Radar Object Detection And Velocity Estimation Using Doppler Effect In Matlab

Analog & Digital Communication Hackathon

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In Partial Fulfilment of the Requirements

for the Degree of

BACHELOR OF TECHNOLOGY

SRM INSTITUTE OF SCIENCE & TECHNOLOGY
(Deemed to be University u/s 3 of UGC Act, 1956)

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

COLLEGE OF ENGINEERING AND TECHNOLOGY

SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

KATTANKULATHUR - 603 203

APRIL/MAY 2025

SRM Institute of Science and Technology
College of Engineering and Technology

Department of Electronics and Communication Engineering

21ECC302T Analog and Digital Communication

Sixth Semester, 2024-2025 (Even semester)

Title : Radar Object Detection And Velocity Estimation Using Doppler Effect In Matlab

Date of Submission : 30-04-2025

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Uniqueness	5				
Relevance Of Course	5				
Quality of works	10				
Viva	5				
Total	30				

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ABSTRACT

This project simulates a basic radar object detection system by utilizing the Doppler effect, implemented entirely in MATLAB. The simulation models a continuous-wave radar transmitting a high-frequency signal toward a moving target. The received echo, shifted in frequency due to the Doppler effect, is mixed with the transmitted signal to produce a beat signal. Fast Fourier Transform (FFT) is applied to the mixed signal to detect the Doppler frequency shift, allowing the estimation of the target's velocity. The project plots the transmitted signal, received signal, mixed signal, and the frequency spectrum to visualize the detection process. This simulation helps understand fundamental radar principles such as signal generation, Doppler shift, signal mixing, and frequency domain analysis. It serves as a foundational study for students interested in radar technology, signal processing, and real-world object detection systems.

ACKNOWLEDGEMENT

We gratefully acknowledge the resources and knowledge available through various internet sources and technical books, which were instrumental in guiding our research and implementation of Radar Object Detection and Velocity Estimation. Online MATLAB documentation, research articles, and tutorials provided essential insights into simulation techniques, channel modeling, and error-correction methods.

We also appreciate the open-access IEEE papers and conference proceedings that informed our understanding of underwater acoustic and optical communication challenges. The algorithms and theoretical foundations presented in these publications were invaluable in developing our methodology.

Finally, we thank the department of ece for providing us with an opportunity to display our idea and implementation of the project.

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CHAPTER 1

INTRODUCTION

Radar systems play a crucial role in modern technology by enabling the detection, tracking, and measurement of distant objects. One of the key phenomena utilized in radar is the Doppler effect, which causes a frequency shift in the received signal when a target is moving relative to the radar source. This project focuses on simulating a simple radar object detection system using MATLAB, demonstrating how the Doppler shift can be used to determine the velocity of a moving target through signal processing and frequency analysis. This can be further explained as:

- Radar systems emit radio waves to detect objects and measure their properties, such as distance and speed.
- The Doppler Effect refers to the change in frequency of a wave relative to an observer moving with respect to the wave source. In radar applications, this effect is utilized to determine the velocity of moving targets.
- In this simulation, a continuous wave radar transmits a high-frequency sine wave toward a moving object. The object reflects the signal back, and due to its motion, the frequency of the reflected signal is shifted—a phenomenon known as the Doppler shift.
- By mixing the transmitted and received signals, a beat frequency is produced, which contains information about the target's velocity.
- Applying a Fast Fourier Transform (FFT) to the mixed signal allows for the detection of the Doppler frequency shift, enabling the estimation of the target's speed.

This simulation provides a fundamental understanding of how radar systems utilize the Doppler Effect for object detection and speed measurement

CHAPTER 2

PROBLEM STATEMENT

Accurately detecting the velocity of moving objects is essential in a wide range of applications such as traffic monitoring, autonomous navigation, military surveillance, and industrial automation. Traditional motion detection methods often fall short in terms of reliability, precision, and adaptability under dynamic and noisy conditions. Radar systems offer a superior alternative by leveraging the Doppler effect, which enables precise measurement of an object's speed based on the frequency shift of reflected electromagnetic waves.

