

AUTOMATIC RADAR WAVEFORM RECOGNITION BASED ON TIME-FREQUENCY ANALYSIS AND CONVOLUTIONAL NEURAL NETWORK



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INTRODUCTION

Automatic radar waveform recognition is one of the fundamental techniques in electronic warfare applications. Researchers have used traditional signal processing methods to extract features, such as Wavelet Analysis and Instantaneous frequency analysis. However, for lacking of efficient ways to characterize the distinctions among different types of radar signals, these methods are sensitive to noise and their generalization ability are limited.

METHOD

The multilayer structure confers deep learning magnificent feature representation ability, and Time-Frequency Analysis reveals the most essential distinction, that is, the frequency variation, of radar waveforms with different modulation types. So we transform radar signals into time-frequency images (TFIs) (shown in the first column of Fig 4) and design a convolutional neural network (CNN) (Fig 1) to recognize them. In addition, we

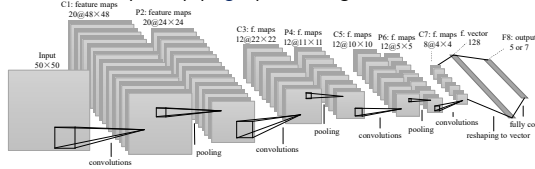


Fig 1: The structure of the designed convolutional neural network

analyze the statistical characteristics of the noise in TFIs and find out that it is locally white. Therefore, we design a filter to suppress the noise in order to improve the recognition rate (Fig 2).

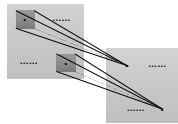


Fig 2: Designed Filter

SIMULATION RESULT

- (1) Five types of radar signals, i.e., linear frequency modulation radar signals (LFM), single carrier radar signals (SCR), phase coded radar signals (PCR), frequency coded radar signals (FCR) and nonlinear frequency modulation radar signals (NLFM) are used for algorithm evaluation. Meanwhile, we re-evaluate the state-of-the-art radar signal recognition method (which is named as ACF-DGM). The results are illustrated in Fig 3.
- (2) Besides, as shown in Fig 4, we design filters to suppress noise so as to improve efficiency, and Fig 5 illustrates the simulation results.
- (3) Furthermore, we add two more types of signals, i.e., PCR and FCR with more complex coding, to evaluate the generalization ability of our algorithm, and the results are depicted in Fig 6.

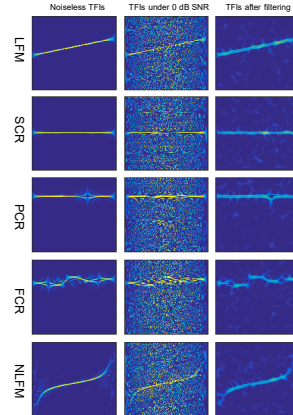


Fig 4: Noise suppression

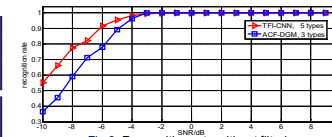


Fig 3: Recognition rate without filtering

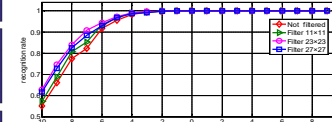


Fig 5: Recognition rate after filtering

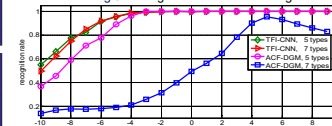


Fig 6: Generalization ability

DISCUSSION

- (1) Due to the powerful feature representation ability of deep learning, our method significantly outperforms the state-of-the-art especially under bad SNR conditions.
- (2) Only a filter with moderate size can give the best recognition rate improvement. A filter with smaller size may be capacity-limited to handle noise under bad SNR conditions, while a bigger one may filter off the high components of signals.
- (3) Time-Frequency Analysis reveals the identities of radar signals with different modulation types and CNN exactly possess the ability to recognize the time-frequency patterns exhibited in TFIs. Consequently, our method could be generalized to more types of differently-modulated radar signals.

CONCLUSION

We combine traditional signal processing method, Time-Frequency Analysis, with deep learning. Additionally, we analyze the statistical characteristics of the noise in TFIs and design filters to suppress it. With impressive recognition rate under a wide range of SNR conditions and strong generalization ability, our method is applicable in real situations.

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