ABSTRACT

Target detection using multiple-input multiple-output (MIMO) radar has recently gained popularity in radar research due to its ability to mitigate the target radar cross-section fading and substantial spatial diversity gain. Recently, an optimal MIMO radar detector, including optimal transmit and receive weightage, has been proposed for the detection of steady targets. A moving target differs the scenario from a steady target case due to its Doppler. Hence, the optimal detector of a steady target case does not work for the case of a moving target. Therefore, in this paper, we proposed a MIMO radar detector for the context of moving targets, including optimal transmit and receive weight schemes. For obtaining the proposed detector, knowledge about the target fading that can be applied to a moving target scenario is a prerequisite. Therefore, we proposed to use a training mechanism in which a few transmit pulses are introduced once in every coherent processing interval, and the corresponding target returns are used to estimate the target fading. However, in a moving target scenario, the target returns are Doppler-steered versions of the target fading. Therefore, it is proposed to compensate the Doppler for target fading estimation by matching a steering vector to the target returns. This type of use of online estimation of the target fading characteristics and applying it for moving target detection is the first of its kind in radar research. The proposed radar is shown to outperform the state-of-the-art MIMO radars addressed in the literature.

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CHAPTER 1

INTRODUCTION

MIMO radars are capable of detecting multiple objects at the same time, even if they are moving at the same speed and are at the same distance from the antenna. Such systems also distinguish the targets based on angle information. As with MIMO, a high resolution can be achieved with a transmission module and any number of receivers. Because it can be influenced by the number of reception modules. However, the more receivers are added, the bigger the aperture, and numerous side lobe occur. This is where MIMO technology is helpful in counteracting the issue with multiple transmitting antennas.

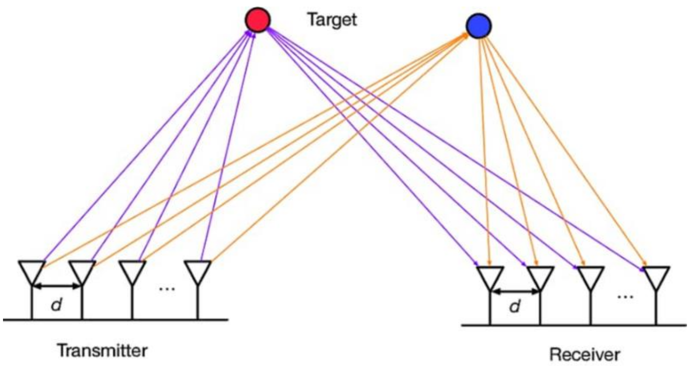

Figure 1 The system model of the bistatic MIMO radar

Multiple Input Multiple Output (MIMO) radar systems offer multiple advantages in comparison to traditional radar architectures. One key benefit lies in their enhanced spatial resolution, which enables more precise target localization and tracking. MIMO radar systems utilize multiple antennas for both transmission and reception, allowing them to form distinct beams and adaptively focus on specific regions of interest. This spatial agility not only improves target discrimination but also enhances overall system robustness in complex and cluttered environments. Another advantage of MIMO radar is its ability to exploit diversity in the signal domain, providing improved performance in terms of target detection and parameter estimation. This diversity arises from the simultaneous transmission of multiple waveform types or the exploitation of different polarizations, enhancing the radar's ability to extract valuable information from the environment. Additionally, MIMO radar systems can mitigate the effects of interference and jamming through spatial filtering, offering improved resilience in electronic warfare scenarios. The increased flexibility in waveform design and adaptability to various operational scenarios further contribute to the versatility of MIMO radar systems. Overall, the advantages of MIMO radar encompass improved spatial resolution, enhanced target detection, robustness in challenging environments, and increased resistance to interference, making them a compelling choice for modern radar applications.

1.1 Objectives

1. Performance Evaluation of Coherent and Non-Coherent MIMO Radar (for the following parameters: SNR, SINR, Probability of false detection, Probability of arrival).
2. Improvement of capacity & quality of efficiency.

1.2 SISO, SIMO, MISO & MIMO Models

1.2.1 Single Input Single Output System (SISO) Model

SISO stands for Single Input Single Output, and it is the simplest radio communication link between a transmitter and a receiver. SISO employs a single transmitting antenna (Single Input) and a single receiving antenna (Single Output).

The system model is,

$$\mathbf{y = Hx + w}$$

where, 'y' is a received signal, 'H' is channel, 'W' is AWGN noise component

where, MT = Transmit Antenna, MR = Receiver Antenna.

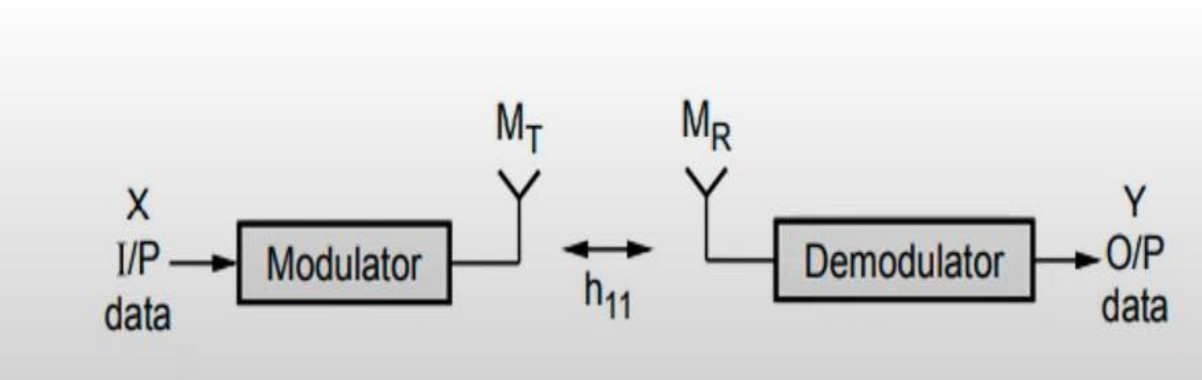

Figure 2 SISO Model

A SISO system has single transmitting antenna MT and single receiving antenna MR. The input data "X" is modulated and transmitted through MT and propagates in the radio channel. The Capacity of SISO system is,

$$C_{SISO} = [B \log_2(1 + S/N)]$$

Where, C = Capacity of the channel, B = Bandwidth, S/N = Signal to Noise Ratio

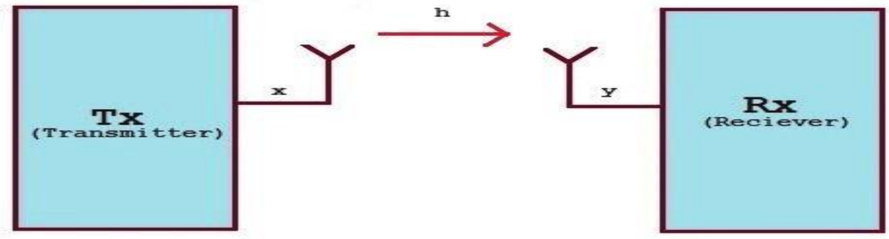

Figure 3 SISO Configuration

When a radio signal travels through the air, it encounters many obstructions such as buildings, mountains, trees, poles, cables, reflecting surfaces, etc. Radio signals are electromagnetic waves, and they undergo a scattering effect when they face any obstacles. These obstructions negatively impact the signal strength, making it very weak by the time it arrives from the transmitter to the receiver. The signal can take multiple routes between the transmitter and the receiver and experiences multipath fading. When multipath fading happens, the characteristics of the signal change leading to a drop in signal quality which introduces errors into the signal.

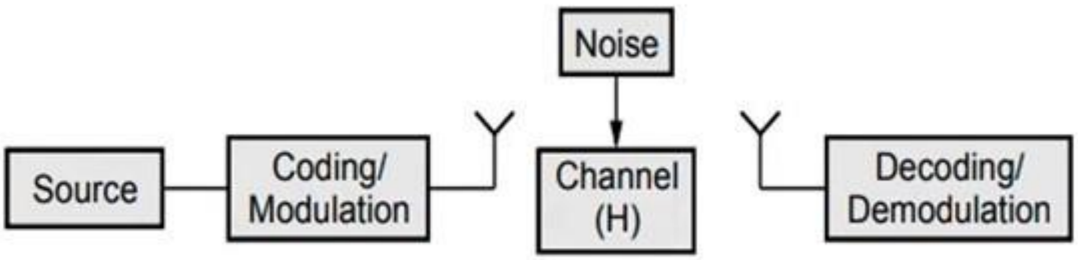

Figure 4 SISO System

1.2.2 Single Input Multiple Output System (SIMO) Model

Single Input Multiple Output employs a single transmitting antenna (single input) and multiple receiving antennas (multiple outputs). The benefit of SIMO is that it allows a network to reduce the negative impact of signal fading by allowing the receiver to catch the same signal through multiple antennas.

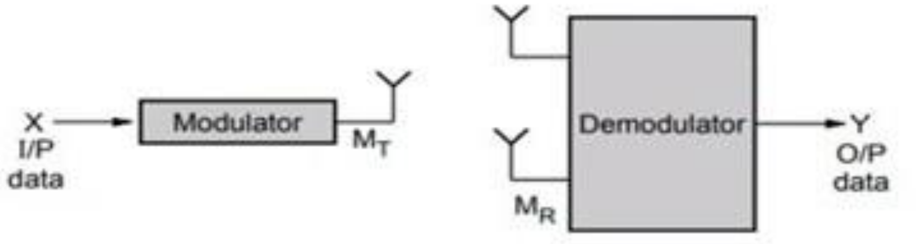

Figure 5 SIMO Model

SIMO is based on the principle of receive diversity that exploits the multipath fading of a radio signal by introducing multiple antennas for multiple paths. The receiving antennas then use antenna diversity to combine the received signals to recreate the signal. SIMO improves the signal link quality while the channel capacity stays the same.

The Capacity of SIMO system is ,

CSIMO = MR.B.log2(1 + S/N)

Where, MR = Number of Antennas, B = Bandwidth, S/N = Signal to Noise Ratio

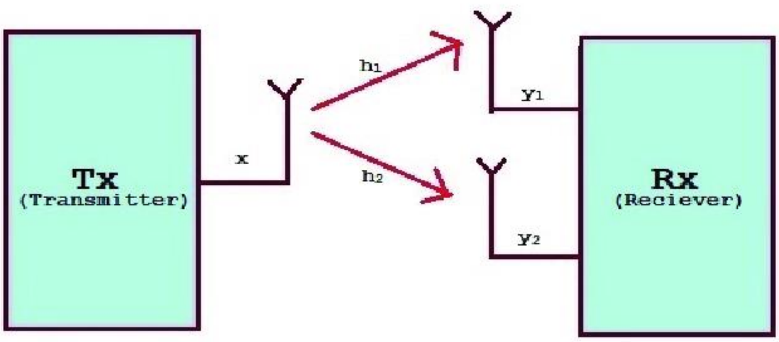

Figure 6 SIMO Configuration

1.2.3 Multiple Input Single Output System (MISO) Model

Multiple Input Single Output employs multiple transmitting antennas (Multiple Inputs) but only one receiving antenna (Single Output). The benefit of MISO is that it has the capability to address the negative impact of signal fading to improve radio link reliability. MISO utilises transmit diversity where multiple copies of the same signal are sent toward the receiving antenna. The communication from the multiple transmitting antennas is encoded differently so that the receiving antenna can accurately decode the communication from different transmitting antennas.

