolution (ΔV) can be expressed as follows.

$$\Delta R = \frac{c}{2B} \tag{19}$$

$$\Delta V = \frac{\Delta f_d}{2f_0} \tag{20}$$

4. Simulation

This chapter is simulated to estimate the target velocity. The distance was calculated to estimate the speed. The distance estimation was performed by FFT using delay time and Doppler frequency. The simulation conditions were 10 array elements, and signal to noise ratio was 15dB. It is assumed that each signal has the same amplitude. Figure 2 shows the signal characteristics of the delay time of the receiver. The output signal can be represented by multiplying the signal incident on each antenna by a delay time and a reference signal. Figure 3 shows the Doppler output signal of the output signal. When the target moves, the Doppler signal appears and the Doppler signal does not appear at the stationary target. Figure 4 shows the distance extracted by multiplying the antenna output signal with the delay time and then applying FFT to the signal that has passed through the correlator. The correlator must be processed within the Dwell time to extract the distance. Figure 5 shows the estimation of the target velocity. It can be seen that the speed measurement error did not occur because the speed measurement spread did not appear.

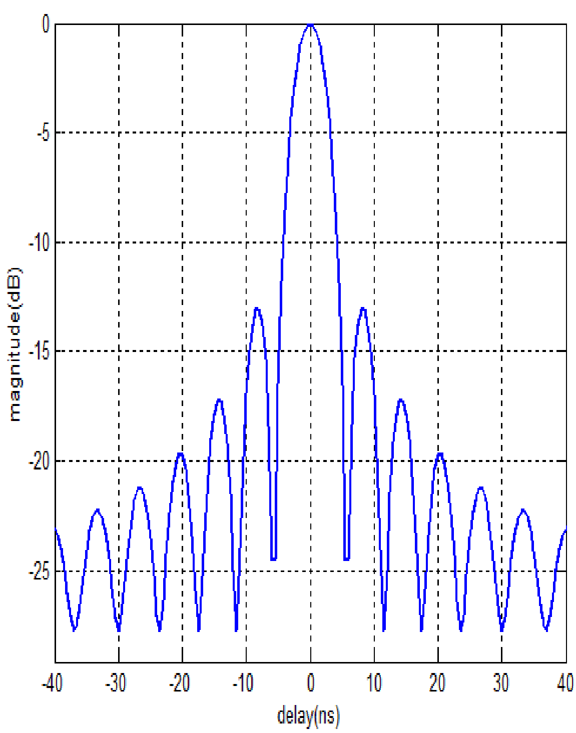

Figure 2. The delay time signal

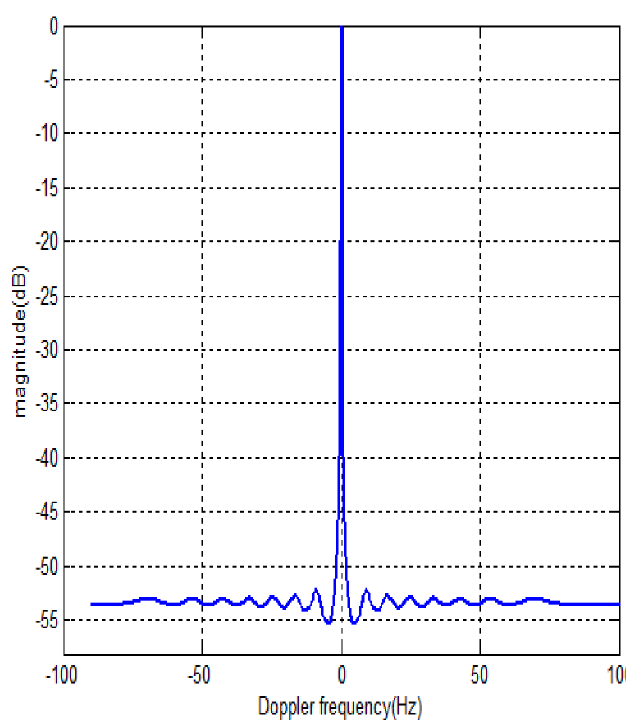

Figure 3. The Doppler frequency signal

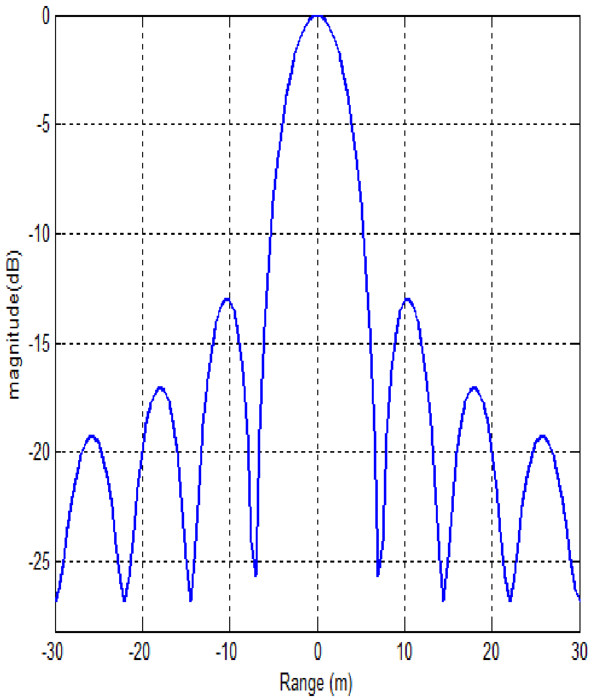

Figure 4. The Range signal

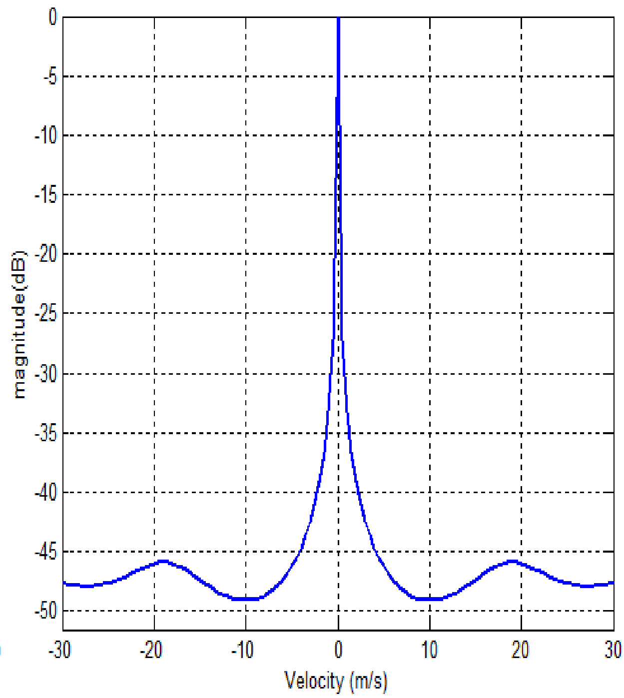

Figure 5. The velocity signal

5. Conclusion

In this paper, we studied a method of estimating target speed using FFT method. The moving target information can estimate the phase, distance, and velocity using the Doppler frequency. By changing the Doppler frequency, you can estimate the distance and velocity of a moving object. The signal received by the receiving antenna is multiplied by the delay time of each array element to transmit the signal to the integrating correlator. The integral correlator compares the correlated signal by processing the signal within the dwell time. The correlated signal uses FFT to extract distance information to calculate the velocity. The velocity spread should not appear to reduce errors in the velocity information obtained. As a result of estimating the velocity in the simulation, it was confirmed that the velocity spread did not appear..

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