

Radar Signal Processing: A Comprehensive Review

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Abstract—Signal processing is at the heart of modern radar system functionality, enabling the accurate extraction of target information in environments filled with clutter and noise. This article presents a comprehensive review of the evolution and current state of radar signal processing techniques, ranging from fundamental principles to cutting-edge innovations. The discussion begins by dissecting the basic framework of data processing, including waveform design, pulse compression, and processing of the radar data cube. We evaluate classical detection algorithms such as Constant False Alarm Rate (CFAR) and super-resolution parameter estimation techniques. Furthermore, this article examines advancements in array processing, particularly in Multiple-Input Multiple-Output (MIMO) systems and Space-Time Adaptive Processing (STAP), which are crucial for mitigating complex interference. A key part of this review highlights the integration of Machine Learning and Deep Learning into cognitive radar schemes, as well as the emergence of Compressive Sensing technology for data efficiency. We also explore new paradigms such as radar-communication convergence (RadCom) within the 6G ecosystem and the potential of quantum radar. In conclusion, this article identifies open challenges, including interference management in automotive radar and the need for real-time computation for targets with low Radar Cross Section (RCS), to provide strategic guidance for future research.

Keywords— Radar Signal Processing, MIMO Radar, CFAR Detection, Machine Learning, Waveform Design, Radar Data Cube.

I. INTRODUCTION

Radar (Radio Detection and Ranging) systems have undergone a paradigm shift since they were first used for military applications in the early 20th century [2]. While radar initially served merely as a tool for detecting the presence of simple objects, modern radar has now evolved into an intelligent sensor capable of high-precision target classification, high-resolution imaging, and multi-target tracking in highly noisy environments. The heart of this transformation lies not merely in the antenna hardware, but in Radar Signal Processing (RSP)—the algorithms and mathematical techniques that translate raw electromagnetic waves into actionable information [1].

1.1. The Evolution of Radar Context

Over the past decade, the scope of radar applications has expanded beyond defense and maritime navigation.

The emergence of autonomous vehicles has established radar as a critical sensor for driving safety due to its ability to operate in all weather conditions. Additionally, the integration of radar into contactless health monitoring (such as heart rate and respiration detection) and satellite-based weather monitoring demonstrates the flexibility of this technology. However, the expansion of these applications brings new challenges: high spectrum density, the need for higher resolution, and demands for power efficiency in mobile devices.

1.2. The Role of Signal Processing

Modern radar signal processing is no longer limited to simple linear filters. With the introduction of concepts such as Digital Beamforming, Multiple-Input Multiple-Output (MIMO) [4][5], and adaptive processing [6], we are now able to manipulate the spatial, temporal, and frequency domains simultaneously. The primary challenge today lies in how to extract weak signals from targets with a small Radar Cross Section (RCS), such as drones or stealth materials, amidst ground clutter and interference from other wireless devices.

1.3. Scope and Contribution of this Review

Although there is already a vast body of literature on radar, the rapid pace of innovation in artificial intelligence (AI) and quantum technology calls for a review that integrates classical techniques with future trends. This article aims to:

- Review the fundamental principles of radar data cubes and waveform design.
- Analyze the effectiveness of the latest detection and parameter estimation algorithms.
- Discuss the role of Deep Learning and Compressive Sensing in addressing computational limitations.
- Map out future research directions, including radar-communication convergence within the 6G ecosystem [8].

II. THEORY

The foundation of radar signal processing lies in the system's ability to transmit electromagnetic waves and analyze the echoes received from targets. This section summarizes the key elements that form the framework of modern signal processing.

2.1. Radar Equation and Signal Model

The fundamental principle of radar is based on the radar equation, which relates transmit power (P_t), antenna gain (G), target range (R), and the target's Radar Cross Section (RCS) (σ). The received signal ($y(t)$) can be mathematically represented as a time-delayed and frequency-shifted version of the transmitted signal ($x(t)$), as shown in Equation 1.

$$y(t) = \alpha \cdot x(t - \tau) e^{j2\pi f_d t} + n(t) \quad [1]$$

Where $\tau = 2R/c$ is the time delay, f_d is the Doppler shift caused by the target's relative velocity, and $n(t)$ represents additive white Gaussian noise (AWGN) [1].

2.2. Waveform Design and Pulse Compression

The wave design determines the radar's resolution and detection capability.

