

A Survey on Radar Techniques for Detection, Tracking, and Classification of Aerial Threats

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Abstract—The use of unmanned aerial vehicles (UAVs) for different applications has increased many folds in recent years. The UAVs are expected to change the future air operations. However, there are instances where the UAVs can be used for malicious purposes. The detection, tracking, and classification of UAVs is challenging compared to manned aerial vehicles (MAVs) mainly due to small size, complex shapes, and ability to fly close to the terrain and in autonomous flight patterns in swarms. In this survey, we will discuss current and future aerial threats, and provide an overview of radar systems to counter such threats. We also study the performance parameters of radar systems for the detection, tracking, and classification of UAVs compared to MAVs. Finally, limitations of radar systems and comparison with other techniques that do not rely on radars for detection, tracking, and classification of aerial threats are also provided.

Index Terms—Aerial threats, classification, detection, manned aerial vehicles (MAVs), radar, swarms, stealth, tracking, unmanned aerial vehicles (UAVs).

I. INTRODUCTION

Radar systems are popular and widely used methods for the detection, tracking, and classification of aerial vehicles. Radar technology was first introduced in 1935 [1]. The research and development of radars were accelerated during the second world war and proved to be extremely effective during the war. Since then, radars have seen decades of improvements in overcoming many challenges. Modern radar systems nowadays use advance electronics, compact antennas, phased arrays, and efficient signal processing to achieve reduced response times, high accuracy, low probability of false alarm (PFA), unambiguous aerial vehicle detection and tracking at extended ranges, detection and tracking of multiple aerial vehicles simultaneously, integration with multiple sensors (airborne, ground, and sea-based), and operations in different terrains [2], [3]. The extensive training data of different terrains and potential aerial vehicles aided with efficient classification algorithms have helped in the real time classification of different types of aerial vehicles in complex environments. The basic operation of a pulse radar system is shown in Fig. 1, where a pulse is transmitted from the radar, and the reflection of the pulse from the aerial vehicle is used to detect and subsequently track the aerial vehicle over time.

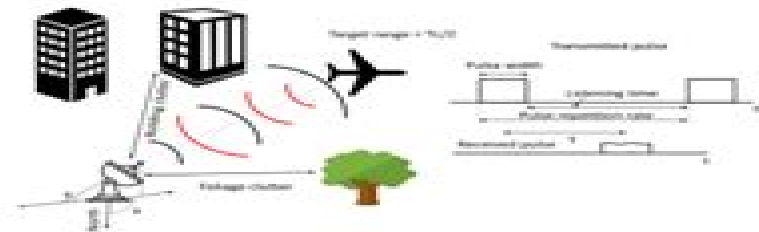


Fig. 1: Basic operation of a pulse-based radar.

Compared to radar systems, the aerial vehicles have also grown in sophistication. The modern aerial vehicles present challenges to conventional and modern radar systems. For example, stealth technology [4], and unmanned aerial vehicles (UAVs) [5] are difficult to detect by modern radar systems at desired ranges. Compared to stealth technology utilized mainly for manned aerial vehicles (MAVs)¹ which is extremely expensive, complex, and under strict governmental controls, the UAVs offer inherent stealth features. This is mainly due to the small size, complex shapes, and non-metallic construction material of UAVs, and their ability to autonomously fly close to terrain. Moreover, their simple design and ease of manufacturing from off-the-shelf and widely available components, and ease of quick modifications have made countermeasures against UAVs challenging. UAV research and development is one of the fast growing industries in the world. According to [6], the overall UAV global market share (in military, law enforcement, government, commercial, and consumer domains) is estimated at \$27.4 billion in 2021 and is expected to reach \$58.4 billion by 2026.

The affordable prices of readily available components, as well as simple assembly and control of UAVs have allowed the use of UAVs in all the major conflicts of the world. In the last two decades, a large number of different types

¹While MAV is typically used to refer to micro aerial vehicles in the literature, we use it to refer to manned aerial vehicles in this survey.