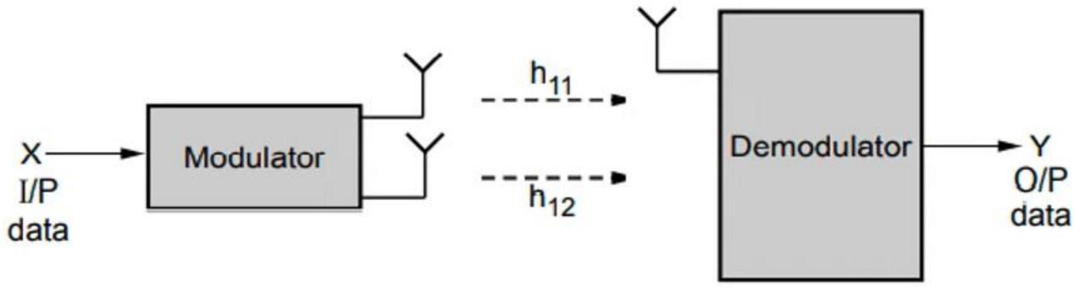

Figure 7 MISO Model

MISO ensures better signal quality while consuming less power when used between a base station transmitter and a mobile phone receiver. It also benefits from the fact that all the power-intensive work of diversity and antenna redundancy is at the base station, which is connected to a dedicated power supply instead of a mobile phone that has a small battery.

The h11 and h12 are the different fading coefficients. The Capacity of MISO system is,

CMISO = MT.B.log2(1 + S/N)

Where, MT = number of transmit antennas, B = Bandwidth, S/N = Signal to Noise Ratio

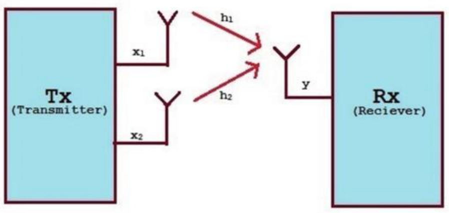

Figure 8 MISO Configuration

1.2.4 Multiple Input Multiple Output System (MIMO) Model

Multiple Input Multiple Output offers the best solution to improve the radio link quality while also improving the throughput (bit rates) for the end-user. MIMO is also referred to as multiple-transmit, multiple-receive (MTMR). In MIMO, the available transmission power is spread over multiple antenna arrays to achieve array gain, which improves spectral efficiency. In addition, diversity gain is achieved by implementing multiple antennas at the transmitter and the receiver to enhance the quality of the signal.

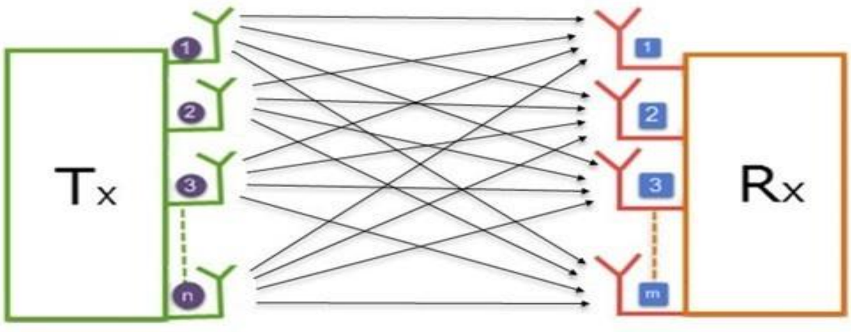

Figure 9 MIMO Configuration

The focus of MIMO antenna technology is on network coverage and network capacity. MIMO is an antenna system that employs multiple antennas at the transmitter (Multiple Input) and multiple antennas at the receiver (Multiple Output). MIMO improves the signal-to-noise ratio (SNR) of a communication system and employs spatial multiplexing, which consists of multiple spatially separated antennas to send and receive the signal in separate data streams.

An Additive White Gaussian Noise (AWGN) channel is considered. The BPSK modulation techniques used for long distance transmission. The MIMO system has higher capacity than other SISO, SIMO & MISO systems. The Capacity of MIMO system is given as,

CMIMO = MT. MR.B.log2(1 + S/N)

Where, MT = Number of transmit antennas, MR = Number of receive antennas, B = Bandwidth, S/N = Signal to Noise Ratio

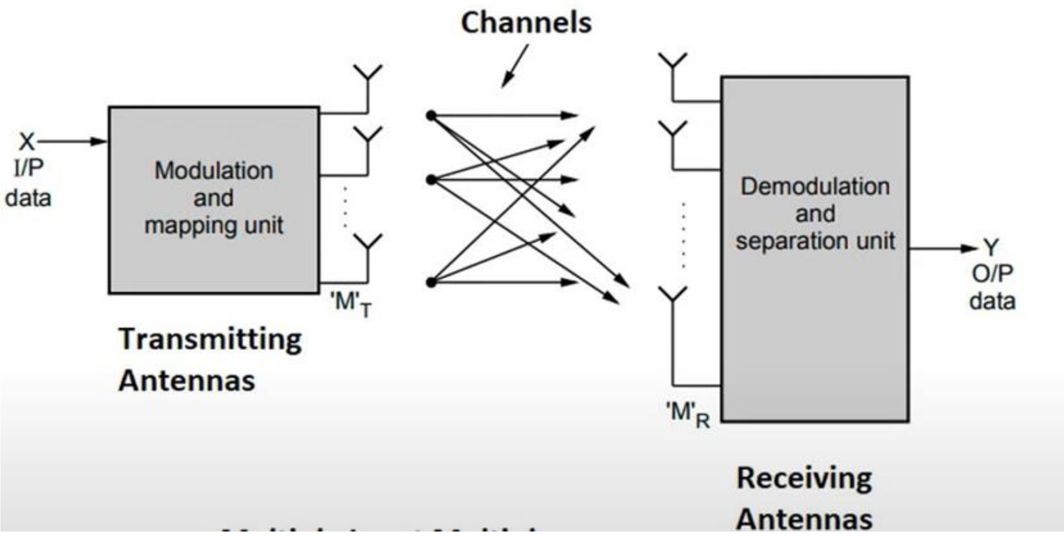

Figure 10 MIMO System

1.3 Why MIMO?

A Single Input Single Output link with one channel ratio connected to a single polarization antenna transmitting RF signal to the same setup at the receiving side. The received signal is not only the one arriving through the line of sight. It fluctuates due to all kinds of fading, in other words, random addition of signals arriving at the receiver because of reflections, when the signal reflects from objects much larger than the wavelength, diffracted signals from the edges of such obstructions, scattering from objects with the size similar to the signal wavelength, flat or frequency selective fading affecting all or only certain frequencies of a wideband signal, or Doppler fading causing frequency shift of a signal when the receiver is moving. All these fading components can severely affect the quality and reliability of a wireless communication system.

MIMO is a set of techniques used to diminish the fading effects and improve throughput capacity, coverage, and reliability of a wireless link. This is a simple wireless link capacity equation is given below:

C=N.B.log(1+S/N)

Where, N=Number of Channels N=1,2,3…… , B=Bandwidth, S/N=Signal to Noise Ratio

Besides the higher bandwidth B, or increasing the signal-to-noise ratio S/N, growing the number of channels on either side of the link is also a way to increase the throughput capacity, where MIMO comes in. Increasing the number of antennas on either or both sides of a wireless link creates multiple possible paths for the signal to arrive at the receiver.

There are a number of benefits that MIMO brings about. They are,

- First is an array gain, which is an increase of received signal SNR from combining the signals arriving from different directions. Array gain improves resistance to noise and therefore the coverage and maximum range of a wireless link.
- Second is reliability, multiple paths through which the signal can reach the receiver increases the probability of a successful data transfer.
- Thirdly, multiple data streams in the same frequency channel enable higher link capacity. The smaller number in an M x N system tells us the minimum number of reliably operable data streams.

In the wireless internet service provider networks, it is common to leverage two independent data streams on each end of a link separated by antenna polarization. This effectively doubles the link capacity despite both polarizations of an antenna use the same frequency.

