Recognition of flying small target based on enhanced quadratic time-frequency analysis

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Abstract. UAVs (Unmanned Aerial Vehicles, UAVs) are flying targets that sail at low altitudes, are slower and smaller in size. Nowadays, the task of detecting and distinguishing flying small targets is very difficult, so how to efficiently recognize flying small targets in real time is a key issue of current research. In order to solve this problem, this paper proposes a method of using pseudo-WVD and image fusion to represent the characteristics of UAVs. First, the SMMWR (Single-mode millimeter wave radar, SMMWR) equipment is used to collect the echo signals of various types of UAVs, and at the same time, the two-dimensional FFT is used to extract the target micro-motion signals in the distance dimension. Secondly, PWVD is used to generate time-frequency graphs of different window functions. Finally, the images fused based on principal component analysis are sent to AlexNet for training. The result proves that the accuracy of recognition rate based on AlexNet can be 93.75%.

1. Introduction

In recent years, as the cost of UAV hardware manufacturing continues to drop, and new technologies such as artificial intelligence technology and 5G communications have been gradually improved and applied, UAV systems and UAV application technologies have ushered in an explosive period. At the same time, drones are also popular in civil and commercial fields such as express delivery, pesticide spraying, medical emergency rescue, and security. However, just as everything has two sides, the widespread popularity of drones also poses many threats to privacy and security. With the commercialization of drones, small drones can now be easily purchased on the Internet, which creates conditions for criminals to abuse and misuse.

In order to solve the problem of flying small target recognition, many researchers at home and abroad have made a lot of research and exploration. In [1], the feature of radar data collected by k-band and x-band radars was fused together. In [2], a feature extraction method based on spectral kurtosis technology is proposed. In [3], a method of fusing direct path and multipath micro-Doppler radar features is proposed to improve the accuracy of UAV classification. In [4], the analysis is based on the combined use of spectrogram and Inverse Radon Transform (IRT), while further using the paired characteristics of propeller blades to improve drone detection and feature extraction capabilities. In [5], the Doppler and bandwidth centroids of the micro-Doppler features are processed by STFT and Singular Value Decomposition (SVD), and three classifiers are used for classification at the same time. In [6], by combining STFT, spectral subtraction, empirical mode decomposition and principal component analysis, the characteristics of the UAV are extracted and input into four different classifiers: SVM, Naive Bayes, Recent Ortho and random forests. In [7], a method based on the principal component analysis of the
micro-Doppler signal and the discrete wavelet transform (PCA-DWT) combined time-frequency and texture features was proposed.

In summary, in the flying small target recognition technology, the use of radar to measure the micro-Doppler characteristics and detection of UAVs is one of the current important research directions. Therefore, this paper uses SMMWR to detect various types of UAVs, then extracts micro-motion features, and finally uses the AlexNet model to identify small flying targets.

2. Process of flying small target recognition

2.1. Detection equipment and various types of drones

TI millimeter wave radar has the characteristics of small size, easy installation and low cost. Therefore, TI's SMMWR was used in this experiment of collecting radar data. The specific radar parameters are shown in Table 1. In the experiment, the UAV was carried out in front of the radar, while the radar and UAV remained relatively stationary. The SMMWR device continuously sends out LFM pulses, which are reflected after encountering the target, and finally the echo signal is received by the receiving end of the radar.

| Name                  | Parameter       |
|-----------------------|-----------------|
| Carrier frequency     | 77GHz           |
| Sampling frequency    | 2000MHz         |
| Pulse width           | 150us           |
| FM slope              | 19.988          |
| Number of sampling points per pulse | 256            |
| Bandwidth             | 2998.2MHz       |
| Sampling period per frame | 512            |
| Sampling frequency    | 2000MHz         |
| Pulse width           | 150us           |
| FM slope              | 19.988          |

2.2. Actual data preprocessing

Because when collecting the echo data of various UAVs, it will be interfered by various clutters that always exist. Therefore, we need to detect whether the target exists and whether it is submerged by noise. What this text experiment uses is 2D CA-CFAR. After confirming that the detection target exists, the distance-Doppler and the known distance of the UAV are used for comparison and verification. After the verification is correct, two-dimensional FFT is used for the echo signal to extract the target micro-motion signal in the distance dimension.

