Check for updates

Research on Signal Detection Methods for Drones in Complex Pendulum Environment

Linjia Zhang

College of Mechanical and Electrical Engineering, South West Petroleum University, Chengdu 610066, China

202031030460@stu.swpu.edu.cn

Abstract. In recent years, drones have been widely used in various industries and have played a significant role. However, with the popularization of civilian drones, the safety issues brought about by drone "black flying" should also be given sufficient attention. Good drone signal detection technology is a prerequisite for achieving drone supervision. As a non cooperative recipient, it is necessary to detect, estimate parameters, identify modulation, and identify protocol for the received drone communication signals. Compared to large or military drones, most small civilian drones use radio frequency signal based wireless monitoring technology. This technology uses radio frequency signals between the drone and the remote control for drone detection, which has strong concealment and all-weather advantages. However, this technology still has the following problems: (1) Small civilian drones generally have lower signal transmission power, and the signal reception section can receive weaker signals at long distances. (2) In complex environments, especially in cities, the noise interference and co frequency interference caused by the complex electromagnetic environment make it difficult to identify the signal band received by the receiving end. This article mainly studies the ability to accurately detect signals emitted by drones under complex electromagnetic interference conditions and weak signal frequencies.

Keywords: Drones; Complex Electromagnetic Environment; Signal Detection Technology

1 Introduction

With the continuous updating and upgrading of science and technology, drones have shown explosive development in various fields. While machine technology brings convenience to many fields, it also inevitably brings problems of control and countermeasures, which urgently need to be solved. On February 7, 2018, a staff member of a certain aviation company in Beijing operated a drone to conduct aerial surveying and mapping of a mining area without possessing the qualification to operate a drone or applying for airspace permission, seriously interfering with the normal flight of military and civil aviation [1]. On August 25, 2019, a security worker at Buckingham Correctional Center in Dearborn, Virginia, discovered a drone carrying a

© The Author(s) 2024

Y. Wang (ed.), *Proceedings of the 2024 2nd International Conference on Image, Algorithms and Artificial Intelligence (ICIAAI 2024)*, Advances in Computer Science Research 115,
https://doi.org/10.2991/978-94-6463-540-9_45

package on the roadside outside the prison [2]. The package contained $500 worth of marijuana, an 8-ball cocaine, a mobile phone, three SIM cards, and a handcuff key. On June 17, 2020, it was suspected that a "black fly" drone was hovering at Hangzhou Xiaoshan International Airport, causing multiple flight delays [3], alternate landings, or cancellations. Drones "black flying" interfere with normal aviation operations, and it is not uncommon for illegal elements to manipulate drones in restricted areas to disrupt important social activities such as summits and leader activities. The security risks it brings have attracted attention from military security experts, civil aviation authorities, and other parties [4].

In order to regulate drones, it is necessary to detect whether any drones have entered the no fly zone, and even further identify the type of drone. It can be said that the premise of drone regulation is the detection and identification of drones. At present, unmanned aerial vehicle detection methods mainly include radar detection, photoelectric detection, sound detection, and radio detection. Among them, radio detection is to determine the existence of targets by analyzing the radio frequency signals of drones and controllers. This method can work at non line of sight and detect at a long distance; It can still work normally under adverse weather conditions such as fog, rain, wind and sand, and at night, especially without being disturbed by birds that often appear in the sky; Not actively transmitting signals is easy to conceal. It is precisely by relying on these advantages that wireless detection has been widely applied and regarded as a promising drone detection technology. Radio detection belongs to the field of signal detection. The working principle of signal detection is to determine whether there is a signal of interest in the received signal containing noise and interference through feature extraction and other methods. It is a front-end technology for signal processing, laying the foundation for subsequent target analysis, recognition, tracking and other work. It is currently a very important research field in theoretical research and engineering applications [5-7].

With the increasing number of communication devices, combined with various types of noise, interference, fading, and multipath effects, a complex and ever-changing electromagnetic environment has been created. How to quickly and accurately detect target signals in complex electromagnetic environments, and grasp the initiative and control power, has become very urgent and important. Breaking through the technical difficulties related to signal detection of small unmanned aerial vehicles in complex electromagnetic environments and researching a fast, accurate, and robust intelligent signal detection algorithm is of great significance [8, 9].