Figure 11 SISO, SIMO, MISO & MIMO COMMUNICATION

CHAPTER 2

LITERATURE SURVEY

Pengfei Gao et al “Waveform Design for MIMO Radar with Consistent Correlation Phase” Multiple Input Multiple Output (MIMO) radar provides additional degrees of freedom (DOFs) by emitting orthogonal waveforms at transmit channels compared to the phase array radar. Therefore, ideal orthogonal waveforms ensure the performance of transmit channels diversity which directly affects the parameter estimation performance of MIMO radar system. The mechanism of existing non-ideal orthogonal waveforms affecting MIMO radar target estimation is described. Furthermore, they proposed an consistent correlation phase criterion that make the phase sequences of correlation function between different waveforms basically consistent. The orthogonal waveforms with consistent correlation phase cause lower sidelobe in transmit spatial frequency domain during spectrum estimating of target[1].Xin Wang et al “Polarization Parameter Estimation of Conformal MIMO Radar Targets” Conformal Multiple-Input Multiple-Output (MIMO) radar make good use of the aperture of the platform, but target polarization scattering parameter is more complicated since the beam patterns of transmit/receive antennas are different from those in free space. They developed signal processing algorithms to estimate the Sinclair matrix of radar targets for conformal MIMO radar, according to the Least Square (LS) criterion and the Maximum Likelihood (ML) criterion. Both unbiased but the ML estimator can achieve the Cramer-Rao bound. The estimation performance is evaluated in theory via numerical results [2]. Vinzenz Janoudi et al “Antenna Array Design for Coherent MIMO Radar Networks” High angular resolution provides improved environmental perception and increases the detection quality of extended targets. Therefore a key requirement towards future radar systems for autonomous driving. The angular resolution of a radar system fundamentally depends on its antenna array aperture size. It is technically difficult and economically challenging to realize a large aperture radar system as a single sensor. Radar networks, consisting of multiple individual radar sensors, mitigate the challenges caused by creating a large aperture radar system. This paper presents a radar network consisting of two individual MIMO radar sensors equipped with L-shaped physical antenna arrays. L-shaped arrays for the individual sensors are chosen to achieve a rectangular equally spaced radar network virtual aperture. Furthermore, the performance of the resulting virtual aperture in the context of DoA estimation. Measurements of a bicycle, conducted with a coherently coupled radar network consisting of 768 virtual channels, demonstrate the performance of a high angular resolution radar system [3]. Mohammed Elmogtaba Barakat et al “Performance Evaluation of Coherent MIMO Radar Assisted with Space-Time Coding” The Use of multiple-input multiple-output (MIMO) technology has revolutionized the radar field by providing higher resolution, improved target detection, and reduced interference. However, interrupting signals can significantly degrade the Performance of MIMO radar systems to transmit and receive signals simultaneously; MIMO radar systems employ multiple antennas at the transmitter and receiver. This allows for improved spatial resolution and increased target detection capabilities. However, MIMO radar systems are susceptible to fading and interference, degrading performance. STC is a technique to mitigate these effects by transmitting multiple signals simultaneously from different antennas. This article evaluates the performance of space-time coding (STC) with coherent multiple-input multiple-output (MIMO) radar. They also investigated the impact of STC on the radar system's detection and estimation capabilities in various scenarios, including target detection in cluttered environments and target tracking in the presence of interference. The simulation results demonstrate that STC can significantly improve the radar system's performance by reducing interference effects and increasing the signal-to-noise ratio. Furthermore, briefed the different STC schemes have varying degrees of effectiveness depending on the specific scenario. Overall, this provides valuable insights into the potential benefits of using STC with coherent MIMO radar for various applications [4]. Syahfrizal Tahcfulloh et al “Phased-MIMO Antenna Arrays of Radar System in Detection Performance” The use of multiple antennas in radar systems that establish antenna arrays in transmitter (Tx) and receiver (Rx) has become of current interest. The Phased-MIMO radar (PMIMO) combines simultaneously the high coherent directional gain capabilities of the phased array (PA) radar and the high multi-target detection capabilities of the MIMO radar. This can be realized because of the use of overlapped subarrays in Tx so that it improves the detection performance flexibly such as the detection and false alarm probabilities. The detection performance of this radar for the optimal detector has been derived and validated and then compared with the performance of other multi-antenna radars based on the effect of the threshold, SNR, and the number of subarrays in Tx. The results of the evaluation show that the PMIMO radar is more flexible through its subarrays variations than the PA and the MIMO radars for its performance capabilities under various target environmental conditions. To achieve a detection performance that fulfil the tolerance of a certain threshold, which is above 35, the resulting false alarm probability is above 10e-4 with a detection probability of more than 99% [5]. Mingxing Wang et al “Coherent Integration and Parameter Estimation for High-Speed Target Detection with Bistatic MIMO Radar” The coherent integration and parameter estimation problem for high-speed target detection using bistatic multiple-input multiple-output (MIMO) radar. Unlike the traditional intrachannel coherent integration that could only focus the target’s energy during the multipulse observation, the bistatic MIMO radar implements joint intrachannel integration and interchannel integration to improve detection performance. However, its difficulties lie in that the high-speed motion results in the range migration (RM) in the intrachannel and the phase and envelope differences among multichannel. To solve these problems, they proposed a multichannel coherent integration methodology in the radon Fourier transform (RFT) domain for the bistatic MIMO radar. They applied the RFT to integrate the target energy in the intrachannel. Then, the multichannel coherent accumulation is performed by the design of the phase compensation function and envelope alignment function. Finally, based on the relationship between the integration peak's location and target parameters, a Broyden-like method and linear equation solving are, respectively, presented to estimate the target's position and velocity. The effectiveness of the proposed method is assessed via simulation experiments and real-measured data. The proposed method detects targets at low signal-to-noise ratios (SNRs) which are not attainable using state-of-the-art methods[6]. Guoxin Zhang el at "Direct Target Localization with Quantized Measurements in Noncoherent Distributed MIMO Radar System" The direct target localization algorithm with quantized measurements for noncoherent multiple-input–multiple-output (MIMO) systems. In this system, each receiver transmits a low-bit quantized version of the echo rather than the full raw data to the fusion center. They constructed a joint likelihood function based on the low-bit data of each receiver, from which the unknown target position can be directly determined. The Cramer–Rao lower bound (CRLB) is derived to analyze the localization performance of our proposed algorithm. To maximize the localization performance, a CRLB-based objective function is designed to obtain the optimum quantization thresholds. The formulated problem is a high-dimensional and nonconvex optimization problem then solved, determines two types of coupled parameters for the quantization thresholds and the complex-valued scaling coefficients of the signal. They proposed a batch gradient descent embedded particle swarm optimization algorithm to solve this problem effectively. Numerical results show that the proposed algorithm delivers superior performance in terms of maximizing the overall localization performance, and the 3-bit quantized algorithm is able to provide performance that is very close to the unquantized algorithm. Experimental data recorded by three small radars are also provided to demonstrate the effectiveness of the proposed algorithm [7]. Sergio López Fernández et al **"**MeasurementBased Analysis of a Non-Coherent MIMO Radar Network for Automotive Applications**"** They performed a measurement-based analysis of a four-module cooperative radar network for automotive applications. The radar network is mounted on the front bumper of a car and operates as a multiple-input multiple-output system with 192 channels that exploits spatial diversity. They also presented an analysis of four different real-world scenarios in which the car is moving and encounters both static and moving targets. The results focus on the behaviour of the network through a non-coherent signal processing that is capable of including the bistatic paths while reducing the complexity of the setup. They include quasi-monostatic and bistatic responses as well as a combined network response that fuses the information from all the modules. This approach offers robustness against miss detections and ghost targets as well as improvements in target identification [8]. Abbas Sheikhi & A. R. Zamani “Coherent Detection for MIMO Radars” Superiority of Multiple-Input Multiple-Output (MIMO) radars over conventional phased array radars have been recently shown in many aspects. MIMO radars have better detection performance and can extract target information more precisely than phased array radars. The problem of target detection using temporal coherent pulse terrain is considered for MIMO radars. They have introduced a structure that is suitable for coherent processing. Based on the structure, they have formulated the problem as a hypothesis test. One decision rule is developed for detection of target with unknown amplitude embedded in Additive White Gaussian Noise (AWGN) with known power using the Generalized Likelihood Ratio Test (GLRT). Another adaptive scheme for the case of unknown power is presented. They have also proposed an ad-hoc Constant False Alarm Rate (CFAR) detector against AWGN with unknown power. Performance of these detectors have been evaluated analytically. The results show the superiority of the MIMO radars with temporal coherent processing over the conventional phased arrays [9]. Dontamsetti Satya Ganesh et al “A Novel Transmit Weight Scheme for MIMO Radar Multiple Target Detection” Multiple-input multiple-output (MIMO) systems have shown a new paradigm of radar research in recent times. MIMO radar with transmit and receive schemes received special attention from many research topics due to their ability to improve system performance. Recently, a joint transmits and receive weight scheme is proposed for MIMO radar, outperforming the existing receive combining schemes of MIMO radar. However, the scheme can tackle the detection of only one target in a coherent processing interval (CPI) for optimal performance. The scheme still works for multiple resolvable targets in a CPI with transmit weights selected optimally for only one target. Hence, the performance deteriorates due to the deviation in the transmit weights for other targets [10].

CHAPTER 3

REQUIREMENTS

3.1 Google Colab

It is shortly called Colaboratory. It is a powerful and user-friendly cloud-based tool provided by Google for collaborative and interactive computing. Leveraging the capabilities of Jupyter Notebooks, Google Colab allows users to write and execute code in a dynamic environment directly from their web browsers. One of its key advantages is the provision of free access to GPU (Graphics Processing Unit) and TPU (Tensor Processing Unit) resources, enabling users to accelerate their computations, particularly in the realm of machine learning and data analysis. Google Colab seamlessly integrates with popular machine learning libraries such as TensorFlow and PyTorch, making it a preferred choice for researchers, data scientists, and educators. Furthermore, it supports real-time collaboration, allowing multiple users to work on the same document simultaneously. The tool also facilitates easy sharing of notebooks, making it a valuable asset for collaborative projects and educational purposes. Its user-friendly interface, coupled with the ability to run code on Google's powerful infrastructure, makes Google Colab an accessible and efficient tool for a wide range of computational tasks in various domains.

3.2 Python Programming Language

It is a versatile and widely-used programming language that excels in application programming across various domains. Python's simplicity, readability, and extensive set of libraries make it a popular choice for developing diverse applications. In the realm of web development, frameworks like Django and Flask empower developers to create robust and scalable web applications efficiently. Python's strength in scientific computing and data analysis is evident through libraries such as NumPy, pandas, and Matplotlib, making it a go-to language for researchers and data scientists. Additionally, Python's support for automation and scripting is prominent in system administration, where it is employed to streamline tasks and manage infrastructure. With the advent of machine learning and artificial intelligence, Python has become a dominant language due to frameworks like TensorFlow and PyTorch, allowing developers to build sophisticated models and applications.

CHAPTER 4

PROPOSED METHODOLOGY

The two detection techniques, Coherent and Non-Coherent detection are used for MIMO Radar target detection and Parameter estimation.

4.1 Coherent Detection

Coherent detection in radar systems, in case of Multiple-Input Multiple-Output (MIMO) configurations, is a sophisticated approach aimed at leveraging phase information to enhance radar performance. In MIMO radar, multiple antennas are employed for both transmission and reception, enabling the system to capitalize on spatial diversity. Coherent processing is a fundamental aspect of this technique, involving the careful combination of received signals from different antennas while preserving phase relationships. This coherence is essential for accurate target parameter estimation, including range, velocity, and angle. Through array signal processing techniques such as beamforming and spatial filtering, MIMO radar optimally extracts information about targets while suppressing interference. Doppler processing, crucial for velocity estimation, relies on maintaining phase coherence between transmitted and received signals. Coherent detection in MIMO radar finds applications in scenarios demanding improved resolution, accuracy, and robustness, making it particularly beneficial for target detection, tracking, and imaging in complex environments with multiple targets and clutter. Despite the computational challenges and synchronization requirements associated with coherent detection, its advantages make it a valuable approach in advanced radar systems. Here, we used Some algorithms which uses Coherent Detection for parameter estimation & target detection. They are Least Square, Capson’s, STAP & Amplitude and Phase Estimation.

4.1.1 The Least Squares Algorithm

The least squares algorithm can be used in both coherent and non-coherent detection, but its specific application and the way it is used can vary depending on the context. The Least Squares algorithm is a mathematical technique used for minimizing the sum of the squares of errors between observed and computed values. It is widely used in various fields, including target detection and parameter estimation. In both target detection and parameter estimation, the Least Squares algorithm is a powerful tool for finding the best-fitting model to the available data. The key is to formulate an appropriate mathematical model and design an objective function that captures the relationships between the parameters and the observed data.

In coherent detection, the received signal is processed while preserving both phase and amplitude information. The least squares algorithm can be applied to various tasks in this context. In radar, for example, least squares can be used for estimating parameters such as target range, velocity, and direction of arrival, especially in scenarios where the signal model is well understood and the phase information is crucial for accurate estimation. In communication systems, least squares can be employed for channel estimation, equalization, and symbol detection when phase information is available and important, as in some coherent communication systems.

Consider a radar system trying to estimate the position and velocity of a moving target. The Least Squares algorithm could be used to minimize the difference between the predicted and observed radar measurements, providing accurate estimates for the target's position and velocity. The various steps involved in target detection and parameter estimation are discussed below.

Steps for Target Detection:

• Model Formulation: Define a mathematical model that represents the expected behaviour of the target and background. This model typically involves parameters that need to be estimated.

• Data Collection: Gather observational data, which may include sensor readings, images, or other relevant measurements.

• Objective Function: Formulate an objective function that quantifies the difference between the observed data and the model predictions. The objective function is usually a sum of squared differences between observed and predicted values.

• Minimization: Apply the Least Squares algorithm to minimize the objective function. Adjust the model parameters to find the values that minimize the sum of squared errors.

• Thresholding: Set a threshold on the minimized objective function to detect the presence or absence of a target. If the minimized error is below a certain threshold, the target is considered detected.

• Iterative Refinement: In some cases, an iterative refinement process may be employed to improve the accuracy of target detection.

Steps for Parameter Estimation:

• Define Model: Formulate a mathematical model that relates the parameters to the observed data.

• Data Collection: Collect data relevant to the parameters to be estimated.

• Objective Function: Construct an objective function that measures the difference between the observed data and the model predictions

• Least Squares Solution: Apply the Least Squares algorithm to minimize the sum of squared errors and estimate the parameters that best fit the model to the data.

• Parameter Interpretation: Interpret the estimated parameters in the context of the problem being solved.

• Uncertainty Analysis: Assess the uncertainty in the parameter estimates, often by examining the covariance matrix or confidence intervals.

• Validation: Validate the model and parameter estimates using independent data or cross-validation techniques.

