Ambiguity Multiple Target Detection with Frequency Modulated Continuous Wave Radar

Oğuzhan Çam[1*], İlyas Çankaya[2]

[1]Electrical and Electronic Engineering, Ankara Yıldırım Beyazıt University, Ankara
ORCID No: https://orcid.org/0009-0000-2649-4457
[2]Electrical and Electronic Engineering, Ankara Yıldırım Beyazıt University, Ankara
ORCID No: https://orcid.org/0000-0002-6072-3097

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Abstract
In this study, FMCW radar system was used because it is Frequency Modulated and the signal emitted from the transmitting antenna uses a signal type called Linear Frequency Modulation (LFM) Chirp signal. Linear frequency modulation allows the frequency of the signal to increase or decrease linearly over time. Linear frequency modulation achieve to increase the range resolution, which is the radar's ability to distinguish between targets, and makes it more protected against electronic warfare techniques. Therefore, it is widely used in military applications. As in every radar system, range resolution is an important detail in FMCW radar systems. The modules used in the radar system have an effect on the range resolution separately, as well as the processing of the transmitted and received signals is of great importance. In a FMCW radar system designed within the scope of this study, an environment with more than one target was created to provide the best range resolution, and a modeling and simulation study was carried out to determine the distances, velocities and angular positions of ambiguity multiple targets by processing the transmitted and received signals with CA-CFAR and MUSIC algorithms.

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1. INTRDOUCTION

Frequency Modulated Continuous Wave (FMCW) radar systems are used to detect the position, speed, and distance of moving or stationary objects. FMCW radars are classified under the structure classification due to their unique structure and components, which include a transmitter antenna, receiver antenna, mixer, and Radar Control Board. Compared to pulse radars, FMCW radars have a simpler structure, lower production cost, and better range detection capability. They also overcome the limitation of continuous wave radars in detecting multiple targets (Ali & Erçelebi, 2017; Şeflek & Yaldız, 2020). In this study, Ambiguity Multiple Target Detection tecnique is used for the detection of multiple targets in a single radar measurement (Aulia, Suksmono & Munir, 2015). This technique is based on the principle of range-Doppler ambiguity, and its implementation in a FMCW radar system requires advanced signal processing techniques such as pulse compression, matched filtering, CFAR, MUSIC, and FFT. In the next parts of the study, the examination of the features of the FMCW

*Resp author; e-mail: oguzhancam@windowslive.com

Radar System, the examination of its general structure, the stages of the simulation carried out in the MATLAB software for ambiguity multiple target detection were mentioned with FFT, CFAR and MUSIC algorithms. Finally, the results obtained were evaluated and an idea was given about what the future works could be.

2. AMBIGUITY MULTIPLE TARGET DETECTION WITH FMCW RADAR

2.1. System Information

Frequency Modulated Continuous Wave (FMCW) radar is a type of radar that uses a continuous transmission of electromagnetic waves at a specific frequency, which is then modulated over time. By analyzing the frequency shift of the reflected wave, the range and velocity of the object can be determined. FMCW radar systems typically use a gradualy changing waveform as shown in Figure 1, in which the frequency of the transmitted wave is linearly swept over a specific range. This allows for a high range resolution and low probability of intercept by enemy radar systems.

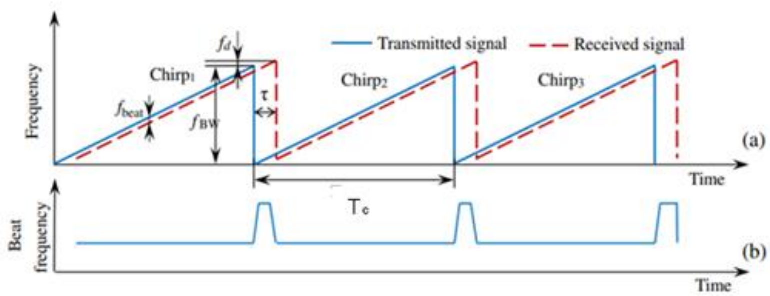

Figure 1. FMCW radar waveform princple for a single moving target the transmitted and received signal (a), the corresponding beat frequency (b)