The current unmanned aerial vehicle detection and recognition methods mainly include radar detection, passive detection, acoustic detection, and other aspects, realize the capture and analysis of drone signals.

In terms of radar detection, the Merlin system in the United States and the Accipiter system in Canada were the earlier commercialized "low slow small" target radar detection systems. The UK's AUDS system utilizes optical and radar search to achieve drone target detection The Falcon Shield anti drone electronic warfare system released by the Italian Finmeccanica Group detects drone signals through radar and photothermal imaging, and performs recognition, tracking, and interference [10]. In China, at the China International Aviation and Aerospace Exhibition in 2021, Electronica released the first set of export oriented integrated anti UAV command system "Tianqiu" [11], which can quickly detect and track UAVs through radar guidance. These unmanned aerial vehicle detection systems, which integrate radar and optoelectronic equipment, have a wide range of applications, high accuracy, but also high cost, and are suitable for important summits and major national events.

In terms of passive detection, Xie et al. designed an FPGA system that can parallel and real-time detect unmanned aerial vehicle flight control signals and image transmission signals. By scanning and intercepting the radio frequency signals emitted by drones through passive detection at the receiving end, the layered experimental verification method and dual source detection and identification algorithm are used to verify that the system can detect and identify the number, type, and frequency band of drones in complex electromagnetic environments in cities. Yang et al. designed a passive radar array system that can detect drone signals, which uses a unified circular array to receive drone signal echoes. The experiment proves that the system can effectively distinguish between drones and estimate the flight speed of target drones. China DJI Corporation has launched a Yunshao UAV early warning system, which receives UAV signals through antennas, amplifies and demodulates the signals, and transmits the signal information to the system information platform, achieving spectrum detection and analysis of UAVs in the region.

2 Research Methods

2.1 Equipment and Facilities

In this experiment, MATLAB was selected as the simulation software. MATLAB is a commercial mathematical software produced by MathWorks in the United States, used in fields such as data analysis, wireless communication, deep learning, image processing and computer vision, signal processing, quantitative finance and risk management, robotics, and control systems. This software is mainly used to build the entire system model, process signal data, and output useful signals.

In addition, the experiment also used LABVIEW software as the upper end to display the output signal waveform and analyze it as a whole. Hardware selection:personal computer.

2.2 Technical Methods

A direct idea to achieve the detection of electromagnetic signals radiated by small unmanned aerial vehicles is to obtain time-series sampled signals in the ISM frequency band and analyze them. However, in noisy environments, transient features based on time series signals may suffer losses, and the amplitude may exhibit severe distortion, leading to a significant decrease in detection accuracy.

At present, the most widely used signal detection method is energy detection. Researchers start with energy and model the observed signal as a stationary random process. By calculating whether the energy accumulates to a certain value within a certain time interval or frequency band, they can determine whether the signal exists.

This method detects signals by comparing decision thresholds, which is simple in algorithm, low in computational complexity, and does not require prior information of the signal. Its drawbacks are also very prominent, with a significant decrease in detection performance under low signal-to-noise ratio conditions. The energy detection algorithm has become the most widely used detection method due to its lack of prior knowledge of signals and fast detection speed.

Traditional signal processing can start from the time domain or frequency domain, analyzing the similarity and correlation of signal waveforms in the time domain, which is more intuitive, but cannot reflect the relationship between frequency and time. At this point, time-frequency analysis needs to be introduced, which is an effective tool for unmanned aerial vehicle signal detection and recognition. By using various time-frequency transformation tools such as short-time Fourier transform, WVD distribution, wavelet transform, and Gabor expansion, signal analysis methods are no longer limited to the time or frequency domain, increasing the accuracy of signal description.

In this experiment, due to the lack of well preserved and powerful drones, simulation was used for the experiment.