CHAPTER 3

OBJECTIVES

The objectives of the project include:

- To simulate a basic radar system using MATLAB.
- To model the transmission and reception of radar signals affected by the Doppler Effect.
- To detect the Doppler frequency shift using signal mixing and FFT.
- To accurately estimate the velocity of a moving target.
- To visualize transmitted, received, and mixed signals

CHAPTER 4

SYSTEM DIAGRAM AND DESCRIPTION

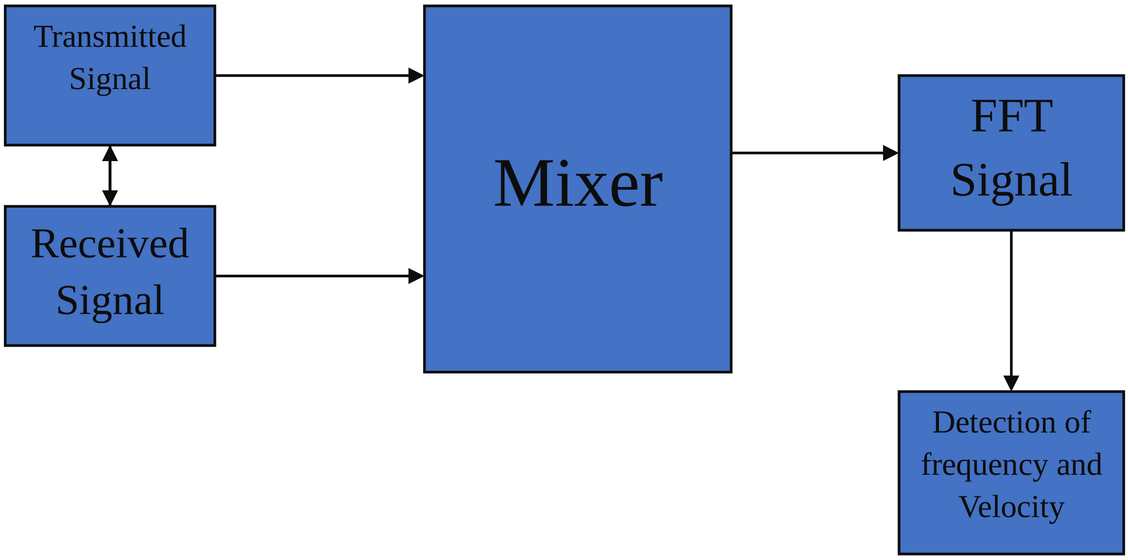

Figure-1: Block Diagram of Radar Object Detection Using Doppler Effect

The block diagram illustrates the basic working principle of a radar object detection system using the Doppler effect.

- The process begins with the generation of a Transmitted Signal, usually a continuous high-frequency wave.
- This signal propagates through the air and reflects back from a moving target, resulting in a Received Signal that contains a Doppler frequency shift.
- The Received Signal is then processed using a Fast Fourier Transform (FFT) to convert it from the time domain to the frequency domain, making it easier to identify frequency shifts.
- In parallel, the Received Signal is mixed with the Transmitted Signal using a Mixer to produce a beat frequency, which contains information about the target's motion.
- Finally, by analyzing the output of the FFT, the Doppler Shift is detected, which allows calculation of the target's velocity relative to the radar.

This structure demonstrates the essential steps in a Doppler radar system for object detection and speed estimation.