FMCW radar has many advantages and is commonly used in various applications, including automotive radar and industrial process control. Military applications such as air defense and surveillance also rely on FMCW radar due to its ability to detect small and slow-moving targets, as well as its low POI. The FMCW radar system consists of a transmitter, receiver, modulator, demodulator, and antenna. The signal of FMCW radar can be modulated in four different types of signals including triangular, sinusoidal, square, and sawtooth. The system block diagram typically includes a transmitter, antenna, mixer, local oscillator, signal processor, display, and control unit as shown Figure 2. Overall, FMCW radar is a radar system that allows for accurate range and velocity detection, making it a valuable asset in a variety of fields.

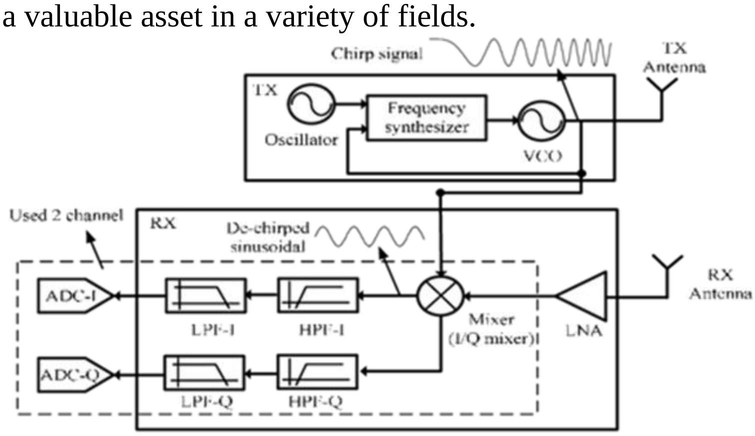

Figure 2. The block diagram of fmcw radar (sangdong, bong-seok, daegun and lee, 2015)

The System Block Diagram of FMCW Radar is typically includes the following components:

1. Transmitter: This component generates and amplifies the radio frequency (RF) signal that will be transmitted by the antenna. The signal is typically a continuous waveform that is frequency modulated (FMCW) to provide range information.
2. Antennas: These components transmit and receive the RF signals. The transmit and receive antennas can be separate or combined into a single element.
3. Mixer: This component combines the transmitted and received signals, creating an intermediate frequency (IF) signal.
4. Local Oscillator (LO): This component generates a reference frequency that is mixed with the received signal in the mixer.
5. Signal Processor: This component performs various signal processing functions on the IF signal, such as filtering, amplification, and demodulation. The signal processor also extracts range and velocity information from the IF signal.
6. Display: This component presents the radar data to the operator in a meaningful way, such as on a radar scope or map.
7. Control Unit : This component control the overall system, it contains all the parameters of the radar system and it communicate with the signal processing unit.

2.2. MATLAB Simualtion

The FMCW Radar Simulation for detecting Ambuguity Multiple Target on Matlab is follows steps :

1. It defines the parameters of the radar system as shown in Table 1, such as the speed of light, bandwidth, carrier frequency, number of ADC samples, number of chirps per frame, pulse repetition interval, and others.
2. It defines the two target according to informations in Table 2. It simulates the movement of two targets over time by calculating their locations at each point in the time axis. It sets up some variables such as range and velocity axis, and angle axis.
3. It simulates Transmitted Signal
4. It simulates Received Signal
5. It simulates Mix Signal with Transmitted and Received Signal
6. It simulates FFT Operations
7. Apply CA-CFAR Algorithm for detecting multiple target
8. Appy MUSIC Algorithm for detecting multiple target

Table 1. Parameters of FMCW radar

Parameters of FMCW Radar	
Center Frequency	24 GHz
Bandwith	150 MHz
Number of ADC Samples	256
Number of Chirps	256
Time Period	10 microsecond
Number of Transmitter Antenna	1
Number of Receiver Antenna	4
Range Resolution	1

Table 2. Target range, angle,velocity and coordinates

Target Informations	Range (m)	Angle (Degree)	Velocity(m/s)	Coordinate X	Coordinate Y
Target 1	50	-15	10	-12.941	48.2963
Target 2	100	10	-15	17.3648	98.4808

2.2.1. Transmitted Signal

Before generating the transmitter signal in MATLAB simulation code for FMCW radar, time delays between targets and transmitter-receiver pairs in a 3D space are calculated using the Euclidean distance formula. Arrays of transmitter and receiver locations and target locations over time are created, and delays are stored in cell arrays. Transmitter signal is then generated based on specified radar signal parameters in the parameters of FMCW Radar as shown in Figure 3 .

