International Journal of Internet, Broadcasting and Communication Vol.16 No.4 72-77 (2024)
http://dx.doi.org/10.7236/IJIBC.2024.16.4.72

IJIBC 24-4-8

FMCW Interference Signal Remove Method for Target Distance Estimation

Kwan Hyeong Lee

Professor, Division of AI Convergence, Daejin University, Korea
khlee@daejin.ac.kr

Abstract

There are various sensor technologies used to obtain target information, such as camera-based position estimation methods, LiDAR, radar, and sensor fusion. Radar technology is capable of estimating long-distance targets and determining positions even in challenging environments, such as rain, snow, fog, and darkness. Sensor data provides position information such as speed, distance, azimuth, and elevation. This paper focuses on distance measurement among these position parameters. The method for acquiring distance information applies the linear limited minimum variance method to improve the signal-to-noise ratio of the received signal, remove interference, and estimate the distance from the radar to the target using the radar equation. Through simulation experiments, the transmission signal is generated by mixing the source signal and the interference signal, and the reception signal is input to the antenna. The target distance is estimated by removing signals other than the desired components from the received signal. The simulation results show that the signal-to-noise ratio is improved by removing the interference signal, and the target distance estimation accuracy is improved.

Keywords: *FMCW, LFM, Distance Estimation, Radar, Interference Signal Remove*.

1. Introduction

There are various methods for detecting objects, including cameras, LiDAR, and radar. Each technology has its own advantages and disadvantages, but in this study, we will focus on target detection using radar technology. Target detection involves analyzing the signals received from the object. The signal arriving at the receiver includes information, interference, and noise, so interference and noise must be removed to extract the desired signal. This study aims to accurately estimate the desired target's information by eliminating interference in the IF(Intermediate Frequency) region of the FMCW(Frequency Modulated Continuous Wave) radar. FMCW radar is a specialized technology that uses short-wavelength electromagnetic waves to measure the distance, speed, and angle of an object by transmitting these waves toward the target. FMCW radar differs from conventional pulse radar systems, which transmit short pulses[1]. While pulse radar sends signals at specific intervals, FMCW radar transmits continuously.

Manuscript Received: September. 9, 2024 / Revised: September. 14, 2024 / Accepted: September. 19, 2024
Corresponding Author: khlee@daejin.ac.kr
Tel: +82-31-539-1925, Fax: +82-31-539-1890
Professor, Division of AI Convergence , Daejin University, Korea

FMCW radar measures distance by varying the frequency of the output signal over time, allowing the time difference between the transmitted signal and the signal reflected from the target to be compared. The frequency difference between the transmitted and received signals, which is proportional to the time delay, is then used to calculate the distance. FMCW radar offers advantages such as a simple structure and easy miniaturization. However, the modulation signal can leak into the IF output of the frequency mixer, causing significant interference in the beat signal and reducing the sensitivity of the received signal[2].

In this study, we remove the low-power receiving signal of the FMCW radar and the leakage modulation interference generated from the transmitter module and amplify the signal to have a voltage level that can be processed. The final output of the FMCW radar is a bit signal with interference removed and a voltage proportional to the size of the bit signal to detect the target.

The structure of this paper is as follows. Chapter 1 discusses the applications and fields of use for FMCW radar. Chapter 2 explains the role and characteristics of the FMCW radar system using a block diagram. Chapter 3 details the method for removing interference signals. Chapter 4 presents the performance results of the study through simulation experiments. Finally, Chapter 5 provides the conclusion

2. FMCW Radar Signal Model

FMCW consists of multiple LFM(Linear Frequency Modulation) waveforms. An LFM is a waveform with linearly modulated frequency, also known as a chirp waveform or chirp signal. The core of FMCW radar is a chirp signal that increases linearly in frequency over time. The chirp signal consists of a start frequency, bandwidth, and duration, and the slope of the chirp represents the rate of frequency change[3]. When the transmission waveform of the FMCW radar is generated, it is converted into an analog signal by the DAC (Digital-to-Analog Convertor). The digital-to-analog signal contains various high-frequency (harmonic) components that depend on the sample rate. These high-frequency components are removed by the LPF(Low Pass Filter), and the filtered signal is amplified. The carrier frequency is then added before passing through the BPF(Band Pass Filter), after which the signal is further LNA(Low Noise Amplifier) and transmitted.

The received signal reflected from the object is acquired through the receiving antenna. The signal incident on the receiver is amplified, the carrier frequency is removed, and the signal is filtered and converted to an ADC(Analog -to-Digital Convertor) to process the received signal. The transmitted LFM waveform becomes the reference waveform, and by convolution with the received LFM waveform, the distance information of the object can be obtained. The convolution process flips one of the two signals, moves it, multiplies all the values, and displays the added value. At this time, the signal size is the largest in the part where the signals are the most similar, and the time signified by the index corresponding to that part corresponds to the time when the radio wave is reflected from the object and received, and is generally processed in the frequency domain.