CHAPTER 5

METHODOLOGY AND IMPLEMENTATION

The methodology and implementation in the execution of this project involved the following steps:

- Firstly, to understand the objective to simulate a radar object detection system using the Doppler effect.
- Develop the conceptual flow: transmit a signal, receive an echo with Doppler shift, mix signals, and apply FFT.
- Use the Doppler shift formula: $fd = (2 \times v) / \lambda$, where v is the target velocity and λ is the wavelength.
- Select MATLAB as the software tool for simulation and use basic functions like plot(), fft(), cos(), etc.
- Define system parameters such as radar frequency, speed of light, sampling rate, and simulation time.
- Generate a transmitted signal as a continuous wave at a specified frequency.
- Simulate a received signal by applying a Doppler frequency shift to the transmitted signal.
- Mix the transmitted and received signals to produce a beat frequency signal.
- Perform FFT on the mixed signal to convert it from time domain to frequency domain.
- Identify the Doppler frequency peak from the FFT result and calculate the target's velocity.
- Prepare a simple block diagram to represent the system flow visually.
- Test the MATLAB code by plotting transmitted, received, mixed signals, and FFT results.
- Finally, validate if the detected Doppler frequency and calculated velocity match the expected values.

The various components and elements used in the methodology and execution of the project are :

- **Transmitted Signal Generation:**

  A continuous-wave (CW) signal at a specific carrier frequency (e.g., 24 GHz) is generated to simulate the radar’s outgoing signal. This signal serves as the reference for detecting changes upon reflection.

- **Received Signal Modeling:**

  The received signal is modeled as a cosine wave with the original carrier frequency shifted by the Doppler effect, representing the echo from the moving object.

- **Signal Mixing:**

  The transmitted and received signals are multiplied (mixed) together to produce a beat signal. This beat signal contains the Doppler frequency component, which simplifies further analysis.

- **Doppler Frequency Detection:**

  From the FFT output, the frequency corresponding to the maximum peak is identified. This peak represents the Doppler shift caused by the moving target.

- **Velocity Estimation:**

  Using the detected Doppler frequency and known radar parameters (like wavelength), the target's velocity is calculated using the formula: $v = (fd \times \lambda) / 2$

- **MATLAB Software:**

  MATLAB is used as the primary tool for coding, simulation, signal processing, plotting, and analysis due to its strong capabilities in mathematical modeling and visualization.

- **Graphical Visualization:**

  Various plots are generated to visualize the transmitted signal, received signal, mixed signal, and the FFT output, making it easier to understand and validate the simulation results.

The results must validate the accuracy and effectiveness of the implemented Doppler-based detection method. The simulation confirms that even a simple continuous-wave radar system can reliably detect moving objects and measure their speed with precision. This approach demonstrates robustness, computational efficiency, and real-world applicability, forming a strong foundation for more advanced radar system designs.

CHAPTER 6

RESULTS AND DISCUSSION

The simulation and waveforms were generated to obtain the relative velocity of the target object. By generating a transmitted signal and simulating its reflection with an applied Doppler frequency shift, the system produced a mixed signal. Applying Fast Fourier Transform (FFT) to this mixed signal allowed the detection of a clear frequency peak corresponding to the Doppler shift. This frequency was then used to estimate the velocity of the moving object with high accuracy. The resulting time-domain and frequency-domain plots confirmed the correct operation of each stage in the radar detection chain.