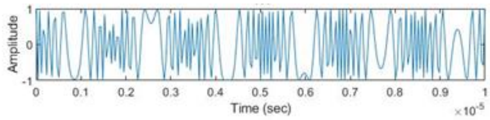

Figure 3. Tranmitted signal

2.2.2. Mixed Signal

In this part of the MATLAB Simulation Code, a mixed signal is generated by combining two target signals with the transmitted signal as shown in Figure 4. The code calculates the phase of the transmitted and received signals, as well as range and Doppler dependent frequencies for the two targets. A nested for loop is used to iterate over all the transmitter-receiver pairs, and the resulting mixed signal is stored in a cell array called "mixed".

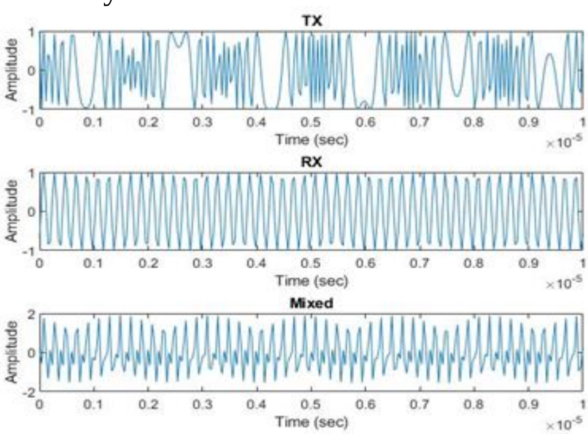

Figure 4. Transmitted, received, and mixed signal

2.2.3. FFT Operations

The FFT part of code reshapes the mixed signal data and applies a 2D Fourier transform to create a Range-Doppler Map (RDM). It reshapes the mixed signal data into a 3D array called "RDC" and applies a 2D FFT on it using "fft2" and "fftshift" functions to create a 4D array called "RDM" with dimensions of number of ADC, number of Chirps, multiplying the number of receiver and transmitter antennas, number of CPI and plots the Range-Doppler Map using the "imagesc" function as shown in Figure 5. It also applies a colormap, sets the color axis limits and adds x and y labels.

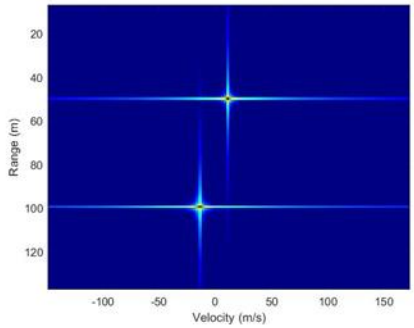

Figure 5. The range-velocity graph after FFT operations

2.2.4. CA-CFAR Algorithm

This part of code applies a Constant False Alarm Rate (CFAR) detection algorithm to a Range-Doppler Map (RDM) in order to identify target returns as shown in Figure 6. The CFAR algorithm compares the power of the target return to the power of the surrounding noise and decides if the target return is real. It defines the number of guard cells and training cells and the desired false alarm rate and also defines an SNR offset value in dB. The RDM data is passed in dB scale. It calls the "ca_cfar" function which takes in RDM data, number of guard cells, number of training cells, desired false alarm rate, and SNR offset as inputs, and returns the range-Doppler map with a CFAR mask applied to it, CFAR detected ranges, CFAR detected Doppler values and the threshold value. The CFAR algorithm used here is Cell Averaging CFAR (CA-CFAR) which compares the power of the target return to the average power of the surrounding noise.

