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REVIEW ARTICLE

A Mini-Review on SDR Based Radar Classification System: Recent Advances and Challenges

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HIGHLIGHTS

- *Review of SDR based radar classification systems*
- *Potential problems and limitations*
- *Future directions*

Keywords:

- *Software Defined Radio*
- *Electronic Support Measures*
- *Radar Classification*
- *Parameter Extraction*
- *Clustering*

GRAPHICAL ABSTRACT

The shift from analog to digital technologies has transformed radio systems, and Software Defined Radio (SDR) has introduced unparalleled flexibility and adaptability by executing operations through software-based approaches. In recent times, the burgeoning popularity of SDR has augmented their applicability within the realm of Electronic Support Measures (ESM), enabling their utilization for the purpose of radar classification. This short review aims to evaluate existing SDR based radar classification systems in the literature. Firstly, an overview of the existing SDR based radar classification systems is provided for the intended purpose. Subsequently, the process of SDR based radar classification is elucidated. Emphasis is then placed on the primary research obstacles encountered in SDR based radar classification. This is succeeded by a concise examination of unresolved matters to direct forthcoming research endeavors. Furthermore, a brief mention is made of the ongoing research studies conducted by the authors.

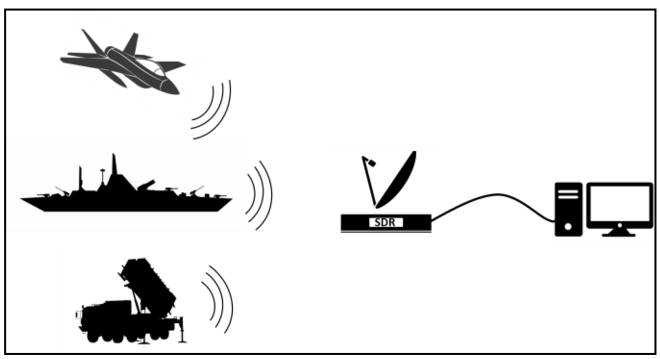

Figure A. SDR based radar classification scenario

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Aim of Article: *In this study, it was aimed to examine the SDR based radar classification methods in the literature and to establish the foundation for the ongoing study.*

Theory and Methodology: *Proposed SDR based radar classification process stages were explained.*

Findings and Results: *The importance of processing speed in SDR based radar classification systems, a factor directly impacted by both sampling rate and system bandwidth, is underscored.*

Conclusion: *This paper presents a review of SDR based radar classification systems and guides the ongoing project within the framework of the results found.*

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ABSTRACT

The shift from analog to digital technologies has transformed radio systems, and Software Defined Radio (SDR) has introduced unparalleled flexibility and adaptability by executing operations through software-based approaches. In recent times, the burgeoning popularity of SDR has augmented their applicability within the realm of Electronic Support Measures (ESM), enabling their utilization for the purpose of radar classification. This short review aims to evaluate existing SDR based radar classification systems in the literature. Firstly, an overview of the existing SDR based radar classification systems is provided for the intended purpose. Subsequently, the process of SDR based radar classification is elucidated. Emphasis is then placed on the primary research obstacles encountered in SDR based radar classification. This is succeeded by a concise examination of unresolved matters to direct forthcoming research endeavors. Furthermore, a brief mention is made of the ongoing research studies conducted by the authors.

Keywords: *Software Defined Radio, Electronic Support Measures, Radar Classification, Parameter Extraction, Clustering*

I. INTRODUCTION

The principal operational objective of an Electronic Support Measures (ESM) system lies in the detection of potential threats and the surveillance of a designated spatial domain for the identification of electromagnetic emission sources. For this purpose, ESM system scrutinizes pulse-by-pulse measurements acquired through its receiver, facilitating the discernment of established radar signatures and signaling their existence [1].

A critical and fundamental responsibility of ESM systems involves extracting radar signal parameters. These parameters, collectively known as pulse description word (PDW), include radio frequency (RF), pulse width (PW), pulse amplitude (PA), time of arrival (TOA), and angle of arrival (AOA). The examination of PDWs holds significance in identifying and categorizing distinct features of threat radars within electronic warfare (EW) systems [2].

The transformation of radio technology from analog to digital has permeated various aspects of radio systems, including system control, source and channel coding, and hardware technology. This paved the way for the software-defined radio (SDR) revolution, thereby broadening the horizons of radio-based services through the elimination of constraints imposed by hardware-centric designs [3].