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Radar Techniques for Detection Tracking and Navigation North Atlantic Treaty Organization. Advisory Group for Aerospace Research and Development. Avionics Panel,1966 **An Airborne Radar Technique for Moving-target Detection, Location, and Tracking** John K. Schindler,1973 A novel technique for detecting locating and tracking moving targets from an airborne radar platform is described and analyzed The technique uses the generally dissimilar linear doppler frequency modulated signals from moving targets and stationary ground clutter A matched filter processor is defined and its resolution and ambiguity properties studied as function processor parameters Sub clutter visibility of the processor is then determined Two techniques for digitally implementing the processor are discussed and the computational efficiencies briefly analyzed Finally target angular position can be determined using phase monopulse It is then shown that target velocity both ground speed and target heading can be determined from radar observables Author Radar Techniques for Detection Tracking and Navigation AGARD-NATO,1966-01-01 *Radar techniques for detection tracking and navigation* Organisation Du Traité De L'Atlantique Nord. [Bruxelles.] Agard. [Neuilly-sur-Seine.] Avionics panel. Conférence. [1964, 21-25 septembre. Londres.],1966 Radar Technology Guy Kouemou,2010-01-01 In this book Radar Technology the chapters are divided into four main topic areas Topic area 1 Radar Systems consists of chapters which treat whole radar systems environment and target functional chain Topic area 2 Radar Applications shows various applications of radar systems including meteorological radars ground penetrating radars and glaciology Topic area 3 Radar Functional Chain and Signal Processing describes several aspects of the radar signal processing From parameter extraction target detection over tracking and classification technologies Topic area 4 Radar Subsystems and Components consists of design technology of radar subsystem components like antenna design or waveform design Scientific and Technical Aerospace Reports ,1980 **Remote Sensing of Earth Resources** NASA Scientific and Technical Information Facility,1970 *Technical Abstract Bulletin* ,

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Radar Techniques For Detection Tracking: Bestsellers in 2023 The year 2023 has witnessed a noteworthy surge in literary brilliance, with numerous engrossing novels captivating the hearts of readers worldwide. Lets delve into the realm of popular books, exploring the captivating narratives that have enthralled audiences this year. The Must-Read : Colleen Hoover's "It Ends with Us" This poignant tale of love, loss, and resilience has gripped readers with its raw and emotional exploration of domestic abuse. Hoover skillfully weaves a story of hope and healing, reminding us that even in the darkest of times, the human spirit can succeed. Radar Techniques For Detection Tracking : Taylor Jenkins Reids "The Seven Husbands of Evelyn Hugo" This intriguing historical fiction novel unravels the life of Evelyn Hugo, a Hollywood icon who defies expectations and societal norms to pursue her dreams. Reids captivating storytelling and compelling characters transport readers to a bygone era, immersing them in a world of glamour, ambition, and self-discovery. Radar Techniques For Detection Tracking : Delia Owens "Where the Crawdads Sing" This evocative coming-of-age story follows Kya Clark, a young woman who grows up alone in the marshes of North Carolina. Owens crafts a tale of resilience, survival, and the transformative power of nature, captivating readers with its evocative prose and mesmerizing setting. These bestselling novels represent just a fraction of the literary treasures that have emerged in 2023. Whether you seek tales of romance, adventure, or personal growth, the world of literature offers an abundance of compelling stories waiting to be discovered. The novel begins with Richard Papen, a bright but troubled young man, arriving at Hampden College. Richard is immediately drawn to the group of students who call themselves the Classics Club. The club is led by Henry Winter, a brilliant and charismatic young man. Henry is obsessed with Greek mythology and philosophy, and he quickly draws Richard into his world. The other members of the Classics Club are equally as fascinating. Bunny Corcoran is a wealthy and spoiled young man who is always looking for a good time. Charles Tavis is a quiet and reserved young man who is deeply in love with Henry. Camilla Macaulay is a beautiful and intelligent young woman who is drawn to the power and danger of the Classics Club. The students are all deeply in love with Morrow, and they are willing to do anything to please him. Morrow is a complex and mysterious figure, and he seems to be manipulating the students for his own purposes. As the students become more involved with Morrow, they begin to commit increasingly dangerous acts. The Secret History is a exceptional and suspenseful novel that will keep you speculating until the very end. The novel is a cautionary tale about the dangers of obsession and the power of evil.

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