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Velocity and Distance Estimation of Multiple Objects Using YOLO-Based OFDM Radar System

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***Abstract*—In this study, we propose a method for simultaneously estimating the speed and distance of multiple objects using a YOLO model within an OFDM radar system. The proposed technique inputs a 2D spectrogram image generated from OFDM radar signal processing into the YOLO model to predict the speed and distance of objects. Simulation results demonstrate that the proposed method performs well in recognizing multiple objects. Notably, the speed and distance estimation accuracy improves as the number of OFDM symbols increases and the number of objects decreases. The proposed technology is applicable not only to 5G but also to 6G OFDM signals.**

***Keywords*— Beamforming, OFDM Radar, YOLO, Multi-Object Estimation, Distance, Velocity**

I. INTRODUCTION

5G communication technology utilizes the millimeter-wave (mmWave) band to enable ultra-high-speed data transmission. However, it faces limitations such as strong signal directivity, increased signal attenuation due to obstacles, and reduced propagation distance. To overcome these challenges, beamforming technology is essential. Beamforming is a technique that adjusts the amplitude and phase of signals supplied to multiple antennas, focusing the signal in a specific direction. This approach enables effective communication using high frequencies [1].

Accurate beamforming requires periodic beam searching, which can increase overhead and reduce communication efficiency. However, if the transmitter can measure the speed and distance of the receiver using radar, the beam search overhead can be significantly reduced. One technology that achieves this without the need for dedicated radar frequencies is OFDM (Orthogonal Frequency Division Multiplexing) radar [2]. OFDM radar is a technique that utilizes OFDM signals to detect the position, distance, and speed of objects. It is particularly valuable in quickly identifying the receiver's location during data transmission, making it a key technology for next-generation mobile communications.

This paper proposes a novel technique that incorporates the YOLO model into OFDM radar technology to simultaneously estimate the speed and distance of objects. The proposed YOLO model uses a 2D spectrogram obtained from radar signal processing to estimate the speed and distance of multiple targets at the same time. Simulation results show that the proposed radar technology effectively detects multiple objects, with improved performance as the number of objects decreases and the number of OFDM symbols increases.

II. OFDM RADAR SYSTEM MODEL

Figure 1 illustrates the proposed OFDM radar system model. The process of transmitting a signal from the transmitter to the antenna is identical to that of an OFDM transmitter, but with the addition of collecting signals reflected from objects. After removing the CP from the received signal, which is reflected from the object, the OFDM symbols are extracted and converted to the frequency domain through FFT. The modulation is then removed from the signal, and the same operation is repeated for consecutive OFDM symbols, stacking the signals. A new 2D-FFT is applied to the accumulated signals to obtain a 2D spectrum, and the magnitude squared is calculated to produce a 2D periodogram.

This 2D periodogram serves as the input for the YOLO model.

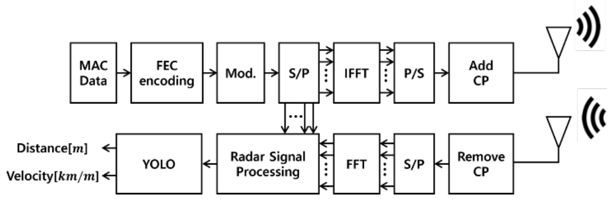
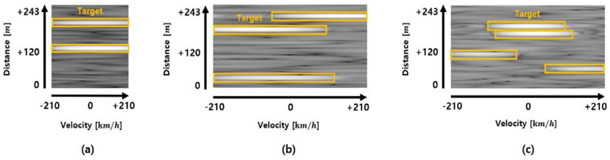


Fig. 1. OFDM Radar System Model

III. 2D PERIODOGRAM

The 2D periodogram can be visualized as a grayscale image, where peak values allow for the estimation of distance and speed. In this grayscale image, higher values are represented as white, while values close to zero are depicted in black. Figure 2 illustrates an example of a periodogram, where the x-coordinate of a bright spot represents speed, and the y-coordinate represents distance. The range of speeds and distances that can be estimated is determined by the specifications of the OFDM signal, while the estimation resolution is defined by the size of the 2D-FFT used to obtain the periodogram. The YOLO model directly performs radar functions by estimating the x and y coordinates of the peak points. The 2D FFT size for generating the periodogram is denoted as N_{FFT} x M_{FFT}. To enhance distance and speed resolution, values larger than N and M are used for N_{FFT} and M_{FFT}, respectively. If a peak is detected at the elements $(\hat{n}, \hat{m})$, the distance and speed of the target can be calculated as shown in equations (1) and (2).



(a)

(b)

(c)

Fig. 2. 2D Periodogram (a) 2symbol (b) 4symbol (c) 8symbol

$$d = \frac{c_0 \hat{n}}{2 \Delta f N_{FFT}} \tag{1}$$

$$v = \frac{c_0 \hat{m}}{2 f_c T_0 M_{FFT}} \tag{2}$$

IV. PROPOSED VELOCITY AND DISTANCE ESTIMATION METHOD

In this study, we propose a method for simultaneously estimating the speed and distance of objects by using 2D periodogram signals as input to the YOLO model. YOLO, a CNN-based algorithm that extracts both regions and features, is well-suited for addressing this radar problem. The YOLO output is trained to directly predict the speed and distance of the detected objects.