- **Linear Frequency Modulation (LFM):** The most common technique in which the signal frequency is linearly swept over the pulse duration. This allows for the use of long pulses for high energy while maintaining sharp range resolution through Pulse Compression.
- **Frequency Modulated Continuous Wave (FMCW):** Often used in short-range radar (such as automotive radar) because it allows for simultaneous range and velocity measurement with low hardware complexity.
- **Phase-Coded Waveforms:** Uses binary or polyphase codes (e.g., Barker or Polyphase codes) to modulate the signal's phase, providing low probability of intercept (LPI) characteristics.

2.3. The Radar Data Cube

The most crucial concept in modern digital processing is the Radar Data Cube. Data received after digitization is organized into a three-dimensional matrix:

- **Fast-time (Range):** Samples taken within a single pulse duration.
- **Slow-time (Doppler):** Samples taken from pulse to pulse within a single Coherent Processing Interval (CPI).
- **Spatial (Azimuth/Elevation):** Data collected from various antenna elements in a phased array or MIMO system. Organizing the data into this cube enables the sequential application of the FFT (Fast Fourier Transform) algorithm to separate targets based on distance, velocity, and angle of arrival (AoA).

2.4. Matched Filtering

Matched filtering is an optimal signal processing technique for maximizing the Signal-to-Noise Ratio (SNR) in the presence of noise. Mathematically, this is achieved by convolving the received signal with the complex conjugate of the transmitted signal. The result of this process is a correlation peak that indicates the target's time position (distance) with high precision.

III. METHODS

3. Core Processing Algorithms

After the digital signals are received and organized into the Radar Data Cube, core processing algorithms are applied to separate targets from environmental clutter and background noise.

3.1. Pulse Compression and Matched Filtering

The first step in the processing chain is to improve range resolution without sacrificing the signal-to-noise ratio (SNR) [2] [17].

- **Matched Filter:** This algorithm compares the received signal with a reference of the transmitted signal. Mathematically, this maximizes the peak power of the target relative to the noise.
- **Windowing:** To reduce sidelobes that can obscure small targets near large targets, windowing techniques (such as Hamming or Taylor) are often applied, although there is a slight reduction in range resolution.

3.2. Constant False Alarm Rate (CFAR) Detection

Target detection cannot be performed using a fixed threshold because noise and clutter levels are constantly changing. The CFAR algorithm adaptively calculates the threshold based on the statistics of the cells surrounding the cell under test (CUT).

- **CA-CFAR (Cell Averaging):** Assumes a homogeneous noise environment. Highly efficient but performs poorly with closely spaced targets.
- **OS-CFAR (Order Statistics):** Sorts noise samples and selects specific values as representations. More robust in multi-target scenarios and with sharp clutter transitions.

3.3. Doppler Processing and MTI

To distinguish moving targets from stationary objects (such as trees or buildings), radar uses Doppler frequency shift.

- **Moving Target Indicator (MTI):** A simple high-pass filter that suppresses signals with zero Doppler shift (stationary objects).
- **Pulse Doppler Processing:** Uses FFT along the slow-time dimension to map targets into specific velocity bins. This allows for target separation based on their radial velocity.

3.4. Parameter Estimation and Super-Resolution

Once a target is detected, parameters such as range (R), velocity (v), and angle of arrival (Θ) must be estimated with high precision [1].

- **FFT-based Estimation:** Fast but limited by the Rayleigh resolution (bin width).
- **Super-Resolution Algorithms:** Techniques such as MUSIC (Multiple Signal Classification) and ESPRIT enable the separation of targets within the same resolution bin by utilizing signal-space and noise-space decompositions.

3.5. Tracking Algorithms

After initial detection, the tracking algorithm ensures the continuity of the target's identity from one processing interval to the next.

- Kalman Filter: The industry standard for estimating target state (position and velocity) under linear noise conditions.
- Interacting Multiple Models (IMM): Used for targets performing sudden maneuvers, by combining multiple dynamic models simultaneously.

4. Advanced Array Processing

Advanced array processing enables the radar to precisely determine the target's direction of arrival (DOA), mitigate interference, and improve angular resolution without significantly increasing the physical size of the antenna.

4.1. Digital Beamforming (DBF)

Digital beamforming replaces analog phase shifters with digital processing to form a "beam" of sensitivity in a specific direction.