Firstly, in MATLAB, a complex electromagnetic environment is simulated by directly using various signal sources. At the same time, the same method is used to simulate the signal source of drones, and most communication signals of drones operate in the 2.4-5.8GHz ISM frequency band. Therefore, special attention should be paid to the output frequency band of simulation signals. After building the system model in MATLAB, run and perform signal processing. Input the output signal into LABVIEW software and display the waveform. Analyze the data of the final waveform and draw conclusions.

2.3 Experimental Principle

Radio detection is used to identify drones by capturing radio frequency signals sent by drones and controllers. Each drone's radio frequency signal is not exactly the same and has its own characteristics. These characteristics are determined by the hardware and controllers of the drone, as well as the software and protocol patterns of the communication system. Even drones of the same model have subtle differences. The specific performance is that the signal carries a variety of information, including the specific frequency band, signal sequence pattern, energy distribution, jump pattern, interval time, etc. These features that can indicate the uniqueness of the signal transmitter are called RF fingerprints. It represents the inherent characteristics of the device itself and is highly recognizable. This method is considered to be a very promising UAV detection technology. However, radio detection is prone to interference from other signals in the environment, and the false alarm rate is high. Therefore, the effective detection of target signals from numerous interferences has become a major challenge for UAV radio detection, which is also the focus of this paper. UAV received signal modeling is as follows:

$$r(t) = \sum_{n=o}^{N-1} y_n(t) * h_n(t) + n(t) \tag{1}$$

In the formula, y(t) is the baseband transmitted signal, h(t) is the time-varying impulse response, N is the total number of transmitters, and n(t) is the additive Gaussian white noise. With the help of discrete Fourier transform, the complex time domain received signal can be converted into a spectrum diagram, and then the UAV signal can be detected and classified from the spectrum diagram.

3 Experimental Subject

3.1 Experimental Process

Firstly, input fdatool into Matlab, edit the required filter, and implement it in Simulink. From the device module, select the signal source and set it to 2.4GHz sine wave as the drone signal, 800MHz cosine wave, and 5GHz sine wave as the interference signal. Connect the three signals to the adder, filter them, and finally connect them to the oscilloscope, as shown in the following Figure 1.

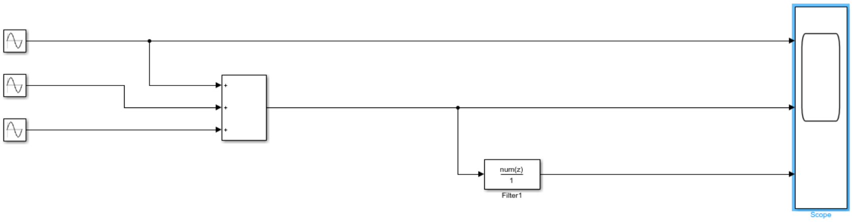

Fig. 1 Experimental structure diagram

The three channels of the oscilloscope display drone signals, complex signals, and filtered signals respectively. Click to run and observe the results.

3.2 Experimental Results

The following is the result of the oscilloscope display (see Figure 2).

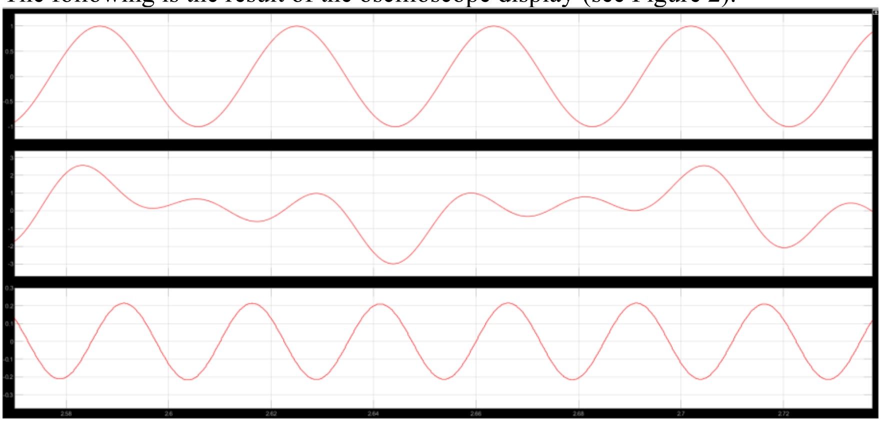

Fig. 2 Experimental results

In the figure above, the three channels respectively show the signal waveform of the UAV, the signal waveform received in a complex electromagnetic environment, and the result obtained after signal processing.