2.3. Feature extraction and training

After the collected data is preprocessed, the pseudo WVD method is used to analyze the target echo to obtain the time-frequency diagram of the target with different window functions, and then PCA is used to fuse the images. The specific situation will be introduced in the next section. Due to the different shapes and other characteristics of each UAV, its echo signals are very different, and the micro-Doppler characteristics are also significantly different. Therefore, the micro-Doppler features in the echoes of different types of UAVs are quite different, and UAVs can be identified based on these features. Finally, neural network training is performed on the extracted micro-motion feature data set. The AlexNet model is selected for training. Perform training operations on 70% of the data in the feature data set, and verify the remaining data to obtain target recognition accuracy and training speed changes.
3. Micro-Doppler feature representation

3.1. Time-frequency analysis
WVD and PWVD belong to the quadratic time-frequency analysis at the same time. Although WVD has good time-frequency aggregation, it is very easy to receive the interference of the cross term. This resulted in an improved PWVD of WVD. PWVD imposes a window function on the basic WVD. The reason is that the actual integral cannot be from positive infinity to negative infinity. The result of windowing makes the complete non-locality of WVD become localized, and to some extent reduces the cross-term interference, but it also reduces the frequency resolution. In order to improve the effect of the image, four different window functions are used to analyze the target echo to obtain the time-frequency diagram of the target. These four window functions are Gaussian window, Hanning window, Hamming window and rectangular window.

3.2. Numbering
PCA transformation is an orthogonal linear transformation based on the amount of information. The transformation mainly uses linear projection to project data into a new coordinate space, so that the new components are distributed according to the amount of information. After the transformation, the components of the principal components are not related to each other. Performing principal component transformation on image data first needs to calculate a standard transformation matrix. Through the transformation matrix, the image data is converted into a new set of image data-principal component data, so as to improve the principal component characteristics of the image. Thus constructing each new Features are linear functions of original features. Therefore, we apply the principal component analysis (PCA) algorithm to determine the fusion image, which can further reduce the correlation and redundancy of each source image to improve the effect of the fusion image. The fused images are shown in Figure 1, Figure 2, Figure 3 and Figure 4.

Figure 1. Single-rotor time-frequency diagram.
Figure 2. Helicopter time-frequency diagram.
Figure 3. Quad-rotor time-frequency diagram.
Figure 4. Eight-rotor time-frequency diagram.
4. Discussion
We build a feature data set based on the previous pseudo WVD time-frequency map after PCA fusion. At the same time, it is used as the input of the neural network method, and the AlexNet model is used for recognition. The recognition effect of the AlexNet model on various types of UAVs is shown in Figure 5.

Figure 5. Acc-loss graph of 8000 iterations on the AlexNet model.

The experimental results after training show that this small flying target recognition method has higher accuracy and faster model training speed. In terms of accuracy, the recognition rate based on the AlexNet model is 93.75%. The feasibility of micro-Doppler feature extraction based on pseudo WVD time-frequency analysis and PCA image fusion is verified.

5. Conclusions
This study uses 77 GHz SMMWR to conduct actual measurement experiments on UAVs outdoors, and conducts detection experiments on small UAVs and large UAVs respectively. Secondly, the micro-motion feature is extracted from the target echo collected by the radar. This paper uses the micro-motion feature based on pseudo WVD time-frequency analysis and PCA image fusion as the target recognition data set. This set is recognized on CNN's AlexNet model, and the recognition rate is 93.75%. The feasibility of this small flying target recognition method is verified.

References
[1] Zhang, P., Yang, L., Chen, G., et al. (2017) Classification of drones based on micro-Doppler signatures with dual-band radar sensors. In: 2017 Progress in Electromagnetics Research Symposium-Fall (PIERS-FALL). Singapore. pp. 638-643.
[2] Pallotta, L., Clemente, C., Raddi, A., et al. (2020) A Feature-Based Approach for Loaded/Unloaded Drones Classification Exploiting micro-Doppler Signatures. In: 2020 IEEE Radar Conference (RadarConf20). Florence. pp.1-6.
[3] Zhang, P., Li, G., Huo, C., et al. (2019) Exploitation of multipath micro-Doppler signatures for drone classification. IET Radar, Sonar & Navigation, 14: 586-592.
[4] Zhang, Y.D., Xiang, X., Li, Y., et al. (2021) Enhanced Micro-Doppler Feature Analysis for Drone Detection. In: 2021 IEEE Radar Conference (RadarConf21). Atlanta. pp. 1-4.
[5] Ritchie, M., Fioranelli, F., Borrion, H., et al. (2017) Multistatic micro-Doppler radar feature extraction for classification of unloaded/loaded micro-drones. IET Radar, Sonar & Navigation, 11: 116-124.
[6] Sun, Y., Fu, H., Abeywickrama, S., et al. (2018) Drone classification and localization using micro-doppler signature with low-frequency signal. In: 2018 IEEE International Conference on Communication Systems (ICCS). Chengdu. pp. 413-417.
[7] Zhao, C., Luo, G., Wang, Y., et al. (2021) UAV Recognition Based on Micro-Doppler Dynamic Attribute-Guided Augmentation Algorithm. Remote Sensing, 13: 1205.