- Receive Beamforming: The signal from each antenna element is multiplied by a complex weight (w) and summed. This allows for the simultaneous formation of multiple beams to monitor the entire space without the need to mechanically rotate the antenna.
- Adaptive Beamforming: Uses algorithms such as Minimum Variance Distortionless Response (MVDR) to automatically place the null (zero sensitivity point) in the direction of the interference source or jammer, while maintaining maximum gain toward the target.

4.2. Multiple-Input Multiple-Output (MIMO) Radar

One of the most significant innovations of the past two decades is MIMO radar. Unlike traditional phased arrays, which transmit coherent waves, MIMO radar transmits orthogonal waves from each transmitter element.

- Virtual Aperture: With M transmitters and N receivers, MIMO radar can simulate a virtual array with $M \times N$ elements. This drastically improves angular resolution.
- Statistical MIMO vs. Coherent MIMO: Statistical MIMO leverages spatial diversity to address fluctuations in target RCS, while Coherent MIMO focuses on improving spatial resolution.

4.3. Space-Time Adaptive Processing (STAP)

STAP is a two-dimensional processing technique that combines the spatial (antenna) and temporal (Doppler pulse) domains. This technique is vital for airborne radar.

- Clutter Mitigation: In moving radar systems, the ground clutter spectrum shifts according to the angle of incidence and the platform's velocity. STAP is capable of distinguishing moving targets from clutter with similar Doppler characteristics by utilizing spatial-temporal correlation.
- Complexity Challenges: The main challenges of STAP are the massive computational requirements and the need

for accurate covariance matrix estimation in a non-stationary environment.

4.4. Compressive Sensing (CS) in Arrays

Compressive sensing is applied to array processing to reconstruct spatial information from far fewer samples than required by the Nyquist theorem.

- Sparse Arrays: Enables the use of randomly placed or sparsely arranged antenna elements (thinned arrays) to achieve high resolution at a lower hardware cost.
- Recovery Algorithms: Uses L1 optimization techniques (such as Orthogonal Matching Pursuit) to find target estimates in a sparse angular domain.

5. Emerging Trends & Future Directions

As the demand for smarter and more efficient sensors grows, radar signal processing is undergoing a paradigm shift from rule-based algorithms toward cognitive and spectrum-integrated systems. [13,14,15]

5.1. Machine Learning and Deep Learning in Radar

The integration of Artificial Intelligence (AI) has transformed how radar classifies targets and manages resources [7].

- Automatic Target Recognition (ATR): The use of Convolutional Neural Networks (CNNs) on Doppler spectrograms or ISAR (Inverse Synthetic Aperture Radar) images to distinguish between pedestrians, vehicles, or drones with accuracy far surpassing that of classical statistical methods.
- Deep Unrolling: A new technique that transforms iterative algorithms (such as Compressive Sensing) into neural network structures to accelerate real-time signal reconstruction.
- Cognitive Radar: The implementation of Reinforcement Learning that enables radar to autonomously adjust transmission parameters (frequency, pulse duration) based on feedback from a dynamic environment. [16,17,18]

5.2. Integrated Sensing and Communications (ISAC)

As we move toward the 6G era, the distinction between communication devices and radar is beginning to blur. The ISAC (or RadCom) concept proposes using the same infrastructure for both functions.

- Joint Waveform Design: A single waveform design (e.g., OFDM-based) capable of carrying data while also serving as a radar probing signal.
- Spectrum Sharing: Signal processing algorithms capable of mitigating mutual interference between cellular base stations and radar sensors operating in the same frequency band (e.g., the millimeter-wave band). [19,20,21,22]

5.3. Quantum Radar and Quantum Signal Processing

Although still in the experimental stage, quantum radar promises a major leap in detection sensitivity [11].

- **Quantum Illumination:** Uses entangled photons to detect targets in environments with extremely high noise levels. Signal processing here focuses on exploiting quantum correlations that are not present in classical signals.
- **Enhanced Stealth Detection:** The potential to detect objects with extremely low RCS that have previously been "invisible" to conventional radar.

5.4. Compressive Sensing and Sparse Processing

To address the data explosion in high-resolution radar (such as 4D imaging), Compressive Sensing (CS) has emerged as the primary solution.

- **Sub-Nyquist Sampling:** Enables signal acquisition at sampling rates below the Nyquist limit without losing important information, which is crucial for reducing the load on the Analog-to-Digital Converter (ADC) and storage memory. [23,24,25]

5.5. Radar on Chip and Automotive Evolution

The trend toward miniaturization is bringing complex signal processing to the System-on-Chip (SoC) level.