The introduction of SDR has yielded unparalleled levels of flexibility and adaptability by liberating radio systems from the constraints of fixed frequency bands, channel bandwidths, and modulation schemes. This liberation is achieved through the implementation of software-based signal processing techniques [3].

Recently, SDR has gained prominence in RF signal capture solutions across both military and civilian applications. The accelerated design evolution of SDR can be attributed to ongoing technological advancements and the widespread adoption of cost-effective digital signal processors (DSPs). The fundamental objective of an SDR system lies in the comprehensive digital processing of radio signals, facilitated by a dedicated DSPs [4]. In contrast to traditional radio systems, where modulation, demodulation, signal generation, signal processing, and signal coding are executed in the hardware domain, SDR performs these operations within the software realm. This unique characteristic imparts to SDR a high degree of flexibility, reconfigurability, and the capacity to selectively engage channels [5].

In this study, the preliminary phase of an ongoing project on the SDR based radar classification system is presented. In this context, the main purpose is to scrutinize the existing SDR based radar classification systems in the literature. In pursuit of this objective, a comprehensive literature review is undertaken to present the existing knowledge on SDR based radar classification system. The next step involves providing an overview of the foundational principles of SDR based radar classification system. In this context, prevalent research challenges are examined. Following this, the study delves into both unresolved issues and ongoing research endeavors by the authors. Hence, it is postulated that this research could provide valuable insights into the advancement of SDR based radar classification system.

The compositional framework of this article is delineated as follows. A comprehensive examination of extant studies on SDR based radar classification is conducted in Section II, exploring various perspectives. Section III provides the methodology of an SDR based radar classification system. Section IV deliberates on the challenges inherent in SDR based radar classification, while Section V addresses open issues and outlines research directions. The article culminates in Section VI, presenting conclusions derived from the discussed content.

II. THE CURRENT STATE-OF-ART SDR BASED ESM SYSTEMS

Several studies in the literature have presented various applications of SDR based ESM systems. In [6], a passive radar receiver platform based on SDR technology showcased its ability to process an 8 MHz bandwidth for measuring transmitter positions. In [7], a novel approach for estimating direction-of-arrival, which divided the desired angular sector into a small number of channels is proposed. This approach achieved radar detection with reduced size, weight, cost, and computational requirements, employing a sampling rate of 2.4 MSps. In [8], an SDR-based ESM system that utilized a pulse detection algorithm to address the issue of undetected pulses caused by overlap is introduced. Experimental results demonstrated a sampling rate of 2.4 MSps. In [9], a scale mixture of normal distributions model was proposed for radar emitter classification and clustering. SDR technology was employed to receive radar signals at a sampling rate of 4.17 MSps, with clustering performed offline. Finally, in [10], an SDR-based radar detector with a processing capability of a 2.4 MHz bandwidth for radar classification is presented.

From the results, these studies highlight the significance of processing speed in SDR-based ESM receivers, which is directly influenced by the sampling rate and bandwidth. Furthermore, the complexity of the classification algorithm also impacts the processing speed.

III. METHODOLOGY

Although there are many different radar classification techniques, they all have the same fundamental processes such as the signal reception, signal parameter extraction, clustering, deinterleaving, database control and displaying the results [11].

A. Signal Reception with SDR

The SDR receiver comprises two principal modules: the analog front-end and the DSP components. The analog front-end is responsible for executing narrowband frequency down-conversion and subsequent analog-to-

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digital conversion (ADC). During down-conversion, the incoming signal undergoes a shift from a high-frequency band to a lower intermediate frequency (IF) band, followed by ADC, which transforms the analog IF signal into a digital representation amenable to subsequent processing. The DSP components manage the residual signal processing responsibilities, encompassing demodulation, filtering, and channel decoding [12].

The direct conversion receiver (DCR) architecture is commonly employed in the RF front-end stage of SDR which performs IQ sampling theory [13].

B. Parameter Extraction

The extraction of radar pulse parameters plays a crucial role in the signal processing pipeline of radar classification. The input for pulse parameter extraction is provided by digitized IQ data which is sent by SDR to host PC. In the process of extracting these parameters, we will compute the signal's envelope to ascertain the envelope of each sample as follow [14]

$$r(t) = \sqrt{x_I(t)^2 + x_Q(t)^2} \quad (1)$$

where $r(t)$ is envelope of the bandpass signal, $x_I(t)$ and $x_Q(t)$ are quadrature components. Radar pulses are discerned by the identification of samples whose enveloped amplitude exceeds a predetermined threshold value. Another essential parameter to derive from pulse information is frequency, and it can be determined through diverse methods. In our study, we will utilize two approaches: Fast Fourier Transform (FFT) and Instantaneous Frequency Measurement (IFM).