4.1.2 Space-Time Adaptive Processing (STAP) algorithm

STAP is a signal processing technique used in MIMO radar systems for target detection and parameter estimation in the presence of interference, clutter, and jamming. It leverages the spatial diversity provided by multiple radar antennas and the coherent integration of the received signals. STAP adapts the weights of the receive antenna array to suppress interference and enhance the detection of targets. STAP algorithms use the phase and amplitude information from multiple antennas to form adaptive beams, which adaptively steer the radar beam towards the target and nullify interference sources. This technique significantly improves target detection and parameter estimation accuracy in complex radar environments.

Consider an airborne radar system that needs to detect and track moving targets on the ground. The STAP algorithm would process the received radar signals from multiple antenna elements over several pulse repetitions, adaptively adjusting the weights to suppress ground clutter and interference. The result is an improved ability to detect and estimate the parameters of moving targets against a cluttered background.

STAP is a sophisticated signal processing technique that requires careful consideration of system parameters, training data, and adaptive processing to effectively mitigate clutter and interference in radar systems, leading to improved target detection and parameter estimation in challenging environments. How the STAP algorithm is generally applied in the context of target detection and parameter estimation is discussed below:

• Basic Principle: STAP processes the radar data in both space and time dimensions to adaptively suppress clutter and interference while enhancing the detection of targets.

• System Model: Formulate a mathematical model of the radar system, including the geometry of the radar array, the transmitted signals, and the received signals.

• Clutter and Interference Mitigation: Use the information from multiple antenna elements (spatial dimension) and multiple radar pulses (temporal dimension) to distinguish between signals from stationary clutter and interference and those from moving targets.

• Covariance Matrix Estimation: Estimate the covariance matrix of the received signals. This matrix characterizes the statistical properties of the clutter and interference.

• Adaptive Weighting: Apply adaptive weighting to the received signals based on the estimated covariance matrix. The adaptive weights are adjusted to maximize the signal-to-interference-plus-noise ratio (SINR) for target detection.

• Detection and Parameter Estimation: Implement a detection algorithm to identify potential target returns in the presence of clutter and interference.

• Training Data: STAP often requires training data to adaptively update its weights and parameters. This training data is typically collected during periods when there are no targets of interest but includes clutter and interference.

• Adaptation and Iteration: STAP is often an adaptive process, and the algorithm may iterate to continuously update and refine the adaptive weights based on real-time or updated training data.

• Performance Evaluation: Assess the performance of the STAP algorithm in terms of its ability to detect targets in the presence of clutter and interference.

3.1.3 Amplitude and Phase Estimation Algorithm

Amplitude and phase estimation algorithms are typically used in coherent detection, where the received signals are processed while preserving both amplitude and phase information. Coherent detection relies on maintaining the phase relationship between the transmitted and received signals, which allows for accurate recovery of not only the amplitude but also the phase of the signal.

In coherent detection, in case of Radar Systems, Amplitude and phase estimation are used for tasks like target range and angle estimation. The phase information is particularly important in radar systems to accurately determine the direction of arrival and speed of targets. In coherent communication systems, phase information is necessary for demodulating and decoding modulated signals. Accurate estimation of both amplitude and phase helps in symbol detection, channel equalization, and coherent demodulation.

4.2 Non-Coherent Detection

Non-coherent MIMO (Multiple-Input Multiple-Output) radar is an alternative to coherent MIMO radar that does not require phase synchronization between the multiple antennas. It can offer advantages in terms of reduced complexity, cost, and power consumption. While it may not provide the same level of performance as coherent MIMO radar in certain aspects, it still has several benefits for target detection.

In Multiple-Input Multiple-Output (MIMO) radar systems, non-coherent detection plays a crucial role in target detection and parameter estimation. Unlike coherent detection, which relies on maintaining phase information across multiple radar antennas, non-coherent detection does not require synchronization of the transmitted waveforms or the coherent processing of received signals. Instead, non-coherent detection in MIMO radar involves processing the magnitudes or power levels of the received signals independently across different antennas. This approach simplifies the hardware requirements and mitigates the challenges associated with phase coherence, making MIMO radar systems more robust and flexible.

Non-coherent detection is particularly advantageous in scenarios with rapidly changing environments, where maintaining coherent phase relationships may be challenging due to target dynamics or interference. By independently processing the magnitude information from each antenna, non-coherent detection in MIMO radar enhances the system's adaptability and resilience, making it well-suited for diverse applications, including target detection in complex and cluttered environments. The simplicity and efficiency of non-coherent detection contribute to the attractiveness of MIMO radar systems, offering improved performance in scenarios where traditional coherent methods face limitations.

Here, we used Some algorithms which uses Non-Coherent Detection for parameter estimation & target detection. They are Least Squares & Amplitude and Phase Estimation.

4.2.1 Least Squares Algorithm

The Least Squares (LS) algorithm can be employed for non-coherent detection, providing a robust and efficient approach to estimate target parameters without relying on coherent phase information across multiple antennas. In non-coherent MIMO radar, the received signals from different antennas are processed independently, and the LS algorithm is used to estimate target parameters such as range, Doppler frequency, and direction of arrival. The LS algorithm minimizes the sum of squared errors between the observed data and the predicted values based on a chosen model. In the context of MIMO radar, this involves estimating the parameters that define the geometry and characteristics of the target scene. By formulating an appropriate mathematical model and employing the LS algorithm, MIMO radar systems can achieve accurate parameter estimation even in the absence of coherent processing. This non-coherent detection approach enhances the system's resilience to dynamic and rapidly changing environments, making MIMO radar well-suited for applications where maintaining phase coherence may be challenging or impractical. The LS algorithm's versatility and ability to handle non-coherent data make it a valuable tool for parameter estimation in MIMO radar, contributing to the system's effectiveness in target detection.

4.2.2 Amplitude and Phase Estimation

In non-coherent detection, does not rely on preserving phase information. It is typically used when the phase of the received signal is either unknown or rapidly changing and cannot be reliably maintained. Amplitude estimation is more relevant, as the phase information is not considered. The algorithm for amplitude and phase estimation for non-coherent MIMO radar is also called Expectation-Maximization (EM) algorithm. The estimation of magnitude (amplitude) and phase, the algorithm allows MIMO radar systems to adapt to changing conditions and interference more effectively. This separation of amplitude and phase estimation enhances the robustness and flexibility of non-coherent detection in MIMO radar. The resulting estimates can then be used for further processing, such as target detection and parameter estimation.

CHAPTER 5

IMPLEMENTATION

5.1 Least Square Algorithm

➢ **For Target Detection**

1. MIMO Radar Parameters:

   - `num_tx_antennas`: Number of transmit antennas.

   - `num_rx_antennas`: Number of receive antennas.

   - `num_snapshots`: Number of snapshots or time samples.

   - `snr_dB`: Signal-to-noise ratio in decibels.

2. Generate Random Targets:

   - Two complex exponential signals (`target1` and `target2`) are generated as random phases. These represent the true targets.

3. Generate Complex Gaussian Noise:

   - Gaussian noise is generated with a specified SNR level.

4. Received Signal at Each Antenna for Each Target:

   - Complex Gaussian noise is added to the received signals for each target at each receive antenna.

5. Combine Transmitted and Received Signals:

   - Transmit signals (`transmitted_signal1` and `transmitted_signal2`) are generated for each target.

   - Received signals are obtained by combining the transmitted signals and adding noise.

6. Least Squares Estimation:

- The LS estimation is performed to estimate the targets. The channel matrix `H` is formed by taking the conjugate transpose of the combined transmitted signal.

- The `np.linalg.lstsq` function is then used to solve the least squares problem, and the estimated targets are obtained.

7. Plotting:

- The code uses Matplotlib to plot the true magnitude of the two targets and the magnitude of the estimated targets using LS.

8. Results Plotting:

- The results are plotted in three subplots:

  - True magnitude of Target 1 and Target 2.

  - True magnitude of Target 2.

  - Estimated magnitude of the targets using LS.

- The legend in each subplot helps identify the corresponding lines.

9. Show the Plot:

- Finally, the `plt.show()` command is used to display the generated plots.

➢ **For Parameter Estimation**

1. Parameters:

- `num_antennas`: Number of antennas in the MIMO radar system.

- `num_snapshots`: Number of time snapshots or samples.

- `num_targets`: Number of targets.

- `snr_dB`: Signal-to-Noise Ratio in dB.

2. Generate Random Complex Weights for Targets:

- `target_weights`: Random complex weights for the targets are generated.

3. Generate Received Signal Matrix:

- The received signal is generated by multiplying the conjugate transpose of the target weights with a complex exponential signal. Gaussian noise is added to simulate a noisy environment.

4. Estimate Covariance Matrix:

- The covariance matrix of the received signal is estimated.

5. Perform Eigendecomposition:

- Eigendecomposition is performed on the covariance matrix to obtain eigenvalues and eigenvectors.

- Signal and noise subspaces are extracted from the eigenvectors.

6. Least Squares Algorithm for Target Weight Estimation:

- The LS algorithm is used to estimate the target weights from the signal subspace.

7. Calculate SNR and SINR:

- SNR (Signal-to-Noise Ratio) and SINR (Signal-to-Interference-plus-Noise Ratio) are calculated based on the estimated target weights and the noise.

8. Monte Carlo Simulation for Detection Performance:

- A Monte Carlo simulation is performed to evaluate the detection performance.

- The energy detector is applied by calculating a test statistic and comparing it to a threshold.

9. Calculate Probability of False Detection and Probability of Arrival:

- The probability of false detection and probability of arrival are calculated based on the Monte Carlo simulation.

10. Display Results:

- The code prints the calculated SNR, SINR, probability of false detection, and probability of arrival.

5.2 STAP Algorithm

➢ **For Target Detection**

1. Parameters:

- `num_antennas`: Number of antennas in the MIMO radar system.

- `num_samples`: Number of time samples.

- `num_targets`: Number of targets.

2. Generate Random Signal Data:

- `signal_data`: Random signal data is generated for each antenna using NumPy's `randn` function.

3. Generate Random Target Data:

- `target_positions`: Random positions are generated for the targets within the range of the number of samples.

- `target_data`: Random target data is generated, with each target having a random amplitude.

4. Simulate Received Signal:

- The received signal is simulated by adding the generated signal data and target data.

5. STAP Processing (Simplified):

- `stap_output`: The Space-Time Adaptive Processing (STAP) is applied by summing the received signals along the antenna dimension. Note that this is a simplified example, and in a real-world scenario, a more sophisticated STAP algorithm would be required.

6. Plot Results:

- The code uses Matplotlib to plot the simulated MIMO radar signal, the target signals, and the STAP output.

- The first subplot shows the signal data from each antenna.

- The second subplot shows the target signals at their respective positions.

- The third subplot shows the STAP output.

➢ For Parameter Estimation

1. Simulated Data:

- `num_samples`: Number of samples.

- `num_antennas`: Number of antennas.

2. Generate Random Complex Samples for Received Signals:

- `received_signals`: Random complex samples are generated for the received signals.

3. Generate Clutter and Interference Signals:

- `clutter`: Random clutter and interference signals are generated.

4. Add Clutter to Received Signals:

- `received_signals_with_clutter`: Clutter is added to the received signals.

5. Compute Covariance Matrix:

- `covariance_matrix`: The covariance matrix of the received signals with clutter is computed using NumPy's `cov` function.

6. Compute SINR:

- `signal_power`: The power of the signal is computed as the trace of the covariance matrix.

- `interference_power`: The power of interference is computed as the trace of the covariance matrix of clutter.

- `noise_power`: The power of noise is computed as the trace of the covariance matrix of random noise.