- **4D Imaging Radar:** The addition of the elevation dimension to automotive radar enables the generation of a dense point cloud, similar to LiDAR, but with the resilience of radar against extreme weather conditions [12]. Moreover, Specifically, Table 1 provides a detailed breakdown of the information presented in this article.

TABLE I
RESEARCH SUMMARY

Aspect	Detail	Description
Research Identity		
Title	Radar Signal Processing: A Comprehensive Review	A thorough review from fundamental techniques to the latest trends
Main topic	Radar signal processing	Covers evolution, algorithms, and future innovations
Research focus	Target classification, detection, high resolution, multi-target tracking	In high-noise and high-clutter environments
Simulation Parameters		
Carrier frequency	10.0 GHz	Basic configuration of the simulated radar
Bandwidth	50 MHz	Basic configuration of the simulated radar
Pulse duration	10.0 us	Affects energy and pulse compression
Range resolution	3.00 m (theory) / 1.50 m (actual)	Better than theory due to LFM + pulse compression
Max unambiguous range	30.0 km	Maximum range without ambiguity

Aspect	Detail	Description
Max Doppler	2,500.0 Hz	Maximum velocity detection limit
Core Techniques Reviewed		
Waveform design	LFM, FMCW, Phase-Coded (Barker/Polyphase)	LFM is most common; FMCW used for short-range radar (automotive)
Radar Data Cube	3D: Fast-time, Slow-time, Spatial	Foundation of modern digital processing; FFT applied across all three dimensions
CFAR detection	CA-CFAR, OS-CFAR	CA-CFAR for homogeneous environments; OS-CFAR more robust in multi-target scenarios
Doppler processing	MTI + Pulse Doppler (FFT)	MTI suppresses static clutter; Pulse Doppler maps target velocities
Parameter estimation	FFT, MUSIC, ESPRIT	MUSIC far superior at separating closely spaced targets (+5 deg vs -5 deg)
Target tracking	Kalman Filter, IMM (Interacting Multiple Models)	Kalman Filter effective for position tracking; velocity estimation still requires EKF
Advanced Array Processing		
Digital Beamforming	Receive + Adaptive (MVDR)	Forms multiple beams simultaneously; MVDR automatically nulls jammers
MIMO Radar	4 Tx x 4 Rx = 16 virtual elements	High hardware efficiency; angular resolution equivalent to a 16-element phased array
STAP	Space-Time Adaptive Processing	Critical for airborne radar; combines spatial and temporal domains
Compressive Sensing	Sparse Arrays + L1 Optimization (OMP)	Reconstructs spatial information from far fewer samples than the Nyquist limit
Emerging Trends & Future Directions		
AI / Deep Learning	CNN (ATR), Deep Unrolling, Cognitive Radar (RL)	CNNs on Doppler spectrograms; RL for autonomous adaptive transmission parameters
ISAC / RadCom	Radar + Communications (6G ecosystem)	Single OFDM waveform serving dual purposes: sensing and data transmission
Quantum Radar	Quantum Illumination (entangled photons)	Still experimental; potential to detect stealth targets with extremely low RCS

Aspect	Detail	Description
4D Imaging Radar	Addition of elevation dimension	Dense point cloud similar to LiDAR but resilient to extreme weather
Open Challenges		
Dense interference	Automotive radar 77-79 GHz, 5G/6G coexistence	Risk of ghost targets; requires adaptive interference avoidance
Computational complexity	MIMO, STAP, Deep Learning	Critical latency (ms) for autonomous vehicles; 4D radar generates millions of points/sec
Low-RCS targets (UAVs)	Drones, stealth materials	Micro-Doppler similar to birds/leaves; requires very high time-frequency resolution
AI explainability	Deep learning black-box models	Critical for military applications; vulnerable to adversarial jamming attacks
Hardware calibration	I/Q imbalance, phase noise, nonlinearity	MIMO sensitive to temperature changes; requires on-the-fly self-calibration
Key Conclusions		
Three future pillars	1) Artificial Intelligence 2) Spectrum Convergence 3) Computational Efficiency	AI for transmission optimization; ISAC as the new standard in 6G; Compressive Sensing + dedicated hardware for data efficiency

IV. ANALYSIS

In the Radar Signal Processing analysis, a simulation was created using the following parameters:

• Carrier Frequency	: 10.0 GHz
• Bandwidth	: 50 MHz
• Pulse Duration	: 10.0 us
• Range Resolution	: 3.00 m
• Max Unambiguous R	: 30.0 km
• Max Doppler	: 2500.0 Hz

These parameters will then be analyzed in detail, with the following radar output results:

- LFM Waveform & Pulse Compression, use Range Resolution 1.50 m (theory: 3.00 m)
- MTI & Range-Doppler Map
- MUSIC vs. FFT DOA Estimation
- MIMO Virtual Aperture vs. Phased Array, use MIMO Virtual Array: 4 Tx × 4 Rx = 16 virtual elements
- Kalman Filter Target Tracking

Moreover, Fig. 1 shows the LFM transmitted waveform, which is the signal emitted by the radar using the LFM (Linear Frequency Modulation) technique, also known as a chirp signal. The x-axis represents time, while the y-axis represents amplitude; the resulting sine wave has a frequency that increases linearly over time. Meanwhile, Fig. 2 shows the Matched Filter Output (Pulse Compression); this graph illustrates the result of processing the reflected signal after it passes through the matched filter—the core process of pulse compression.

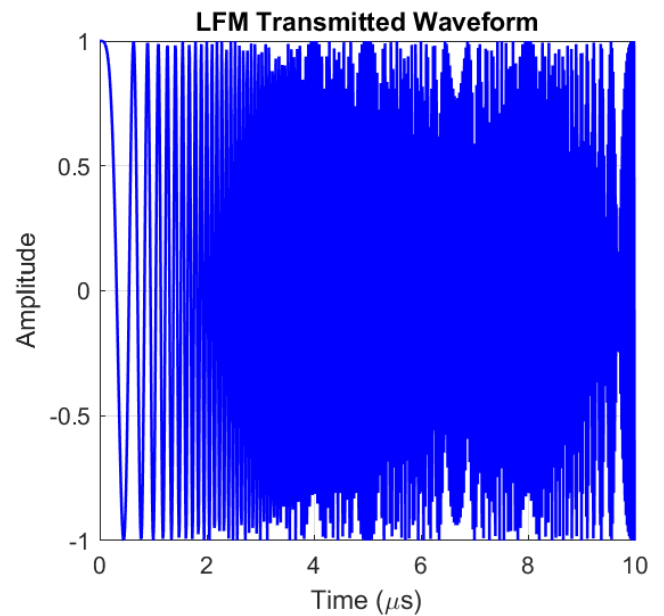


Fig. 1 LFM Transmitted Waveform

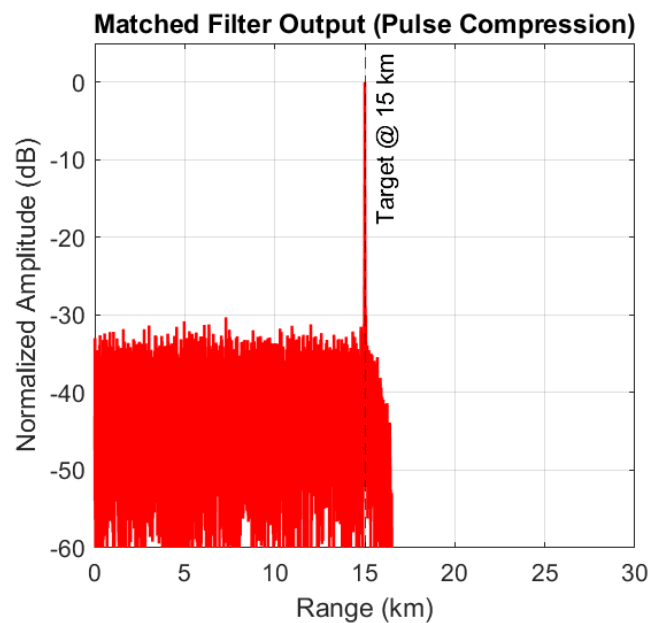


Fig. 2 Matched Filter Output (Pulse Compression)

Furthermore, Fig. 2 shows the matched filter output or pulse compression, illustrating the result of processing the reflected signal as it passes through the matched filter—the core process of pulse compression. The interrelationship between Fig. 1 and Fig. 2, where the LFM signal in Fig. 1 is transmitted and strikes a target—for example, at a certain distance, such as 15 km—and is then reflected back, or the presence of a matched filter, which exhibits a correlation and a sharp peak at 15 km, as shown in Fig. 2.