Figure 1 shows the block diagram of the FMCW radar system, which is divided into a transmitter and a receiver, and the entire block diagram consists of Continuous Wave, AC, LPF, LNA, Mixer, BPF, and antenna. Figure 1 is divided into a transmitter and a receiver, and the entire block diagram consists of Continuous Wave, DAC, LPF, LNA, Mixer, BPF, and antenna. The FMCW transmitter converts the signal generated by the waveform generator into an analog signal and processes it with a low-pass filter. This signal is processed by an amplifier, and the frequency is increased by a local oscillator and the signal is radiated into space using an antenna. The transmission waveform is generated by generating an FM signal from the waveform generator, and the generated signal is converted to a DAC(Digital-to-Analog Convertor) signal, and then the signal is amplified after LPF processing to remove high frequencies. The amplified signal is mixed with a local oscillator signal to increase the frequency, and the signal is transmitted through the transmit antenna after BPF processing. The signal incident on the receiving antenna is mixed with LO and the signal after BPF processing to decrease the frequency and amplify the signal. The amplified signal is converted to DA after LPF processing, and the digital section processes the signal to extract the desired information[4]

The mixer consists of two inputs and one output. When two sine waveform are input to the two input ports of the mixer, the output of the mixer has two properties. The first property is that the instantaneous frequency of the output is the same as the difference between the instantaneous frequencies of the two input sine waveform. Even if the frequency of the sine waveform changes over time, the output frequency at a specific point in time is the same as the difference between the input frequencies at that point in time. The second property is that the starting phase of the output sine wave is the same as the starting phase difference between the two input sine waves. The output frequency of the mixer represents the instantaneous frequency difference between the TX chirp and the RX chirp. Then, the DSP(Digital Signal Processing) can perform a Fourier transform to estimate the distance to the target[5].

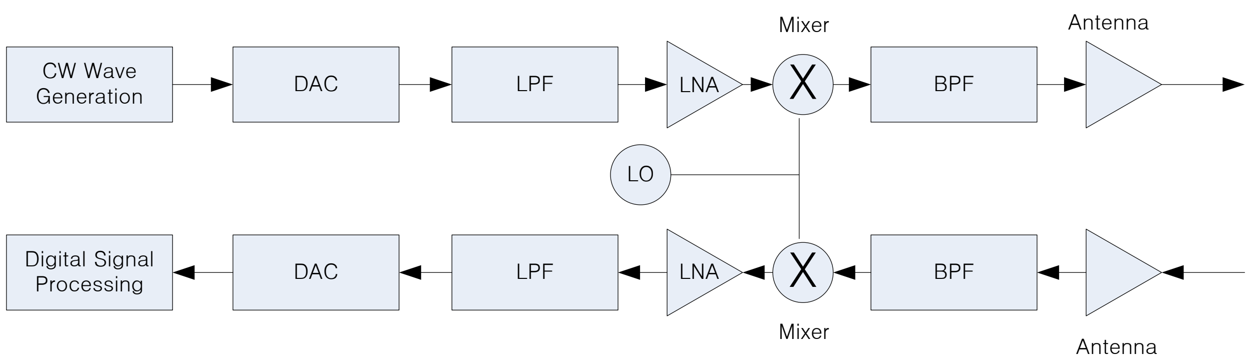

Figure 1. FMCW Radar System Model

3. Target Distance Estimation

3.1 Range Radar Equation of LFM

Range in LFM is calculated from the following relationship:

$$R = \frac{f_b\, T_s\, c}{2\Delta f} = \frac{N\, c}{4\Delta f} \tag{1}$$

R is target range
f_b is bear frequency
T_s is sweep time
Δf is sweep bandwidth of frequency deviation
c is the velocity of light
N is the required size of the FFT(Fast Fourier Transform)

When using FMCW radar triangle waves as frequency modulation signals, the beat frequency according to distance is expressed as follows:

$$f_b = \frac{4\, B\, f_m}{c} R \tag{2}$$

where,

B is sweep bandwidth of voltage control oscillator
f_m is modulation frequency of modulation signal