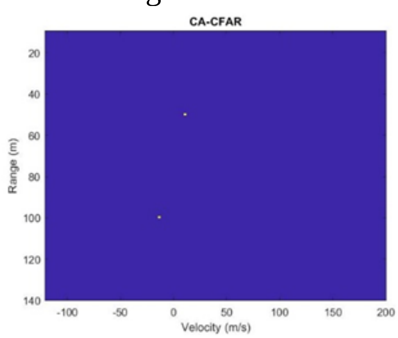

Figure 6. The range-velocity graph after applying CA-CFAR algorithm

2.2.5. MUSIC Algorithm

This part of code applies the Multiple Signal Classification (MUSIC) algorithm to the RDC data to estimate the angle of arrival (AoA) of the targets. MUSIC is a subspace-based technique that is used to estimate the AoA of multiple signals in a noisy Environment. It applies 1D FFT on the RDC along the range dimension and uses a for loop to iterate over all range bins, creating the matrix by summing the outer product of the signal vector for each snapshot and divide it by the number of snapshots and plot "MUSIC Sprectrum" as shown in Figure 7. It then applies the MUSIC algorithm to the created matrix using the estimator object and obtains the DOA estimates. It creates a new figure and plots the range-angle map using the "imagesc" function with the angle values and range values. It also applies a colormap, sets the color axis limits and plot "MUSIC Range-Angle Map" as shown in Figure 8.

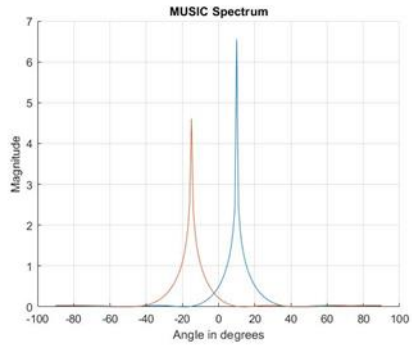

Figure 7. The spectrum graph for angle values of targets with MUSIC algorithm

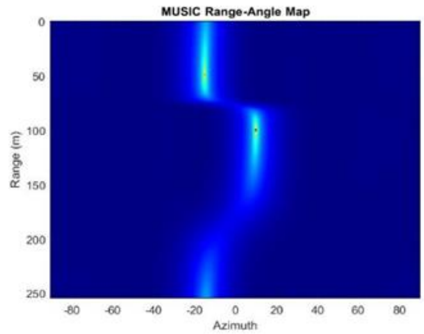

Figure 8. Range-Azimuth graph of targets with music algorithm

3. CONCLUSION

Some signal processing algorithms were applied in the simulation study for the detection of ambiguity multiple targets with FMCW radar in Matlab software. These are FFT, CA-CFAR and MUSIC algorithms. The Range and Velocity information of the targets were determined by the CA-CFAR algorithm. Azimuth angles of the targets were successfully determined with the applying MUSIC algorithm. The location information detected on the targets are Target1(-13.2,49.26), Target2(17.54,99.40). However, the defined target locations are specified as Target1(-12.94,48.30), Target2(17.36,98.48). When the actual and determined results related to the location are compared, it has been observed that there is a 1% margin of error. As a result of this study, it has been confirmed that the detection of ambiguity multiple targets can be successfully performed with FMCW Radar and the performances of CA-CFAR, MUSIC algorithms have been verified. In future work, the different signal processing algorithms that are not used in this study and their performance for target detection can be examined. For example, in this study, the success of detecting target information can be measured by examining signal processing algorithms such as Order Statistic CFAR (OS-CFAR), Adaptive CFAR (ACFAR) and similar instead of CA-CFAR signal processing algorithm, which is one of the CFAR Signal Processing algorithms. This study would provide a more comprehensive understanding of their strengths and weaknesses. Additionally, it would be utility to see how these different algorithms perform under various conditions, such as different noise levels, target ranges, and clutter environments. Furthermore, some other techniques like Machine learning techniques, deep learning techniques can be used to improve the performance of target detection. These techniques can be used to detect target in noisy, cluttered and adaptive environment.

Conflict of Interest

There was no conflict of interest between the authors during the creation of this study.

Contribution of Authors

The authors involved in this study are Oğuzhan Çam, İlyas Çankaya; contributed to all aspects of the study. All authors contributed to the idea, design, inspection, resources, data collection, literature review, critical review and analysis and interpretation sections of the study.

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