3.3 Discussion of Results

Judging from the experimental results, the filter designed in this paper can basically detect a required wave, but it is not perfect, and the output waveform still has defects. Comparing the output signal waveform of the UAV with the signal waveform obtained after filtering, it can be seen that the frequency of the filtered signal is slightly larger than the original output signal. And there is a slight distortion phenomenon may be the order of the filter is not enough, resulting in an imperfect filter.

4 Conclusion

The main problem studied in this experiment is the method of detecting drone signals in complex electromagnetic environments. Through simulation in Simulink, it basically simulates the detection of complex signals in the presence of external interference, and separates the required drone signals from them.

Although this simulation has been largely successful, there are still many areas that need improvement, such as the design of the filter, which can be slightly improved to make the filtered signal closer to the original waveform and minimize the distortion of the output waveform. In addition, other methods can also be used to complete this experiment, such as training and detecting RF signals on the spectrogram of the dataset using the YOLO framework CNN, and establishing a universal signal detection network based on the YOLO object detection network to combat signal detection difficulties in complex environments. In addition, time-frequency analysis and parameter estimation of drone communication signals can be carried out to improve the accuracy of time-frequency parameter estimation under low signal-to-noise ratio conditions. Different recognition methods can be adopted for Wi Fi and non Wi Fi drones, and the algorithm can be validated using actual drone signal data. A drone signal detection and recognition system can be built.

References

1. Su Zhigang, Yan Xiang, Han Bing, et al. Real time detection method for unmanned aerial vehicle RF signals under low signal-to-noise ratio conditions [J]. Signal Processing, 2023, 39 (05): 919-928.
2. Wu Jialu Detection and recognition methods for unmanned aerial vehicle communication signals under low signal-to-noise ratio [D]. National University of Defense Technology, 2021.
3. Qiu Shanshan, Si Xiaoliang, Li Hao, etc Simulation of Aircraft Electromagnetic Environment Effects [C]//Chinese Aeronautical Society, Chinese Academy of Aeronautics. Proceedings of the 5th International Forum on Civil Aircraft Avionics Systems in 2016. China Science and Technology Press, 2016: 5.

4. Duan Yalin, Xue Song, Zang Yunhua, et al. Simulation study of unmanned aerial vehicle communication countermeasures in complex electromagnetic environments [J]. Aerospace Electronic Countermeasures, 2018, 34 (05): 14-17+45.
5. Ge Jiaxin Intelligent Detection Method for Small Unmanned Aerial Vehicle Signal in Complex Electromagnetic Environment [D]. Academy of Military Sciences, 2023.
6. Liu Hao. Development and application of unmanned aerial vehicle countermeasure systems in security enterprises [J]. China Security, 2018 (06): 45-49
7. Li Fuqiang Research on Signal Detection and Separation Algorithms and Their FPGA Implementation [D]. Xi'an University of Electronic Science and Technology, 2016
8. Lei Qing Anti Drone Information. Suspected drone flying black at Hangzhou Airport, with the passenger plane hovering in the air for more than ten circles [EB/OL] https://www.sohu.com/a/402919523_120287438?_trans_=000014_bdss_dkmgyq June 19, 2020
9. Lin D. Research on intelligent photoelectric search and tracking technology for anti UAV in complex background [D]. University of Chinese Academy of Sciences (Xi'an Institute of Optics and Precision Mechanics, Chinese Academy of Sciences), 2020.
10. Luo Huaihong, Lu Yingqi. Current Status and Development Trends of Anti "Low Slow Small" Drone Capabilities Abroad [J]. Aviation Missile, 2019 (06): 32-36.
11. DeTect Inc, An Overview：Radar Technology for Assessment of Avian Issues At Wind Energy Project Sites [Z], 2005.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (http://creativecommons.org/licenses/by-nc/4.0/), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.