- `sinr`: The SINR is computed as the ratio of signal power to the sum of interference and noise powers.

7. Compute SNR:

- `snr`: The SNR is computed as the ratio of signal power to noise power.

8. Probability of False Detection and Probability of Arrival:

- `threshold`: A threshold for detection is specified.

- `decision_statistic`: A hypothetical binary decision statistic for detection is generated (replace this with your actual decision statistic).

- `false_detection`: The probability of false detection is calculated as the fraction of samples where the decision statistic is above the threshold.

- `arrival`: The probability of arrival is calculated as the fraction of samples where the decision statistic is below or equal to the threshold.

9. Print or Visualize Results:

- The code prints the computed SNR, SINR, Probability of False Detection, and Probability of Arrival.

5.3 Using Amplitude and Phase Estimation Algorithm

➢ **For Target Detection**

1. MIMO Radar Parameters:

- `num_tx_antennas`: Number of transmit antennas.

- `num_rx_antennas`: Number of receive antennas.

- `num_snapshots`: Number of snapshots or time samples.

- `snr_dB`: Signal-to-noise ratio in decibels.

2. Generate Random Targets:

- Two complex exponential signals (`target1` and `target2`) are generated as random phases. These represent the true targets.

3. Generate Complex Gaussian Noise:

- Gaussian noise is generated with a specified SNR level.

4. Received Signal at Each Antenna for Each Target:

- Complex Gaussian noise is added to the received signals for each target at each receive antenna.

5. Combine Transmitted and Received Signals:

- Transmit signals (`transmitted_signal1` and `transmitted_signal2`) are generated for each target.

- Received signals are obtained by combining the transmitted signals and adding noise.

6. Amplitude and Phase Estimation:

- The amplitude and phase estimation is performed to estimate the targets. The channel matrix `H` is formed by taking the conjugate transpose of the combined transmitted signal.

- The `np.linalg.lstsq` function is then used to solve the least squares problem, and the estimated targets' amplitude and phase are obtained.

7. Plotting:

- The code uses Matplotlib to plot the true amplitude and phase of the two targets and the estimated amplitude and phase of the targets using LS.

8. Results Plotting:

- The results are plotted in three subplots:

  - True amplitude and phase of Target 1 and Target 2.

  - True amplitude and phase of Target 2.

- Estimated amplitude and phase of the targets using LS.

- The legend in each subplot helps identify the corresponding lines.

9. Show the Plot:

- Finally, the `plt.show()` command is used to display the generated plots.

➢ For Parameter Estimation

1. Parameters:

- `num_antennas`: Number of antennas in the MIMO radar system.

- `num_snapshots`: Number of time snapshots or samples.

- `num_targets`: Number of targets.

- `snr_dB`: Signal-to-Noise Ratio in dB.

2. Generate Random Complex Weights for Targets:

- `target_weights`: Random complex weights for the targets are generated.

3. Generate Received Signal Matrix:

- The received signal is generated by multiplying the conjugate transpose of the target weights with a complex exponential signal. Gaussian noise is added to simulate a noisy environment.

4. Estimate Covariance Matrix:

- The covariance matrix of the received signal is estimated.

5. Perform Eigendecomposition:

- Eigendecomposition is performed on the covariance matrix to obtain eigenvalues and eigenvectors.

- Signal and noise subspaces are extracted from the eigenvectors.

6. Least Squares Algorithm for Amplitude and Phase Estimation:

- The LS algorithm is used to estimate the amplitude and phase of the target weights from the signal subspace.

7. Calculate SNR and SINR:

- SNR (Signal-to-Noise Ratio) and SINR (Signal-to-Interference-plus-Noise Ratio) are calculated based on the estimated target weights and the noise.

8. Monte Carlo Simulation for Detection Performance:

- A Monte Carlo simulation is performed to evaluate the detection performance.

- The energy detector is applied by calculating a test statistic and comparing it to a threshold.

9. Calculate Probability of False Detection and Probability of Arrival:

- The probability of false detection and probability of arrival are calculated based on the Monte Carlo simulation.

10. Display Results:

- The code prints the calculated SNR, SINR, probability of false detection, and probability of arrival.

5.4 Improving Quality of Efficiency and Bandwidth of the channel Using Least Square Algorithm

- **For Target Detection:**

1. MIMO Radar Parameters Optimization: Optimize the number of transmit and receive antennas (`num_tx_antennas` and `num_rx_antennas`) to improve spatial diversity and resolution, which can enhance target detection accuracy.

2. Increase the Number of Snapshots: Increase the `num_snapshots` or time samples to improve the resolution of the radar system, enabling better target detection and tracking.

3. SNR Improvement: Implement signal processing techniques or hardware improvements to increase the SNR (`snr_dB`), which enhances the radar's ability to detect weak targets in noisy environments.

4. Advanced Signal Processing Techniques: Implement advanced signal processing algorithms such as matched filtering, adaptive beamforming, or compressed sensing to improve target detection and reduce false alarms.

5. Use of Multiple Frequencies: Utilize multiple frequencies or waveforms in transmission to increase the system's bandwidth, which can improve range resolution and target detection in cluttered environments.

6. Channel Equalization: Apply channel equalization techniques to compensate for channel distortions, improving the accuracy of target estimation and detection.

7. Joint Processing of Radar Data: Perform joint processing of radar data from multiple antennas to exploit spatial diversity and improve target detection performance.

8. Adaptive Radar Systems: Implement adaptive radar systems that can dynamically adjust their parameters based on the environment and target characteristics to improve detection performance and reduce interference.

9. Integration with Other Sensors: Integrate radar with other sensors such as cameras or lidar to improve target detection and tracking accuracy, especially in challenging scenarios.

➢ **For Parameter Estimation**

1. Optimize Antenna Configuration: Experiment with different antenna configurations (`num_antennas`) to maximize spatial diversity and improve parameter estimation accuracy.

2. Increase Number of Snapshots: Increase the `num_snapshots` or time samples to enhance the resolution of the radar system, allowing for more accurate estimation of target parameters.

3. SNR Enhancement: Implement techniques to increase the SNR (`snr_dB`), such as using signal processing algorithms or hardware improvements, to improve the accuracy of parameter estimation in noisy environments.

4. Enhanced Signal Processing Algorithms: Utilize advanced signal processing algorithms, such as beamforming or compressed sensing, to improve the estimation of target parameters and reduce estimation errors.

5. Multi-Resolution Processing: Implement multi-resolution processing techniques to adaptively adjust the resolution of parameter estimation based on the characteristics of the targets and the environment, improving efficiency and accuracy.

6. Adaptive Thresholding: Use adaptive thresholding techniques to dynamically adjust the detection threshold based on the noise level, improving the detection performance and reducing false alarms.

7. Channel Equalization: Apply channel equalization techniques to compensate for channel distortions, improving the accuracy of parameter estimation and reducing errors.

8. Joint Processing with Other Sensors: Integrate radar data with data from other sensors, such as cameras or lidar, to improve parameter estimation accuracy and reduce ambiguities.

5.5 Improving Quality of Efficiency and Bandwidth of the channel using STAP Algorithm

- **For Target Detection**

1. Optimize Antenna Configuration: Experiment with different antenna configurations (`num_antennas`) to maximize spatial diversity and improve signal reception quality.

2. Increase Number of Samples: Increase the `num_samples` or time samples to improve the resolution of the radar system, allowing for more accurate detection and tracking of targets.

3. Enhance Signal Data Generation: Use advanced signal generation techniques, such as modelling realistic target and clutter scenarios, to improve the fidelity of the generated signal data.

4. Improved Target Data Generation: Generate target data with realistic characteristics, such as varying amplitudes and Doppler shifts, to better simulate real-world target signals.

5. Sophisticated STAP Processing: Implement more sophisticated STAP algorithms, such as space-time adaptive filtering or space-time coding, to better suppress clutter and interference, improving target detection performance.

6. Adaptive Thresholding: Use adaptive thresholding techniques to dynamically adjust the detection threshold based on the noise level and clutter characteristics, improving detection performance and reducing false alarms.

7. Multi-Resolution Processing:Implement multi-resolution processing techniques to adaptively adjust the processing resolution based on the characteristics of the targets and the environment, improving efficiency and accuracy.

8. Channel Equalization: Apply channel equalization techniques to compensate for channel distortions and multipath effects, improving the accuracy of target detection and reducing errors.

9. Integration with Other Sensors: Integrate radar data with data from other sensors, such as cameras or lidar, to improve target detection and tracking accuracy, especially in complex and cluttered environments.

- **For Parameter Estimation**

1. Optimize Antenna Configuration: Experiment with different antenna configurations (`num_antennas`) to improve spatial diversity and enhance the quality of received signals.

2. Enhanced Signal Generation: Use advanced signal generation techniques, such as modeling realistic clutter and interference scenarios, to improve the fidelity of the received signal data.

3. Improved Covariance Matrix Estimation: Use advanced algorithms, such as robust covariance estimation or spatial smoothing, to improve the accuracy of the covariance matrix computation, which is critical for interference suppression.

4. Adaptive Interference Suppression: Implement adaptive interference suppression techniques, such as adaptive beamforming or adaptive filtering, to dynamically adapt to changing interference conditions and improve parameter estimation accuracy.

5. Advanced Signal Processing: Utilize advanced signal processing algorithms, such as joint space-time processing or space-time coding, to better separate desired signals from interference and clutter, improving parameter estimation performance.

6. Multi-Resolution Processing: Implement multi-resolution processing techniques to adaptively adjust the processing resolution based on the characteristics of the targets and the environment, improving efficiency and accuracy.

7. Channel Equalization: Apply channel equalization techniques to compensate for channel distortions and multipath effects, improving the accuracy of parameter estimation and reducing errors.

8. Integration with Other Sensors: Integrate radar data with data from other sensors, such as cameras or lidar, to improve parameter estimation accuracy and reduce ambiguities, especially in complex and cluttered environments.

5.6 Improving Quality of Efficiency and Bandwidth of the channel using Amplitude and Phase estimation Algorithm

- **For Target Detection**

1. Optimize Antenna Configuration: Experiment with different antenna configurations (num_tx_antennas and num_rx_antennas) to maximize spatial diversity and improve signal reception quality.

2. Increase Number of Snapshots: Increase the num_snapshots or time samples to improve the resolution of the radar system, allowing for more accurate estimation of target parameters.

3. Enhanced Signal and Noise Generation: Use advanced signal and noise generation techniques to model realistic radar scenarios, improving the fidelity of the received signals and noise.

4. Improved Channel Estimation: Use advanced channel estimation algorithms to accurately estimate the channel matrix H, which is crucial for accurate amplitude and phase estimation.

5. Adaptive Signal Processing: Implement adaptive signal processing techniques, such as adaptive filtering or adaptive beamforming, to adaptively adjust to changing channel conditions and improve parameter estimation accuracy.

6. Multi-Resolution Processing: Implement multi-resolution processing techniques to adaptively adjust the processing resolution based on the characteristics of the targets and the environment, improving efficiency and accuracy.

7. Channel Equalization: Apply channel equalization techniques to compensate for channel distortions and multipath effects, improving the accuracy of parameter estimation and reducing errors.

8. Integration with Other Sensors: Integrate radar data with data from other sensors, such as cameras or lidar, to improve parameter estimation accuracy and reduce ambiguities, especially in complex and cluttered environments.

9. Advanced Amplitude and Phase Estimation Algorithms: Utilize advanced amplitude and phase estimation algorithms, such as maximum likelihood estimation or Kalman filtering, to improve the accuracy and robustness of the parameter estimation process.