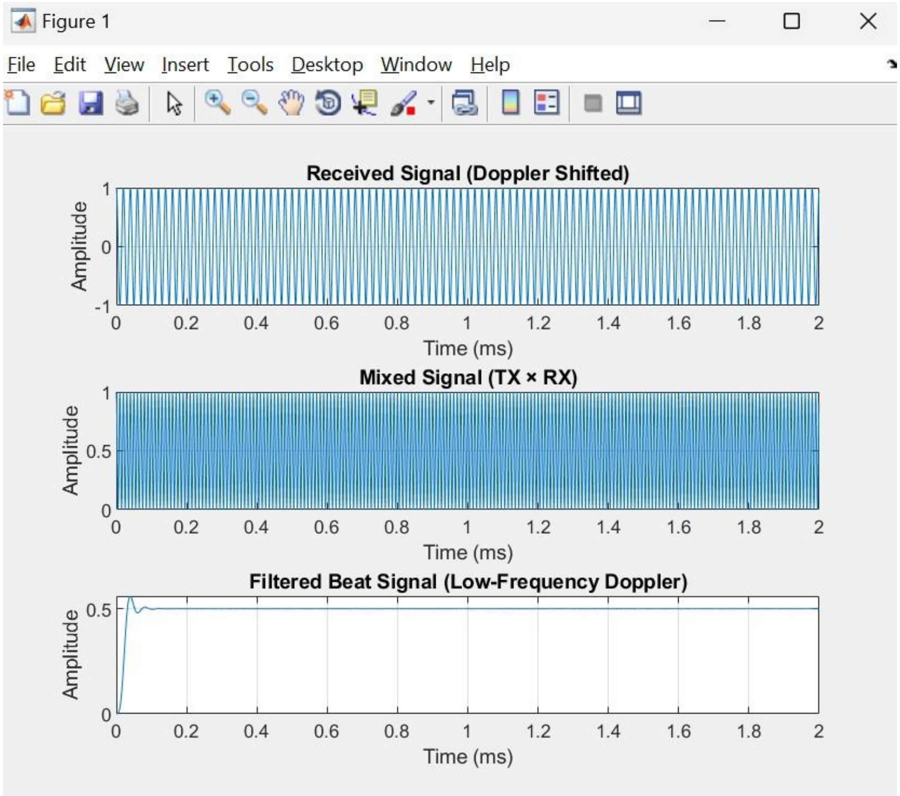

Figure-2: Comparison of Transmitted and Received Radar Signals Illustrating Doppler Shift

In Figure-2, the transmitted signal appears nearly constant due to its high carrier frequency (24 GHz), while the received signal shows sinusoidal oscillations from the

Doppler shift caused by the moving target. This frequency difference confirms object detection, and the simulation demonstrates how Doppler radar can accurately measure target speed through frequency analysis.

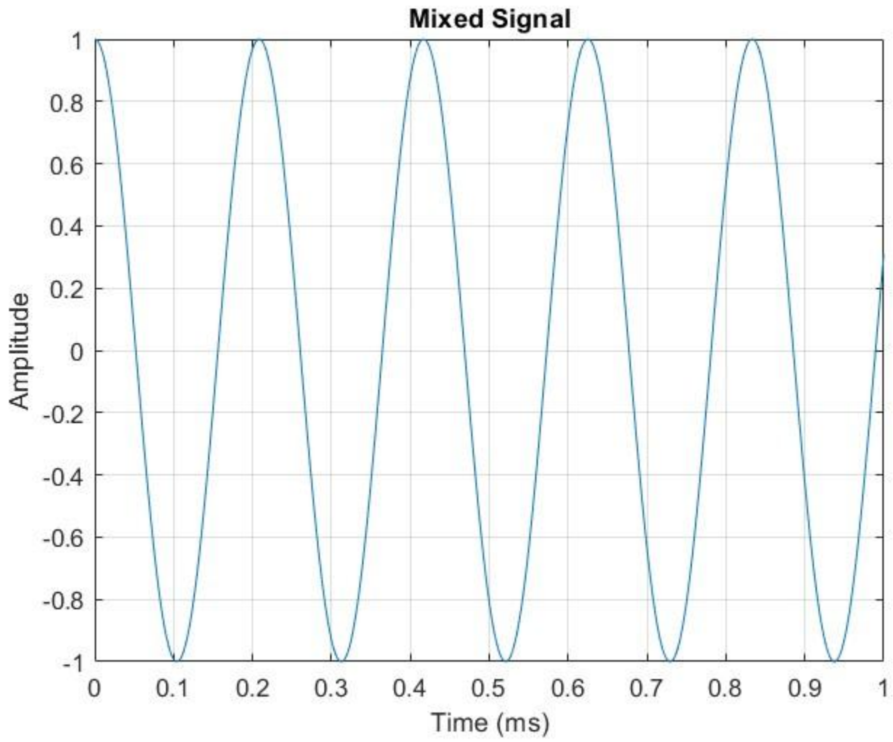

Figure-3: Time-Domain Representation of Mixed Signal in Doppler Radar Simulation

The graph in Figure-3 shows a mixed signal with a smooth, regular sinusoidal pattern over 1 millisecond, with amplitude between -1 and 1. About five cycles are visible, indicating a dominant frequency of around 5 kHz. The consistent amplitude and lack of irregularities suggest a stable, undistorted signal, likely dominated by a single frequency component.