The IF output of the FMCW radar causes interference in the IF output signal depending on changes in the frequency conversion loss of the local oscillator of the frequency mixer. IF performance must take into account the antenna's reflection loss and the propagation delay between the transmitter and receiver ports. If the propagation delay is ignored, the signal reflected from the antenna port is input to the frequency mixer, mixed with the local oscillator signal, and output in the form of DC noise and interference. In the radar equation, the size of the target signal input through the transmitter and receiver can be expressed as follows according to the distance[6-7]. The maximum detection range in FMCW radar can be expressed as follow:

$$R_{max} = \left[\frac{P_{CW}\, G_t\, G_r\, \lambda^2\, \sigma\, L_2}{(4\pi)^3\, K\, T\, F\, B\, (SNR_o)\, L_T\, L_R}\right]^{1/4} \quad (3)$$

where,

P_{CW} is average transmit power of the CW transmitter in watts
G_t is transmit antenna gain
G_r is receive antenna gain
λ is transmission wavelength of transmitted radio wave
σ is target RCS(Radar Cross Section)
L_2 is two-way atmospheric transmission factor
K is Boltzman`s constant($1.38*10^{-23}$)
T is standard noise temperature(290K)
F is receiver noise factor
B is radar receiver`s input bandwidth
SNR_o is output signal to noise ratio
L_T is loss between the radar`s transmitter and antenna
L_R is loss between the radar`s antenna and receiver

3.2 Interference Signal Remove Method

When the signals are uncorrelated, source correlation matrix obviously has to be a diagonal matrix because off diagonal elements have no correlation. When the signals are partly correlated, source correlation matrix is nonsingular. When the signals are coherent, source correlation matrix becomes singular because the rows are linear combinations of each other. $X = [x_1(k), x_2(k), \cdots x_M(k)]$ is the signal vector on array antennas. x(k) is signal steering, n(t) is noise signal. Equation(3) can be rewritten as follow[8-9]

$$X(k) = \sum_{k=1}^{M} A\, e^{j2\pi f(t-(k-1)\tau)+\varphi} + N(k) \quad (4)$$

Where φ is the phase of the *k-th* source, *A* is the amplitude of the *k-th* source, f is the frequency of the *k-th* source, τ is the time delay between adjacent hydrophones corresponding to the *k-th* sources signal, $N(k)$ is the Gaussian noise. The output of a narrowband beam-former is given by

$$Y(k) = W^H X(k) \quad (5)$$

Here $W=[w_1, w_2, \cdots, w_M]^T$ is the complex vector of beam-former weights. $(\ )^T$ And $(\ )^H$ are the transpose and complex conjugate transpose, respectively. w is the weight value of the m-*th*. The sample covariance matrix can be written

$$R_{CO} = \frac{1}{k}\sum_{k=1}^{M} X(k)\, X^H(k) \tag{6}$$

The signal to noise ratio has the following

$$SNR_o = \frac{W^H R_{ss} W}{W^H R_{NN} W} \tag{7}$$

Where $R_{ss} = E[s(t)s^H(t)]$, $R_{NN} = E[N(t)N^H(t)]$, R_{ss} is signal covariance matrices and R_{NN} is nose covariance matrices. E[ ] is expected value. To finding the maximum of equation(7) is equivalent to the following optimization problem as follow

$$\min_W W^H R_{NN} W \qquad \text{subject to} \qquad W^H a = 1 \tag{8}$$

Linearly constrained minimum variance beamforming can be written as follow

$$W = \frac{R_{NN}^{-1} a}{a^H R_{NN}^{-1} a} \tag{9}$$

4. Computer Simulation

The purpose of the experiment is to estimate the desired target by removing the interference signal incident on the FMCW radar receiver. The target is assumed to be located 6 km from the radar. Figure 2 shows the received signal reflected from the object, which is a mixed signal of the transmission signal, interference signal, and noise signal. Figure 3 shows that the target distance is accurately estimated with a signal-to-noise ratio of 25dB. Figure 4 shows that the target distance is estimated to be about 500 meters with a signal-to-noise ratio of about 20dB, and Figure 5 shows that the target distance is estimated to be about 1000 meters with a signal-to-noise ratio of 18dB.

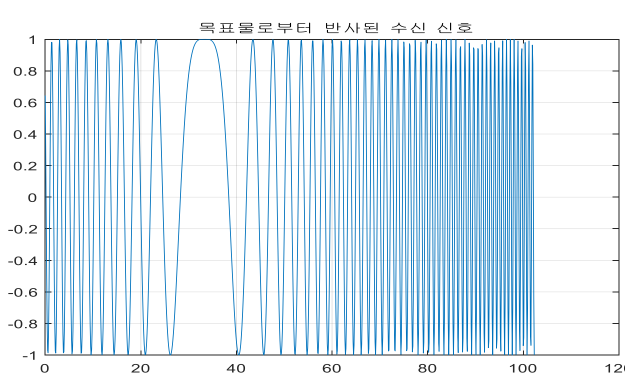

Figure 2. Received Signal

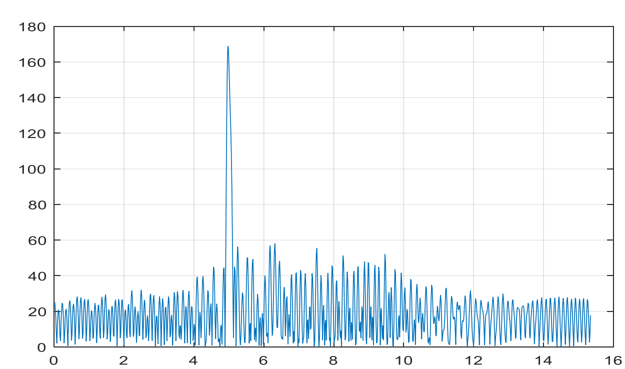

Figure 3. Distance Estimation(5km)