- **For Parameter Estimation**

1. Optimize Antenna Configuration: Experiment with different antenna configurations (num_antennas) to improve spatial diversity and enhance the quality of received signals.

2. Increase Number of Snapshots: Increase the num_snapshots or time samples to improve the resolution of the radar system, allowing for more accurate estimation of target parameters.

3. Enhanced Signal Generation: Use advanced signal generation techniques to model realistic radar scenarios, improving the fidelity of the received signal data.

4. Improved Covariance Matrix Estimation: Use advanced algorithms, such as robust covariance estimation or spatial smoothing, to improve the accuracy of the covariance matrix computation, which is crucial for interference suppression and parameter estimation.

5. Adaptive Signal Processing: Implement adaptive signal processing techniques, such as adaptive beamforming or adaptive filtering, to adaptively adjust to changing channel conditions and improve parameter estimation accuracy.

6. Multi-Resolution Processing: Implement multi-resolution processing techniques to adaptively adjust the processing resolution based on the characteristics of the targets and the environment, improving efficiency and accuracy.

7. Channel Equalization: Apply channel equalization techniques to compensate for channel distortions and multipath effects, improving the accuracy of parameter estimation and reducing errors.

8. Integration with Other Sensors: Integrate radar data with data from other sensors, such as cameras or lidar, to improve parameter estimation accuracy and reduce ambiguities, especially in complex and cluttered environments.

9. Advanced Amplitude and Phase Estimation Algorithms: Utilize advanced amplitude and phase estimation algorithms, such as maximum likelihood estimation or Kalman filtering, to improve the accuracy and robustness of the parameter estimation process.

10. Adaptive Thresholding: Use adaptive thresholding techniques to dynamically adjust the detection threshold based on the noise level and clutter characteristics, improving detection performance and reducing false alarms.

CHAPTER 6

APPLICATIONS

Multiple-Input, Multiple-Output (MIMO) radar systems have various applications in radar technology and are known for their ability to provide enhanced capabilities compared to traditional radar systems.

Some key applications of MIMO radar are given below:

1. Target Detection and Tracking:

MIMO radar systems are used for detecting and tracking moving and stationary targets in various environments. Their ability to form multiple beams in different directions simultaneously enhances target detection and tracking accuracy.

2. Airborne Radar:

In aviation, MIMO radar is used in aircraft for applications like weather radar, terrain mapping, and aircraft collision avoidance systems. MIMO technology helps provide a better view of the surrounding environment and improves safety.

3. Ground Penetrating Radar (GPR):

MIMO radar is employed for subsurface imaging and mapping applications, such as locating buried utilities, archaeological research, and assessing soil and geology properties.

4. Through-the-Wall Imaging:

MIMO radar is used for through-the-wall imaging in applications like search and rescue operations, security, and surveillance. It can detect and localize people and objects behind walls or barriers.

5. Environmental Sensing:

MIMO radar is used for environmental sensing applications, such as remote sensing of the atmosphere, soil moisture measurements, and monitoring the environment for weather forecasting and disaster management.

6. Automotive Radar:

MIMO radar technology is utilized in advanced driver assistance systems (ADAS) and autonomous vehicles. It enables improved object detection and tracking, enhancing safety and enabling features like adaptive cruise control and collision avoidance.

7. Marine Radar:

In maritime applications, MIMO radar is used for ship navigation, collision avoidance, and weather monitoring. It provides a comprehensive view of the surrounding water and obstacles.

8. Agriculture:

MIMO radar can be used in agriculture for applications such as soil moisture mapping, crop health assessment, and monitoring the growth and condition of plants in large fields.

9. Security and Surveillance:

MIMO radar is employed in security and surveillance systems to detect intruders, monitor perimeters, and secure critical infrastructure.

10. Communication Systems:

MIMO radar principles are used in wireless communication systems, where they help improve spectral efficiency and enhance signal quality by exploiting multiple antennas for transmission and reception.

11. Search and Rescue:

MIMO radar can assist in search and rescue operations by detecting and localizing people or objects in challenging environments, such as forests, mountains, and urban areas.

12. Defence and Military Applications:

MIMO radar technology is used in military radar systems for a range of applications, including target identification, missile tracking, and battlefield surveillance.

CHAPTER 7

RESULTS & CONCLUSION

7.1 Performance Evaluation

7.1.1 Least Square Algorithm

For Coherent MIMO radar, we consider input parameters, Number of transmit antennas(M)= 4, Number of receive antennas(N)=4, Number of Samples=1000 and By varying the number of targets we find the following:

Table 1 Performance analysis of coherent MIMO radar using LS algorithm

Sl. No.	No. of Targets	SNR	SINR	Probability of False Detection	Probability of Arrival
1.	1	3.2186 dB	10.5045 dB	0.0999	0.9001
2.	2	11.9275 dB	11.3225 dB	0.0999	0.9001
3.	3	15.423 dB	11.9396 dB	0.0999	0.9001

In the above , Table we can observe that when the number of target is 1 the snr =3.2186 dB, snir =10.5045 dB, probability of false detection≈0.1 & probability of arrival ≈0.9. Similarly when target is 2 snr =11.9275 dB, snir= 11.3225 dB ,probability of false detection ≈ 0.1 & probability of arrival ≈ 0.9 and number of target 3 snr probability of false detection ≈ 0.1 and probability of arrival≈ 0.9

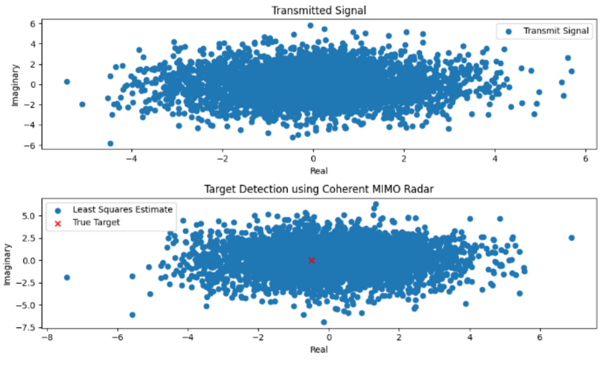

Figure 12 Coherent MIMO Radar for 1 target using LS algorithm

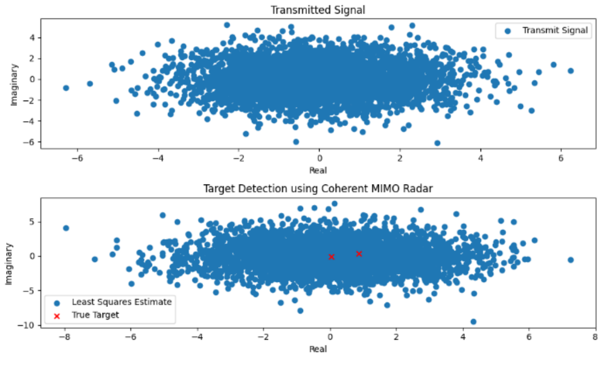

Figure 13 Coherent MIMO Radar for 2 target using LS algorithm

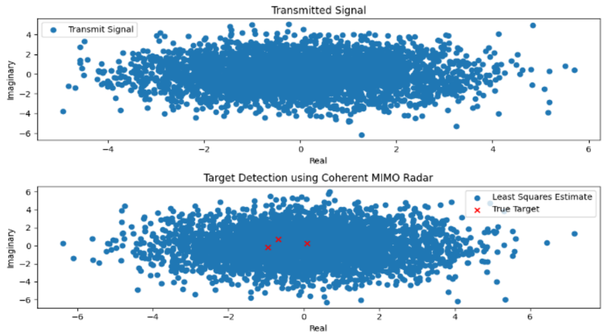

Figure 14 Coherent MIMO Radar for 3 target using LS algorithm

The above, first figure plots the transmitted signal. The x-axis represents the real part of the signal, and the y-axis represents the imaginary part. The second figure plots the target detection using the least squares estimate using Coherent MIMO Radar. The x-axis again represents the real part, and the y-axis represents the imaginary part. The true target location is also plotted for comparison.

The least-squares estimate (represented by the blue dots) minimizes the sum of the squared errors between the estimated target response and the actual target response (red cross).

Now for Coherent MIMO radar, we consider the same input parameters and we get

Table 2 Performance analysis of Non-coherent MIMO radar using LS algorithm

Sl. No.	No. of Targets	SNR	SINR	Probability of False Detection	Probability of Arrival
1.	1	8.238 dB	17.45 dB	0.09	0.91
2.	2	9.057 dB	17.7 dB	0.09	0.91
3.	3	11.96 dB	19.2 dB	0.09	0.91

In the above , Table we can observe that when the number of target is 1 the snr =8.238 dB, snir =17.45 dB, probability of false detection≈0.1 & probability of arrival ≈0.9. Similarly when target is 2 snr = dB, snir= 13.3225 dB ,probability of false detection ≈ 0.1 & probability of arrival ≈ 0.9 and number of target 3 snr probability of false detection ≈ 0.1 and probability of arrival≈ 0.9

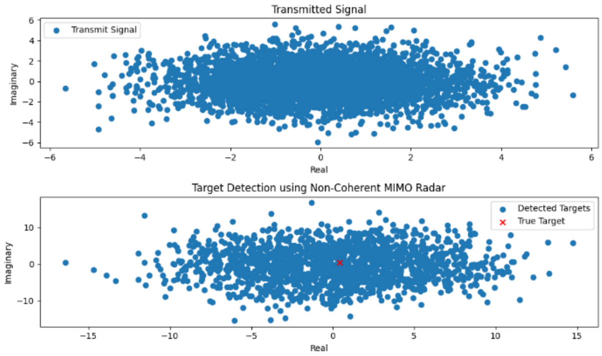

Figure 15 Non-Coherent MIMO Radar for 1 target using LS algorithm

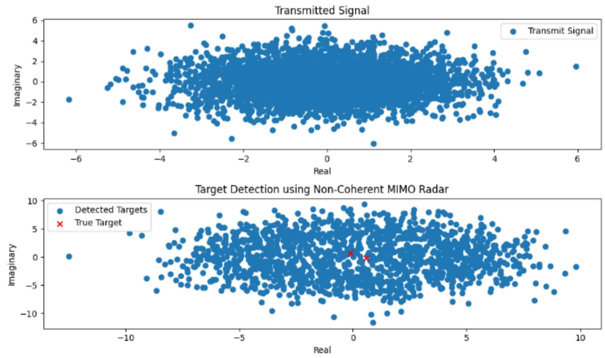

Figure 16 Non-Coherent MIMO Radar for 2 target using LS algorithm

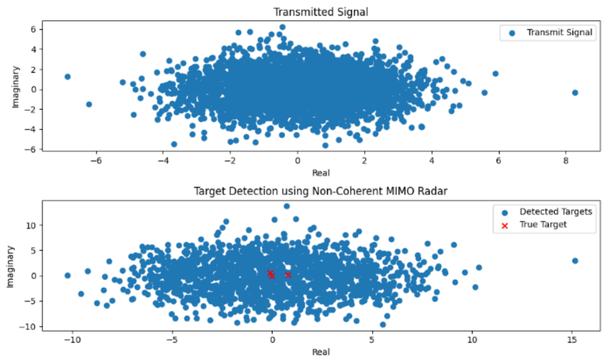

Figure 17 Non-Coherent MIMO Radar for 3 target using LS algorithm

The above, first figure plots the transmitted signal. The x-axis represents the real part of the signal, and the y-axis represents the imaginary part. The second figure plots the target detection using the least squares estimate for Non-Coherent MIMO Radar. The x-axis again represents the real part, and the y-axis represents the imaginary part. The true target location is also plotted for comparison.