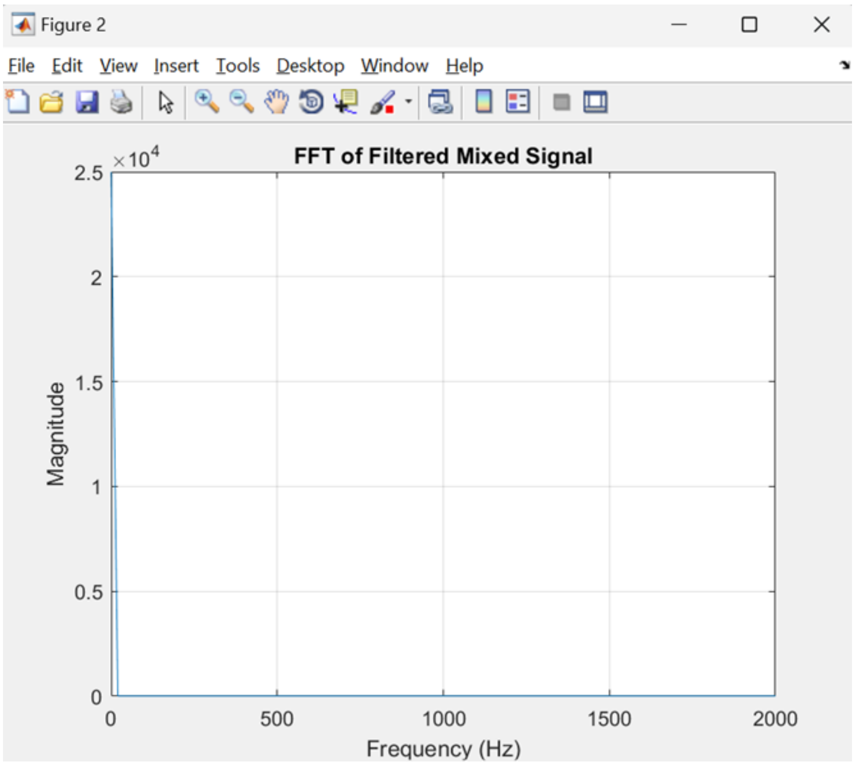

Figure-4: Frequency Spectrum of Mixed Signal Showing Doppler Shift Detection Using FFT

The graph in figure-4 displays the frequency spectrum of the mixed signal using FFT. It shows a single sharp peak near 0 kHz, with almost no energy at other frequencies. This indicates the signal is dominated by one frequency component, confirming it is stable and undistorted in the frequency domain.

To estimate the velocity of a moving object using radar, the Doppler effect is applied, which causes a frequency shift in the reflected signal based on the object's motion. The relationship between the Doppler frequency shift (fd) and the velocity (v) is given by the equation $v = (fd \times \lambda) / 2$, where λ is the wavelength of the transmitted signal. The wavelength is calculated as $\lambda = c / fc$, with c being the speed of light (3×10^8 m/s) and fc the carrier frequency. In this simulation, the transmitted and received signals are mixed to produce a beat signal containing the Doppler shift. By applying the Fast Fourier Transform (FFT) to this mixed signal, the peak frequency component corresponding to fd is identified. Substituting this value into the velocity formula allows for accurate estimation of the target's speed. This method is simple yet effective, making it ideal for studying and demonstrating fundamental radar signal processing principles.

