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.
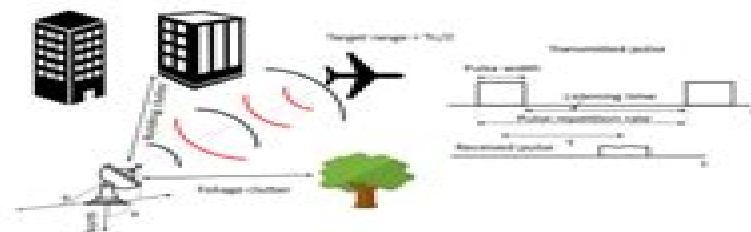

Fig. 1: Basic operation of a pulse-based radar.

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

[1]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.

Radar Techniques For Detection Tracking

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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 TECHNIQUES FOR DETECTION TRACKING AND NAVIGATION- 8TH ANNUAL SYMPOSIUM- PAPERS- AGARD, AVIONICS PANEL. , Knowledge Based Radar Detection, Tracking and Classification* Fulvio Gini,Muralidhar Rangaswamy,2008-07-31 Discover the technology for the next generation of radar systems Here is the first book that brings together the key concepts essential for the application of Knowledge Based Systems KBS to radar detection tracking classification and scheduling The book highlights the latest advances in both KBS and radar signal and data processing presenting a range of perspectives and innovative results that have set the stage for the next generation of adaptive radar systems The book begins with a chapter introducing the concept of Knowledge Based KB radar The remaining nine chapters focus on current developments and recent applications of KB concepts to specific radar functions Among the key topics explored are Fundamentals of relevant KB techniques KB solutions as they apply to the general radar problem KBS applications for the constant false alarm rate processor KB control for space time adaptive processing KB techniques applied to existing radar systems Integrated end to end radar signals Data processing with overarching KB control All chapters are self contained enabling readers to focus on those topics of greatest interest Each one begins with introductory remarks moves on to detailed discussions and analysis and ends with a list of references Throughout the presentation the authors offer examples of how KBS works and how it can dramatically improve radar performance and capability Moreover the authors forecast the impact of KB technology on future systems including important civilian military and homeland defense applications With chapters contributed by leading international researchers and pioneers in the field this text is recommended for both students and professionals in radar and sonar detection tracking and classification and radar resource management 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 **Technical Abstract Bulletin** , *Remote Sensing of Earth Resources* NASA Scientific and Technical Information Facility,1970 Department of Defense Appropriations for Fiscal Year 1970, Hearings Before ..., 91-1 United States. Congress. Senate. Appropriations Committee,1969 **Hearings, Reports and Prints of the Senate Committee on Appropriations** United States. Congress. Senate. Committee on Appropriations,1969 **Army Science and Technology Master Plan** United States. Department of the Army,2001 *Army Science And Technology Master Plan 2001, Volume 1, January 2001* ,2001 *Department of Defense Appropriations for Fiscal Year ...* United States. Congress. Senate. Committee on Appropriations,1971 Department of the Air Force United States. Congress. Senate. Committee on Appropriations,1969 **Scientific and Technical Aerospace Reports** ,1980 **Hearings Before and Special Reports Made by Committee on Armed Services of the House of Representatives on Subjects Affecting the Naval and Military Establishments** , Hearings on Cost Escalation in Defense Procurement Contracts and Military Posture and H.R. 6722 ... United States. Congress. House. Committee on Armed Services,1973 Department of Defense Appropriations for Fiscal Year 1970 United States. Congress. Senate. Committee on Appropriations,1969 **Infrared and Millimeter Waves V4** Kenneth J. Button,2014-04-08 Infrared and Millimeter Waves is a series of books that compiles the work of several authors with each volume focusing on certain aspects of infrared and millimeter waves such as sources of radiation instrumentation and millimeter systems This book concerns itself with millimeter systems Comprised of seven chapters this book discusses several systems that involve the use of millimeter waves such as radars and missile guidance systems The first chapter provides a comprehensive overview of millimeter waves while the succeeding chapter discusses several technologies that involve millimeter systems such as radar missile guidance and imaging systems This book will be of great use to researchers and professionals whose work involves infrared and millimeter waves

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