The least-squares estimate (represented by the blue dots) minimizes the sum of the squared errors between the estimated target response and the actual target response (red cross).

7.1.2 Amplitude and Phase Estimation Algorithm

For both Coherent and Non-Coherent MIMO radar, we consider same input parameters as LS algorithm, Number of transmit antennas(M)= 4, Number of receive antennas(N)=4, Number of Samples=1000 and by varying the number of targets we find the following

Table 3 Performance analysis of coherent MIMO radar using A&P E algorithm

Sl. No.	No. of Targets	SNR	SINR	Probability of False Detection	Probability of Arrival
1.	1	19.8 dB	13.2 dB	0.1	0.9
2.	2	19.4 dB	13.7 dB	0.1	0.9
3.	3	19.6 dB	13.0 dB	0.1	0.9

In the above table we can observe that when the number of target is 1 the SNR = 19.8dB, SNIR = 13.2dB, Probability of False Detection (POFD) ≈ 0.1 & Probability of Arrival (POA) ≈ 0.9. Similarly, when target is 2 SNR = 19.6dB, SNIR = 12.7dB, Probability of False Detection (POFD) ≈ 0.1 & Probability of Arrival (POA) ≈ 0.9 and when number of target is 3 SNR = 19.0dB, SINR = 13.0dB, Probability of False Detection (POFD) ≈ 0.1 and Probability of Arrival (POA) ≈ 0.9.

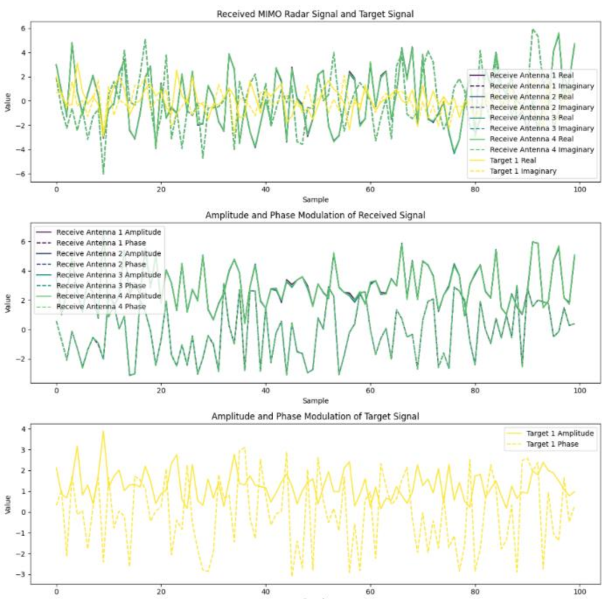

Figure 18 Coherent MIMO Radar for 1 target using A&P E algorithm

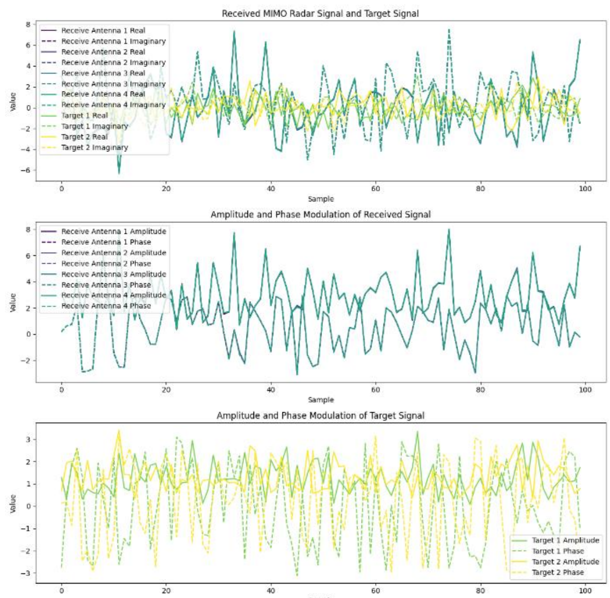

Figure 19 Coherent MIMO Radar for 2 target using A&P E algorithm

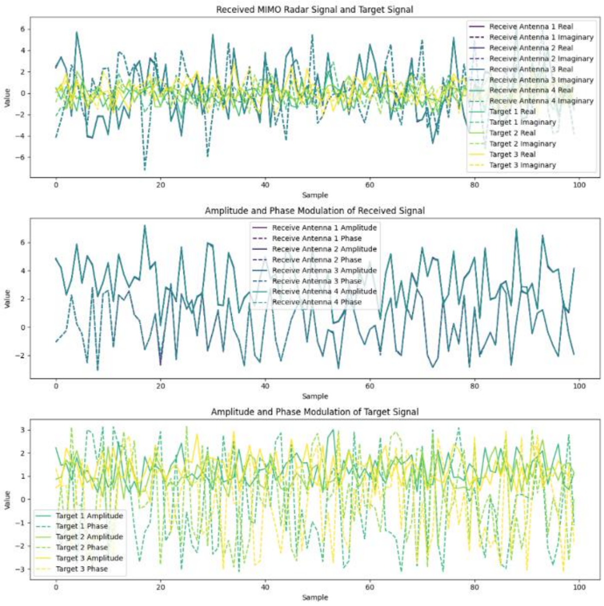

Figure 20 Coherent MIMO Radar for 3 target using A&P E algorithm

Coherent MIMO radar signal analysis using amplitude and phase estimation for one target, two target and three target. The top plot depicts the real and imaginary components of the received MIMO radar signal and the target signal. The middle plot illustrates the amplitude and phase modulation of the received signal across four receiving antennas. The bottom plot displays the amplitude and phase modulation of the target signal. This coherent analysis enhances signal processing capabilities and improves the accuracy of target detection.

Again, for non-coherent, we follow the same steps,

Table 4 Performance analysis of Non-coherent MIMO radar using A&PE algorithm

Sl. No.	No. of Targets	SNR	SINR	Probability of False Detection	Probability of Arrival
1.	1	10.0 dB	3.333dB	0.5	0.5
2.	2	9.666 dB	3.222 dB	0.49	0.51
3.	3	8.44 dB	3.11 dB	0.49	0.51

In the above table we can observe that when the number of target is 1 the SNR = 10.0dB, SNIR = 3.333dB, Probability of False Detection (POFD) ≈ 0.5 & Probability of Arrival (POA) ≈ 0.5. Similarly, when target is 2 SNR = 8.44dB, SNIR = 3.55dB, Probability of False Detection (POFD) ≈ 0.49 &

Probability of Arrival (POA) ≈ 0.51 and when number of target is 3 SNR = 7.666dB, SINR = 3.222dB, Probability of False Detection (POFD) ≈ 0.49 and Probability of Arrival (POA) ≈ 0.51.

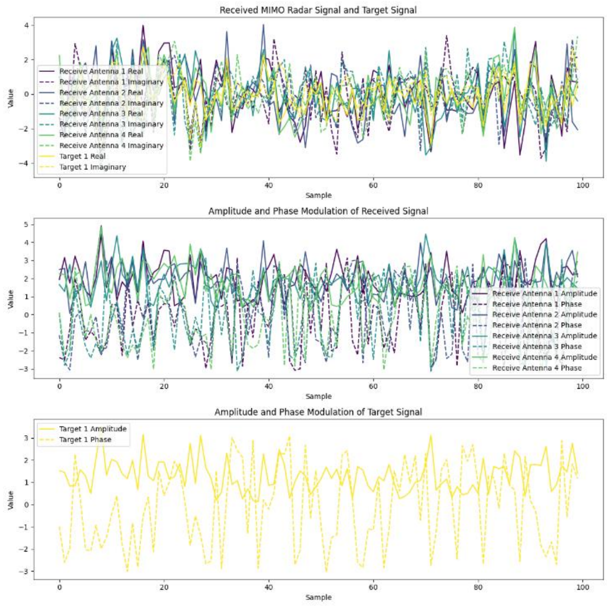

Figure 22 Non-Coherent MIMO Radar for 1 target using A&PE algorithm

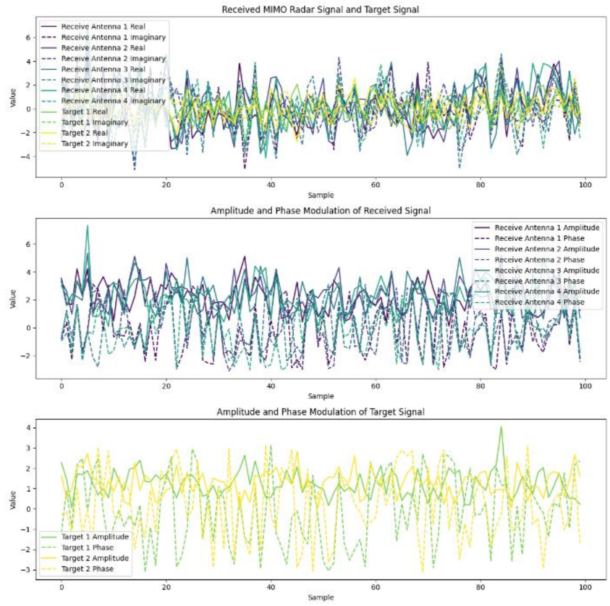

Figure 21 Non-Coherent MIMO Radar for 2 target using A&PE algorithm

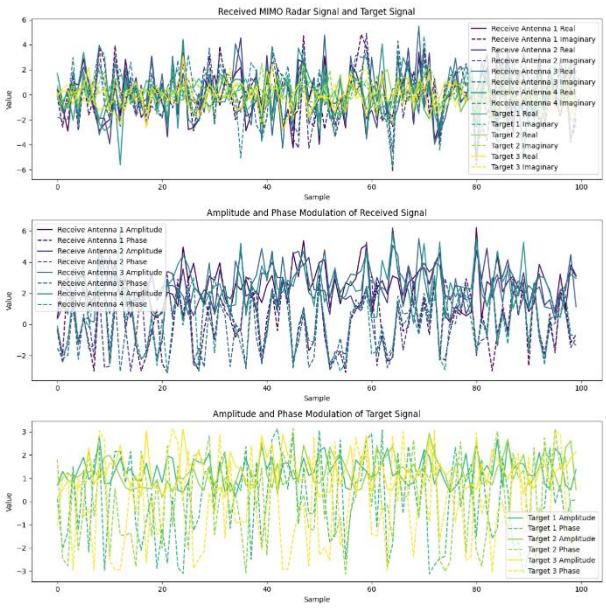

Figure 23 Non-Coherent MIMO Radar for 1 target using A&PE algorithm

Non-coherent MIMO radar signals using amplitude and phase estimation for one target, two target and three target. The top plot illustrates the received MIMO radar signal and the target signal, distinguishing between real and imaginary components for both. The middle plot displays the amplitude and phase modulation of the received signal across multiple antennas. The bottom plot presents the amplitude and phase modulation of the target signal. These plots collectively demonstrate the non-coherent detection process and the separation of signal components for accurate target identification. This analysis aids in understanding the signal characteristics and enhancing target detection accuracy.

