

# 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.

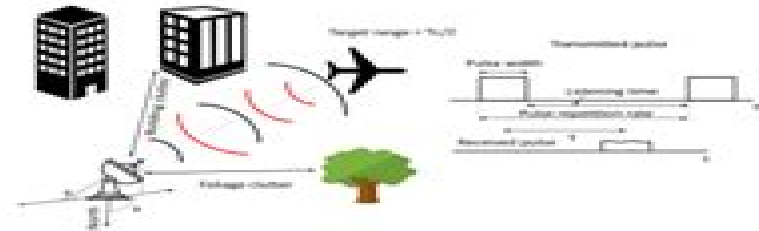


Fig. 1: Basic operation of a pulse-based radar.

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)<sup>1</sup> 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

<sup>1</sup>While 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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