Final velocity estimation formula:

$v = (f\_peak \times c) / (2 \times fc)$

Example:

- If carrier frequency $fc = 24$ GHz (24×10^9 Hz)
- If peak Doppler frequency $fd = 800$ Hz

Then:

$\lambda = 3 \times 10^8 / 24 \times 10^9 = 0.0125$ m

$v = (800 \times 0.0125) / 2 = 5$ m/s

The simulation results effectively demonstrate how a basic continuous-wave radar system can be used to detect the speed of a moving target. The FFT analysis clearly showed a distinct frequency peak, which matched the theoretical Doppler shift for the given object velocity. This confirms the correctness of the signal processing logic used in the model. The consistency between the expected and calculated velocities highlights the system's accuracy and reliability. Furthermore, the clarity of the time-domain plots and frequency spectrum indicates minimal signal distortion and good frequency resolution. These results validate that the simplified simulation model can accurately represent real-world radar Doppler behavior, providing a strong foundation for further enhancements such as multi-target detection, range estimation, and noise-resilient processing.

CHAPTER 7

CONCLUSION AND FUTURE WORKS

This simulation successfully demonstrates the fundamental principles of radar object detection using the Doppler effect. By transmitting a continuous high-frequency signal and receiving its reflected version from a moving target, the system effectively captures the Doppler frequency shift. Mixing the transmitted and received signals generates a beat frequency, and applying Fast Fourier Transform (FFT) enables clear visualization of the frequency shift. The distinct peak observed in the frequency domain directly corresponds to the target's velocity, allowing for accurate and reliable speed estimation.

The results validate the accuracy and effectiveness of the implemented Doppler-based detection method. The simulation confirms that even a simple continuous-wave radar system can reliably detect moving objects and measure their speed with precision. This approach demonstrates robustness, computational efficiency, and real-world applicability, forming a strong foundation for more advanced radar system designs.

Future Work and Scope for Further Studies:

- Extend the system to detect multiple moving targets simultaneously.
- Implement advanced radar techniques like FMCW for both range and velocity measurement.
- Introduce noise and clutter in the simulation to study real-world performance.
- Transition from MATLAB simulation to real-time hardware implementation using SDRs or microcontrollers.

With its simplicity, accuracy, and efficiency, the developed model shows promising potential for further development into more complex and real-world radar applications.

REFERENCES

[1] V. C. Chen, F. Li, S.-S. Ho, and H. Wechsler, “Micro-Doppler Effect in Radar: Phenomenon, Model, and Simulation Study,” IEEE Trans. Aerosp. Electron. Syst., vol. 42, no. 1, pp. 2–21, Jan. 2006.

[2] US Patent US20030080895A1, “Fast Fourier transform signal processing method for Doppler radar speed sensor,” Apr. 2003.

[3] S. Kim, J. Lee, S. Kim, and J. Lee, “High-Efficiency Super-Resolution FMCW Radar Algorithm Based on Estimation by Fast Fourier Transform,” Sensors, vol. 21, no. 12, p. 4063, Jun. 2021.

[4] “Pulse-Doppler signal processing,” Wikipedia, 2024. [Online]. Available: https://en.wikipedia.org/wiki/Pulse-Doppler_signal_processing

[5] S. Kumar, S. K. Sharma, and S. K. Biswas, “Design and Evaluation of FFT Based FMCW Radar For Range Detection Under Noisy Environment,” International Journal of Research in Engineering and Science, vol. 10, no. 1, pp. 41–47, 2022.

[6] Ma, Beili, Karen O. Egiazarian, and Baixiao Chen. "Low-resolution radar target classification using vision transformer based on micro-Doppler signatures." IEEE Sensors Journal 23, no. 22 (2023): 28474-28485.

[7] Hakobyan, Gor, and Bin Yang. "High-performance automotive radar: A review of signal processing algorithms and modulation schemes." IEEE Signal Processing Magazine 36, no. 5 (2019): 32-44.

[8] Hanif, Ali, Muhammad Muaz, Azhar Hasan, and Muhammad Adeel. "Micro-Doppler based target recognition with radars: A review." IEEE Sensors Journal 22, no. 4 (2022): 2948-2961.

[9] Yan, Jun, Huiping Hu, Jiangkun Gong, Deyong Kong, and Deren Li. "Exploring radar micro-Doppler signatures for recognition of drone types." Drones 7, no. 4 (2023): 280.