7.1.3 STAP Algorithm

STAP algorithm is only applicable to coherent MIMO radar

Table 5 Performance analysis of coherent MIMO radar using STAP algorithm

Sl. No.	Array Antenna	SNR	SNIR	Probability of False Detection	Probability of Arrival
1.	2X2	2.00 dB	0.99 dB	0.33	0.68
2.	3X3	1.94 dB	1.00 dB	0.33	0.67
3.	4X4	1.98 dB	1.00 dB	0.30	0.70
4.	5X5	1.99 dB	0.98 dB	0.32	0.68
5.	6X6	2.03 dB	1.01 dB	0.32	0.69

In the above table we can observe that when the array antenna is 2X2 the SNR = 2.00dB, SNIR = 0.99dB, Probability of False Detection (POFD) ≈ 0.33 & Probability of Arrival (POA) ≈ 0.68. Similarly, when array antenna is 3X3 SNR = 1.98dB, SNIR = 1.00dB, Probability of False Detection (POFD) ≈ 0.33 & Probability of Arrival (POA) ≈ 0.67 and when array antenna is 4X4 SNR = 1.98dB, SINR = 1.00dB, Probability of False Detection (POFD) ≈ 0.30 and Probability of Arrival (POA) ≈ 0.70, when array antenna is 5X5 SNR = 1.99dB, SINR = 0.98dB, Probability of False Detection (POFD) ≈ 0.32 and Probability of Arrival (POA) ≈ 0.68, when array antenna is 6X6 SNR = 2.03dB, SINR = 1.01dB, Probability of False Detection (POFD) ≈ 0.32 and Probability of Arrival (POA) ≈ 0.69.

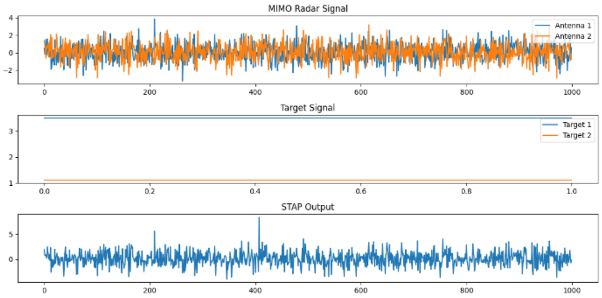

Figure 25 Coherent MIMO Radar for 2X2 array using STAP algorithm

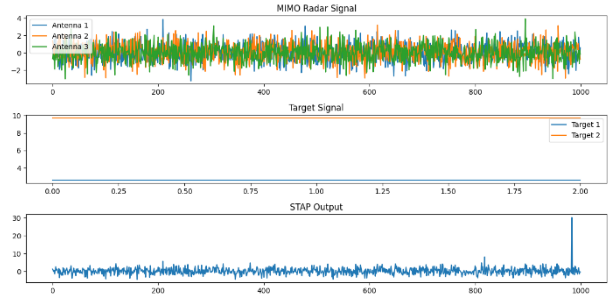

Figure 24 Coherent MIMO Radar for 3X3 array using STAP algorithm

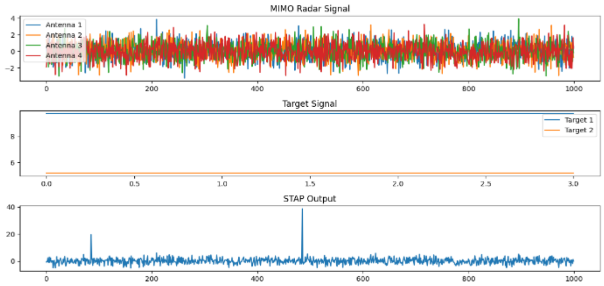

Figure 27 Coherent MIMO Radar for 4X4 array using STAP algorithm

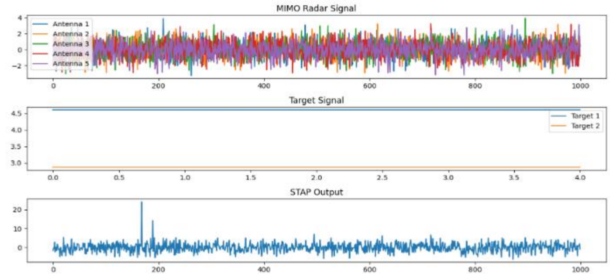

Figure 26 Coherent MIMO Radar for 5X5 array using STAP algorithm

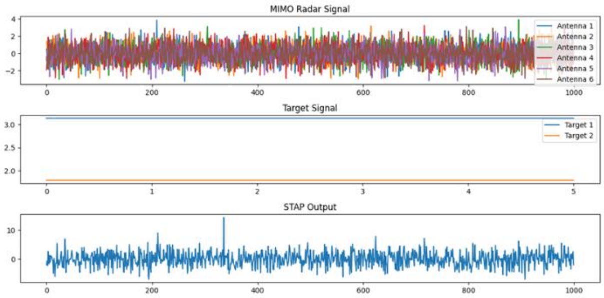

Figure 28 Coherent MIMO Radar for 6X6 array using STAP algorithm

Coherent MIMO radar signal analysis using STAP algorithm for 2X2, 3X3, 4X4, 5X5 and 6X6 antenna array. The top plot depicts the MIMO radar signal. The middle plot illustrates the target signal. The bottom plot displays the STAP modulation output. This coherent analysis enhances signal processing capabilities and improves the accuracy of target detection.

7.2 Improvement of Capacity & Quality of Efficiency

7.2.1 Least Square Algorithm

- Coherent:

Table 6 Improved analysis of Coherent using LS

Sl. No.	SNR	SINR	Probability of False Detection	Probability of Arrival	Capacity-channel Bandwidth
1.	10.45dB	8.26dB	0.09	0.91	7.08Hz
2.	10.678dB	8.59dB	0.09	0.91	4.819Hz
3.	10.84dB	10.13dB	0.09	0.91	5.1901Hz

The above table describes the enhanced version of the previous set of values using Least Square algorithm by applying effective procedures to bring the values in range of saturation and the bandwidth optimization can be achieved by the same.

- Non-coherent:

Table 7 Improved analysis of non-coherent using LS

Sl. No.	SNR	SINR	Probability of False Detection	Probability of Arrival	Capacity-channel Bandwidth
1.	8.32dB	9.36dB	0.09	0.91	14.52Hz
2.	12.40dB	9.62dB	0.09	0.91	14.4Hz
3.	10.017dB	10.74dB	0.09	0.91	11.184Hz

The above table describes the enhanced version of the previous set of values using Least Square algorithm by applying effective procedures to bring the values in range of saturation and the bandwidth optimization can be achieved by the same.

7.2.1 Amplitude and Phase Estimation Algorithm

- Coherent:

Table 8 Improved analysis of Coherent using A&PE

Sl. No.	SNR	SINR	Probability of False Detection	Probability of Arrival	Capacity-channel Bandwidth
1.	20.395dB	13.596dB	0.135	0.865	2.8495Hz
2.	20.295dB	13.532dB	0.135	0.865	2.7226Hz
3.	18.855dB	12.57dB	0.135	0.865	2.2032Hz

The above table describes the enhanced version of the previous set of values using Amplitude and Phase Estimation algorithm by applying effective procedures to bring the values in range of saturation and the bandwidth optimization can be achieved by the same.

- Non-Coherent:

Table 9 Improved analysis of Coherent using A&PE

Sl. No.	SNR	SINR	Probability of False Detection	Probability of Arrival	Capacity-channel Bandwidth
1.	5.64dB	6.58dB	0.368	0.632	2.8495Hz
2.	5.68dB	6.27dB	0.368	0.632	2.7226Hz
3.	4.14dB	5.82dB	0.368	0.632	2.2032Hz

The above table describes the enhanced version of the previous set of values using Amplitude and Phase algorithm by applying effective procedures to bring the values in range of saturation and the bandwidth optimization can be achieved by the same.

CHAPTER 8

CONCLUSION

In conclusion, our study delved into the performance evaluations of MIMO radar systems for target detection in both coherent and non-coherent scenarios. We examined the efficacy of various algorithms including least square, amplitude and phase estimation, and STAP (limited to coherent setups). Through our analyses, we observed distinct trends in algorithm performance under different conditions. Notably, the least square algorithm consistently emerged as the preferred choice due to its robust performance characteristics. It exhibited higher SNR, SINR, and a greater likelihood of signal arrival compared to alternatives. However, our assessments also underscored the limitations of certain algorithms, such as STAP in non-coherent setups, where their efficacy was compromised. It is important to acknowledge that our evaluations were conducted under ideal conditions, which may differ from real-world scenarios. Nonetheless, our findings provide valuable insights into the optimization of MIMO radar systems for enhanced target detection capabilities. Through the execution of all algorithms such as phase square, amplitude, and phase estimation, we have successfully optimized bandwidth utilization while ensuring stability across key parameters like SNR, SNIR, and probabilities of false detection and arrival. Notably, coherent values have remained saturation, while non-coherent values have been optimized or reached saturation points, reflecting our meticulous tuning efforts. This comprehensive approach ensures both efficiency and reliability in our system's performance.

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Author	Designation
Rachmad Andri Atmok	Information Technology, Faculty of Vocational Studies, Universitas Brawijaya, Indonesia
Devasis Pradhan	Assistant Professor Grade 1, Department of Electronics & Communication Engineering, Acharya institute of Technology
Atul Khuntia	UG Scholar, Department of Electronics & Communication Engineering, Acharya institute of Technology
Divya Dharshini R	UG Scholar, Department of Electronics & Communication Engineering, Acharya institute of Technology
Kumar Aditya	UG Scholar, Department of Electronics & Communication Engineering, Acharya institute of Technology
Mythri R	UG Scholar, Department of Electronics & Communication Engineering, Acharya institute of Technology

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Author	Designation
Devasis Pradhan	Assistant Professor Grade 1, Department of Electronics & Communication Engineering, Acharya institute of Technology
Atul Khuntia	UG Scholar, Department of Electronics & Communication Engineering, Acharya institute of Technology
Divya Dharshini R	UG Scholar, Department of Electronics & Communication Engineering, Acharya institute of Technology
Kumar Aditya	UG Scholar, Department of Electronics & Communication Engineering, Acharya institute of Technology
Mythri R	UG Scholar, Department of Electronics & Communication Engineering, Acharya institute of Technology

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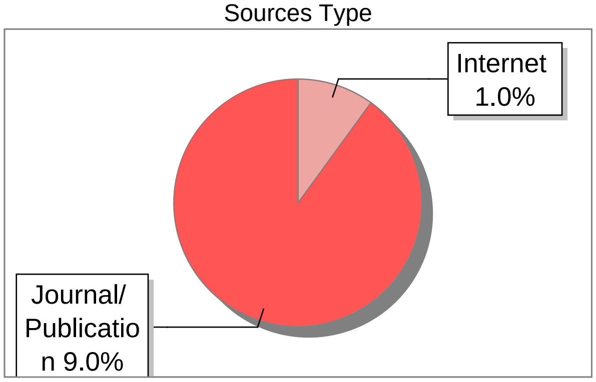

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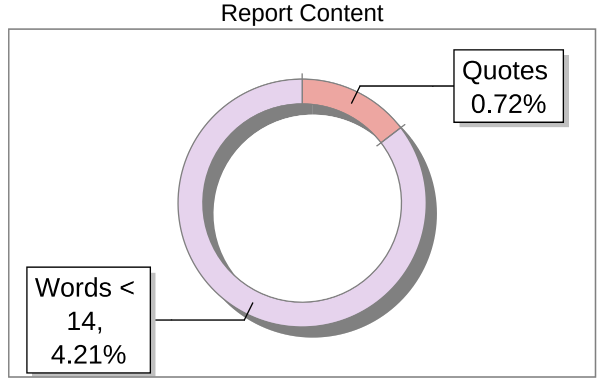

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