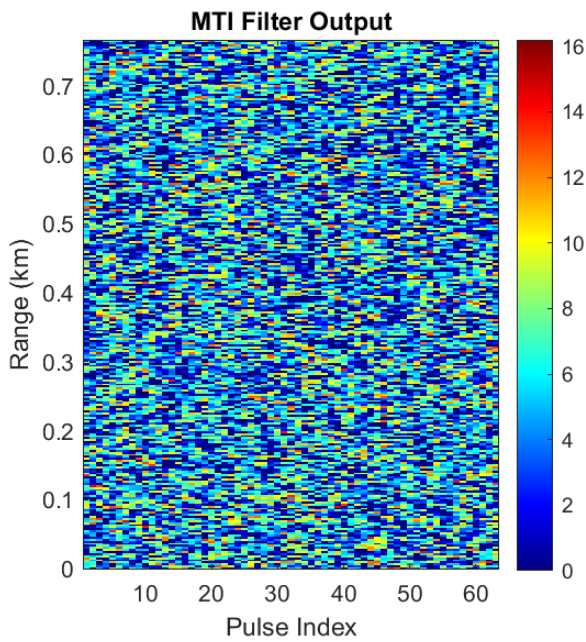


Fig. 3 MTI Filter Output

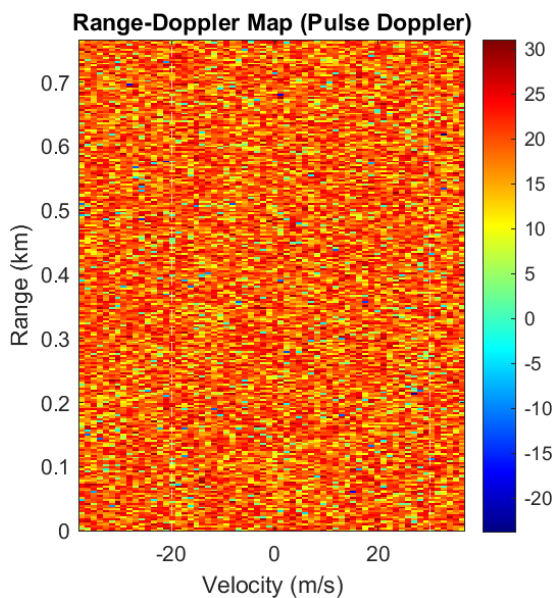


Fig. 4 Range-Doppler Map (Pulse Doppler)

Fig. 3 shows the MTI (Moving Target Indicator), a technique for distinguishing moving targets from static clutter such as buildings, terrain, stationary rain, and other objects. The dominant blue color indicates that static clutter has been successfully suppressed or eliminated; the remaining elements are noise, shown as yellow and cyan spots. Based on these results, no moving targets were detected. MTI works by subtracting Pulse 1 and Pulse 2 to eliminate clutter and identify moving targets. In other words, when two consecutive pulses are subtracted, stationary objects produce identical signals that cancel each other out, while moving objects produce a difference. Meanwhile, Fig. 4 is a Range-Doppler Map or Pulse Doppler, which is a 2D representation that simultaneously displays the distance and velocity of targets using Pulse Doppler. The red or orange colors indicate very high levels of noise or clutter. Fig. 3 and Fig. 4 represent complementary stages of radar signal processing.

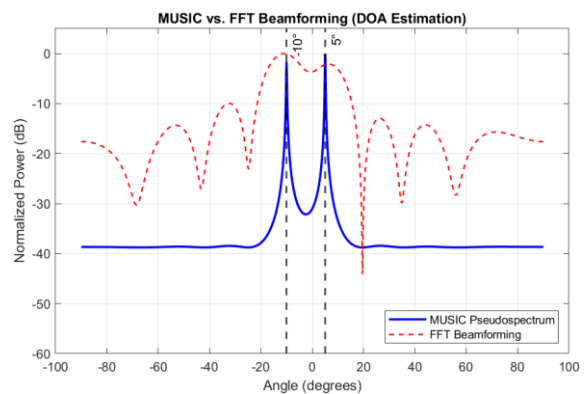


Fig. 5 MUSIC vs. FFT Beamforming (DOA Estimation)