Among the various versions of YOLO, we use YOLOv5, with the hyperparameters used for training summarized in Table 1. The 2D periodogram is appropriately resized and used as input to the YOLO model, with input sizes of 320x320 for 2 symbols, and 640x320 for 4 and 8 symbols.

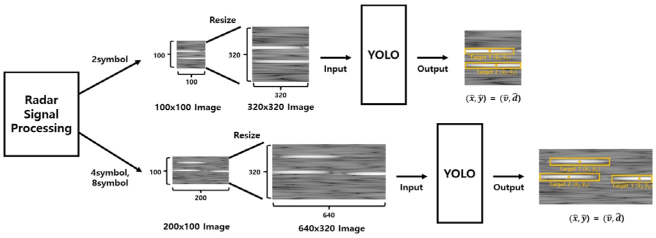


Fig. 3. Block Diagram for Velocity and Distance Estimation of Multiple Objects Based on YOLO

TABLE I. YOLO HYPERPARAMETERS

Hyperparameters	***Values***		
	2symbol	***4symbol***	***8symbol***
Model version	YOLOv5		
Bounding-box	60x6	50x6	40x8
Learning rate	0.001	0.001	0.001
Batch size	16	32	32
Epoch	100	100	100
Optimizer	SGD	Adam	Adam

V. SIMULATION AND RESULTS

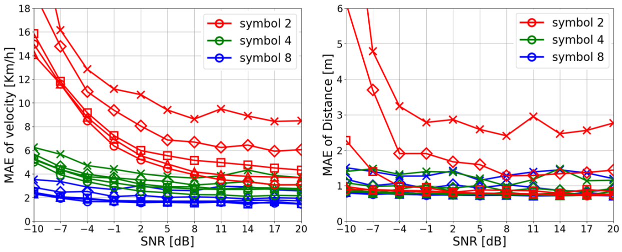
The specifications of the OFDM signal are shown in Table 2. The total OFDM symbol duration is 35.74 microseconds, with a sampling frequency (Fs) of 122.88 MHz and an FFT size of 4,096. Out of these, 1,284 subcarriers are used, resulting in an OFDM signal bandwidth of approximately 40 MHz. The center frequency is 28 GHz, and the cyclic prefix (CP) length is set to 296.

The OFDM signal lengths are set to 2, 4, and 8 symbols to observe performance variations with signal length. The 2D FFT sizes corresponding to each symbol length are 2048x128, 2048x256, and 2048x256, respectively. The training data is generated across an SNR range of [-10dB, 20dB], with 10,000 data samples for each of 1 to 5 objects, resulting in a total of 50,000 data samples. For performance validation, test data is generated at 3 dB intervals within the SNR range of [-10dB, 20dB], with 2,000 samples for each of 1 to 5 objects, resulting in 10,000 data samples for each SNR value, leading to a total of 110,000 test data samples. The mean absolute error (MAE) is used as the performance metric for distance and velocity estimation during testing.

TABLE II. SIMULATION ENVIRONMENTS

Parameter	***Value***
OFDM Symbol Duration	35.74 *us*
Sampling frequency	122.88 MHz
IFFT(FFT) size	4096
Bandwidth	40 MHz
Center frequency	28 GHz
Length of CP	296
Num. of OFDM symbol	2, 4, 8
2D FFT size	2048x128, 2048x256
Cropped region size	100x100, 200x100
Num. of targets	1~5
SNR range	-10~20dB
Num. of Train data	50,000
Num. of Test data	110,000

Figure 4 illustrates the performance of the proposed method in estimating distance and velocity based on SNR, with subfigure (a) representing MAE for velocity and (b) representing MAE for distance. The color of the lines indicates the number of OFDM symbols used: red for 2 symbols, green for 4 symbols, and blue for 8 symbols. The shape of the markers indicates the number of objects: a circle (○) represents 1 object, a triangle (△) represents 2 objects, a square (□) represents 3 objects, a diamond (◇) represents 4 objects, and an X (╳) represents 5 objects. The results shown in Figure 4 indicate that using longer OFDM symbols, specifically 8 symbols, leads to superior distance and velocity estimation performance. Additionally, the fewer the number of objects, the better the estimation accuracy. However, this performance improvement diminishes when longer OFDM symbols are used. These findings suggest that using longer OFDM symbols is advantageous for achieving better performance in OFDM radar systems.



(a) **(b)**

Fig. 4. Performance of Multiple Object Distance and Velocity Estimation Based on SNR

VI. CONCLUSION

In this study, we propose a velocity and distance estimation method using YOLO within an OFDM radar system. By leveraging the YOLO model, it is possible to estimate the distance and velocity of objects from 2D spectrogram images without requiring prior information about the number of objects or SNR. Simulation results demonstrate that implementing radar with 8 OFDM symbols yields superior estimation performance regardless of the number of objects. Consequently, the findings of this study are expected to play a significant role in the convergence of communication and sensing technologies in 5G and 6G mobile communications.

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keywords: {Array signal processing;MIMO communication;5G mobile communication;Computer architecture;Radio frequency;Antenna arrays;Hybrid beamforming;mmWave;massive MIMO;HetNet;radio access network},

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