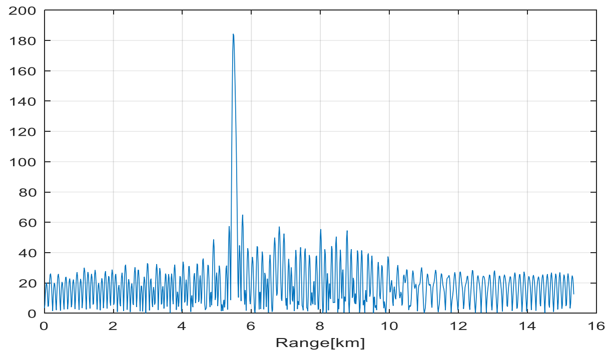

Figure 4. Distance Estimation(5.5km)

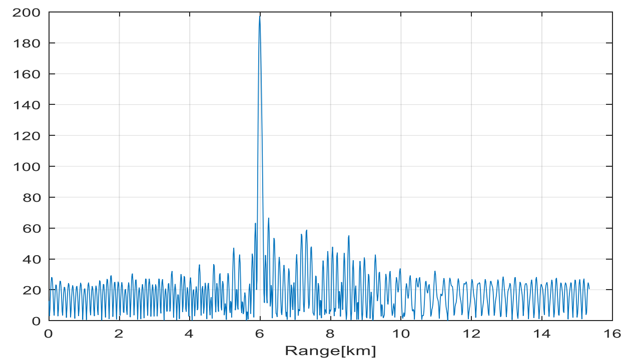

Figure 5. Distance Estimation(6km)

5. Conclusion

This paper studied to accurately estimate the distance of a desired target. The interference signal cancellation technique improved the signal-to-noise ratio by applying the linear constraint minimum dispersion beamforming method to the received signal. In the simulation experiment, the target distance estimation was shown while changing the signal-to-noise ratio. The experimental results show that the signal-to-noise ratio improves as the ability to remove interference signals from the received signal increases, thereby improving the accuracy of target distance estimation. In general, the method to improve the accuracy of distance estimation for a target is to increase the transmission power or improve the signal-to-noise ratio. However, the method to improve the transmission power and the signal-to-noise ratio decreases the efficiency of the communication system. The signal interference and noise removal method of this study improved the efficiency of the system in terms of the cost of the existing research.

References

[1] M. Jankiraman, FMCW Radar Design, Artech House, pp.19, 2004.
[2] M. Skolnik, Introduction Radar System, McGraw Hall, pp. 54, 2000.
[3] R. Bassem and F. Mahafza, Radar System Analysis and Design using Matlab, Chapman Hall CRC, pp. 68, 2000.
[4] B. Allen and M.Ghavarri, Adaptive Array System, Wiley, pp. 154, 2005.
[5] L. Chand Godara, Smart Antennas, CRC Press, pp.114, 2004.
[6] Zhibang. Luo, Yi. Liao, and Mengdac.Xing, “Target Indication with FMCW-OAM Radar”, IEEE Geoscience and Remote Sensing Letters, Vol.20, No.1, pp.1-5, September 2024. DOI:https://doi.org/10.1109/LGRS.2023.3314459
[7] Kyung-Min. Lee, In-Hyeok.Lee, Min-Gon.Cho, Kyung-Tae.Kim, “Range Resolution Improvement using Cross-Track Interferometry for FMCW Radar” Geoscience and Remote Sensing Letters, Vol.20, No.1, pp.1-5, July 2023. DOI: https://doi.org/10.1109/LGRS.2023.3299295
[8] Peng.Zhang and Zhengguang.Xu, “A Dual-Frequency Phase Ambiguity Resolution Method for FMCW Radar High-accuracy Ranging”, in Proc. ’IEEE Transactions on Instrumentation and Measurement, pp.14-17, February.26-28,2024. DOI: https://doi.org/10.1109/TIM.2024.3371009
[9] Xu. Zhengguang, Chen. Yaling, and Zhang. Peng, “A Sparse Uniform Linear Array DoA Estimation Algorithm for FMCW Radar”, IEEE, Vol. 30, No. 1, pp.823-827, July 2023. DOI: https://doi.org/10.1109/LSP.2023.3292739