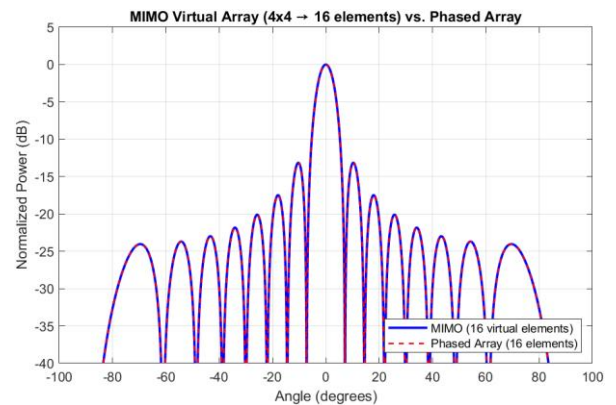


Fig. 6 MIMO Virtual Array (4x4 - 16 elements) vs. Phased Array

Furthermore, Fig. 5 shows a graph comparing MUSIC and FFT beamforming (DOA estimation), which is a technique for determining the direction from which a signal or target is coming using an antenna array. MUSIC works by taking data from the antenna array, calculating the covariance matrix, performing an eigen decomposition of the signal subspace and noise subspace, finding the angle where the steering vector and

noise subspace intersect, and then determining the peak or location of the target. Conclusion: As shown in Fig. 5, MUSIC is far superior at separating two closely spaced targets—+5 degrees and -5 degrees—while FFT is unable to clearly distinguish between them.

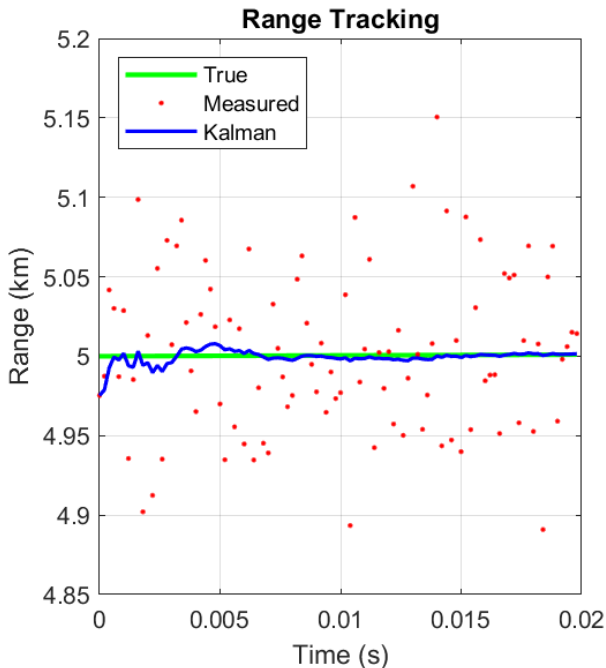


Fig. 7 Range Tracking

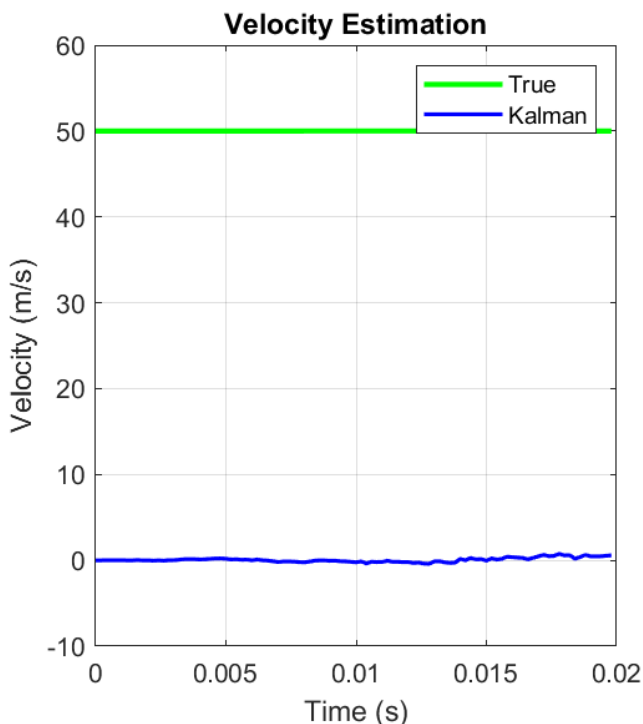


Fig. 8 Velocity Estimation

Meanwhile, Fig. 6 compares a virtual MIMO array with a phased array, illustrating the radiation patterns or beam patterns of these two modern radar antenna architectures. MIMO is capable of replicating the performance of a 16-element phased array using only 8 physical antennas—4 transmitters and 4 receivers—making it more hardware-efficient without sacrificing angular resolution.