FFT and IFM represent discrete signal processing methodologies characterized by unique applications and operational principles. FFT excels in scrutinizing the spectral composition of a signal across time, yielding valuable information regarding its frequency characteristics. Conversely, IFM is dedicated to discerning the instantaneous frequency of a signal, delivering real-time insights into its dynamic frequency variations [15].

C. Clustering

Clustering is another important process for radar classification. During this phase, the parameters extracted and designated as PDW serve as the input. AOA, RF, and PW emerge as pivotal parameters for clustering purposes. These parameters play a significant role in the clustering algorithm, facilitating the differentiation of distinct radars within a multi-radar environment.

IV. RESEARCH CHALLENGES

Although the existing studies have made various contributions to the field of the SDR based ESM systems, there are still some certain difficulties and limitations needed to discuss in the development of a SDR based radar classification system.

A. Wideband Receiving

In order to achieve expanded frequency coverage, SDR systems necessitate operation at high sampling rates. However, this exigency mandates a proportional increase in processing speed. The intricate relationship between sampling rate and processing speed is crucial, as it directly influences the system's ability to effectively capture, process, and analyze signals across a wider spectrum. Consequently, the achievement of extended frequency coverage in SDR configurations entails a meticulous optimization of sampling rates and processing capabilities to ensure the seamless reception and manipulation of signals within the targeted frequency span.

B. Channel Limitation

SDR configurations may adopt either a singular or multiple channel structure. The singular channel architecture proves inadequate for AOA calculations. In a multi-channel structure, the pivotal determinants of efficacy include synchronization mechanisms and data processing speed. Nevertheless, the specific SDR under consideration is equipped with a two-channel configuration, rendering AOA calculations inherently unreliable.

V. OPEN ISSUES AND RESEARCH DIRECTIONS

From the discussion provided in the previous section, it is evident that there are some challenges in the implementation of the SDR based radar classification. One of the aspects to consider is the method of acquiring the signal in real-time without losing any samples, and subsequently utilizing it for further processing.

In order to increase the processing speed, the use of Graphical Processing Unit (GPU) parallelization is crucial. Traditionally, FFT computations heavily rely on the Central Processing Unit (CPU), resulting in memory bottlenecks and impeding the execution of crucial tasks. However, by harnessing the parallel processing capabilities of the GPU, GPU accelerated FFT effectively transfers the computationally intensive FFT operations from the CPU, thereby freeing up resources for other essential calculations. This approach not only enhances the overall processing speed but also optimizes memory allocation and minimizes data transfers between the CPU and GPU [16].

On the other hand, because we are not able to calculate AOA parameter due to channel limitations, clustering will use RF and PW parameters only. For clustering task, Density-based spatial clustering of applications with noise (DBSCAN) is particularly noteworthy among clustering algorithms. DBSCAN excels in managing noise, outliers, and variable data densities, standing out for its effectiveness. Unlike traditional algorithms dependent on predefined shapes or centroids, DBSCAN identifies clusters based on local data point density, providing robustness against noise and varied cluster shapes. Furthermore, its capability to detect clusters of arbitrary shapes and sizes makes DBSCAN well-suited for analyzing radar pulse data characterized by non-uniform densities and shapes [17].

VI. CONCLUSION

In this study, as a part of an ongoing project, a literature review is conducted to provide the current state of understanding of SDR based radar classification. In this context, the existing studies are presented, and the research challenges are discussed. One of the crucial discoveries indicates that in order to function at a broader range of frequencies, it is imperative to enhance the processing speed. It can be increase with GPU parallelization. Alternatively, in order to achieve precise classification, it is imperative to employ a proficient clustering algorithm. In this regard, the utilization of DBSCAN is recommended owing to its inherent benefits in extensive-scale scenarios.

Our current focus is on developing a radar classification system based on SDR technology that can operate across a broader range of frequencies. We aim to conduct a thorough experimental study to evaluate the performance of this system, which we plan to complete in the near future.

CONFLICTS OF INTEREST

They reported that there was no conflict of interest between the authors and their respective institutions.

RESEARCH AND PUBLICATION ETHICS

In the studies carried out within the scope of this article, the rules of research and publication ethics were followed.

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