Fig. 7 shows range tracking, which is the result of a Kalman filter or tracking radar with a range of 4.85 km to 5.2 km. The Kalman filter process involves noisy measurements or midpoint estimates; the Kalman filter process consists of two steps: prediction, which determines the position, and updating, which determines the correction. There is a smooth blue estimate and a more accurate green estimate. The Kalman Filter is considered successful when the blue line is very close to the green line, even though the measurements are highly noisy.

Moreover, The velocity estimation in Fig. 8 illustrates range tracking. The Kalman filter is configured only for position tracking, not velocity. Possible solutions include [1] using the state vector $[r,v]$, [2] extending the observation time to detect the Doppler effect, [3] initializing V_0 , and [4] using an Extended Kalman Filter (EKF) for nonlinear models. These steps are appropriate but still need to be supported by model improvements so that the velocity estimation can work accurately.

V. CONCLUSION

This article has provided a comprehensive overview of the evolution of radar signal processing, ranging from basic techniques to the latest innovations. It can be concluded that the transition from single-channel processing to multi-dimensional intelligent systems such as MIMO and Cognitive Radar has drastically improved target detection, resolution, and classification capabilities.

The future of radar signal processing will be heavily influenced by three main pillars:

- **Artificial Intelligence:** AI is no longer merely a classification tool but has become an integral part of transmission optimization and radar resource management.
- **Spectrum Convergence:** The integration of radar and communication functions (ISAC) will become the new standard, particularly within the 6G ecosystem.
- **Computational Efficiency:** The challenges of processing high-volume data require synergy between efficient algorithm design (such as Compressive Sensing) and dedicated hardware architectures.

Although challenges related to interference and low-RCS target detection persist, advancements in spatio-temporal processing and quantum technology offer an optimistic path for the development of the next generation of more robust and adaptive radars.

VI. FUTURE RESEARCH

6. Challenges and Open Problems

Although radar signal processing has made remarkable progress, the transition from the laboratory to large-scale real-

world implementation faces several significant technical and practical challenges.

6.1. Mutual Interference in Dense Scenarios

With the proliferation of automotive radar (ADR) and IoT sensors, the spectrum environment has become extremely congested.

- **Interference Mitigation:** Radars operating in the same frequency band (e.g., 77–79 GHz) often interfere with one another, causing an increase in the noise floor or the appearance of ghost targets. Signal processing capable of adaptive interference avoidance remains a major challenge.
- **Coexistence:** How can radar “share” the spectrum harmoniously with 5G/6G communication infrastructure without compromising detection performance [8].

6.2. High Computational Complexity vs. Real-Time Constraints

Advanced algorithms such as MIMO, STAP, and Deep Learning require enormous computational power [9][10].

- **Latency:** In critical applications such as autonomous vehicles or missile defense, decisions must be made within milliseconds. Implementing super-resolution algorithms on low-power embedded systems without sacrificing accuracy remains an unsolved challenge.
- **Data Volume:** 4D imaging radar generates millions of point clouds per second, demanding a far more efficient data processing architecture.

6.3. Detection of Low-RCS and Small Targets (UAVs)

Detecting small objects such as commercial drones (micro-UAVs) or targets made of radar-absorbing materials (stealth) remains challenging for conventional algorithms.

- **Clutter Rejection:** Small targets often exhibit Doppler signatures similar to those of birds or leaves blowing in the wind. Separating the micro-Doppler signals of these targets from complex environmental clutter requires extremely high time-frequency resolution.

6.4. Explainability and Robustness of AI Models

Although deep learning has demonstrated impressive results in classification, these models are often viewed as “black boxes.”

- **Explainable AI (XAI):** In military and life-safety applications, operators need to understand why the system classifies certain objects as threats.
- **Adversarial Attacks:** The vulnerability of AI-based algorithms to intentional interference (adversarial jamming) designed to deceive radar classification is an emerging area of security research.

6.5. Hardware-Algorithm Co-design

Hardware imperfections (such as I/Q imbalance, phase noise, and amplifier nonlinearity) are often not perfectly modeled in algorithm simulations.

- **Calibration:** Algorithms that require high phase accuracy (such as MIMO) are highly sensitive to temperature changes and component aging. There is a strong need for the development of algorithms capable of performing on-the-fly self-calibration.

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