UAV detection algorithm based on the difference of power dispersion

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Abstract. With the development and popularization of UAVs, illegal UAV accidents occur frequently. The complex signal environment in the city brings difficulties to detect UAV signal. In order to detect the UAV signal in the complex environment, this paper proposes a UAV detection algorithm based on the difference of power dispersion in time. Firstly, the algorithm performs short-time Fourier transform on the signal to obtain the time-frequency matrix. Secondly, the fixed frequency interference in the matrix is filtered by the local adaptive threshold. Finally, the UAV image transmission signal is detected by the discrete difference in time between image transmission signal and WiFi. Simulation results show that the algorithm can detect UAV signal under constant frequency interference and WiFi interference.

1. Introduction

At present, the means of UAV detection include radar, acoustic wave, infrared and radio detection as shown in the reference [1]. Reference [2] [3] proposed radar detection algorithm, but the size and material of UAV will have a great impact on the detection results. Reference [4] proposed a UAV detection and recognition method based on audio signal analysis. This algorithm can realize UAV detection and recognition, but this algorithm is only suitable for suburban open environment. Reference [5] proposed a visible light detection algorithm for small UAV based on visual saliency, but it is not suitable for night working scenes. The signal detection algorithm proposed in document [6] can realize the single signal detection in WiFi signal, UAV flight control signal or Bluetooth signal, but it can not recognize the mixed signal. Literature [7] carries out mechanics on wireless traffic to detect UAV, and literature [8] carries out in-depth learning on UAV frequency hopping signal and background spectrum template to achieve the purpose of detection. These two methods require a large number of data sets and are not suitable for non cooperative UAV detection. Literature [9] analyzes the spectrum characteristics of UAV, but does not propose detection means, which can not be applied to engineering. The local adaptive threshold algorithm proposed in reference [10] can filter the fixed frequency signal, but it can not filter the WiFi signal.

Most UAV detection algorithms do not well solve the interference between WiFi signal and fixed frequency signal due to different working scenes. To solve this problem, a UAV image signal detection algorithm based on the difference of power dispersion in time is proposed. The algorithm can work in the complex signal environment with fixed frequency interference, WiFi interference and noise interference.
2. Algorithm Principle

2.1 Adaptive Threshold Filtering

Assuming that the time-frequency matrix obtained by short-time Fourier transform of the signal is $S_1$. The adaptive threshold is $T$, which means each row of matrix $S_1$ corresponds to a threshold, and the threshold is related to the size and distribution of each element of the row. For row $i$ of matrix $S_1$, elements greater than the threshold $T(i)$ are retained, and elements less than $T(i)$ are set to zero, that is:

$$
S(i,j) = \begin{cases} 
S(i,j) & S(i,j) \geq T(i) \\
0 & S(i,j) < T(i) 
\end{cases}
$$

(1)

In equation (1), $S_1(i,j)$ represents the elements in row $i$ and column $j$ of the matrix.

The threshold $T(i)$ is the sum of the maximum and minimum values of line $i$ multiplied by the dynamic factor $\mu$, that is:

$$
T(i) = \mu \times \{\max[S(i,:)] + \min[S(i,:)]\}
$$

(2)

The value range of $\mu$ is (0,1) and the step size is 0.04. The adaptive threshold $T(i)$ is to find the most appropriate value of $\mu$. The initial value of $\mu_0 = m/M$, $m$ is the average value of the elements in line $i$, and $M$ is the maximum value of the elements in line $i$.

The selection steps of $\mu$ are:

1) $\mu_0$ is the initial value, and the threshold $T(i)$ at this time is calculated;
2) Calculate the sum of the elements in line $i$ of $S_1$ after the current threshold truncation processing, which named $A_0$;
3) $\mu$ add a step to calculate the sum of the elements in the $i$-th line of $S_1$ after the threshold truncation, which named $A_1$;
4) Calculate the ratio $K$ between $A_0$ and $A_1$, judge whether the first-order difference of $K$ is the maximum value. If yes, output the current value $\mu$, if not, skip to step (2);
5) Get the best $\mu$ Value.

When the optimal adaptive threshold is found, the fixed frequency signal in the time-frequency matrix can be filtered, and the time-frequency matrix at this time can be recorded as $S_2$.

2.2 Signal Time Difference Detection

In order to reduce the complexity of subsequent calculation and highlight the characteristics of image transmission signal, the time-frequency array $S_2$ is binarized, and the appropriate threshold $TH$ is selected to set the elements of matrix $S_2$ to 0 or 1. The threshold $TH$ is the arithmetic average of the maximum and average values in the matrix $S_3$, that is:

$$
TH = \frac{\max(S_3) + \text{mean}(S_3)}{2}
$$

(3)

The time-frequency matrix after binarization is recorded as $S_3$. Compared with the frequency band without image transmission signal, the value in the frequency band with image transmission signal will be larger. While the bandwidth of the image transmitted signal is 20MHz. Therefore, the time-frequency matrix $S_1$ can be divided into groups every 10MHz, as shown in Figure 1.

Figure 1 is an example matrix, not the real time-frequency matrix $S_3$. The horizontal direction of the matrix represents the time dimension and the vertical direction represents the frequency dimension. A column of the matrix represents the energy value of each frequency’s component of the signal after Fourier transform in a window, and a row of the matrix represents the energy value of a certain frequency of the signal in different time components.
Figure 1 time frequency matrix after grouping

The colors in the matrix represent their groups. The groups in the figure from top to bottom are the first group to the fourth group, the second group of simulated image transmission signals and the third group of simulated WiFi signals. Calculate the value of each group. If the group value is larger than others, it is considered that there may be UAV image transmission signal. The specific method is to calculate the group value and average group value. If one group value is greater than twice average group value, it is suspected to be an image transmission signal. There are 4 groups in the figure above, with group values of 0, 32, 9 and 0 respectively, and the average group value is 10.25. The value of the second group is greater than twice group average value, so there may be image transmission signals in this group.

In addition, because the image transmission signal is characterized by uniform distribution in the whole time, WiFi interference only occurs briefly. It can be seen that the dispersion degree of WiFi signal is high and the dispersion degree of image transmission signal is low. Therefore, the second group is divided into several areas again (actually 5 areas). As shown in Figure 2.2:

![Figure 2 areas division within the group](image)

In order to compare the dispersion degree, Figure 2 contains the data of the second group and the third group. It can be seen that the values of each area in the second group are similar, while the values of second area in the third group are larger than others. In this paper, the range is used to judge the dispersion of the signal. Calculate the range (area’s maximum minus minimum) of the two groups of data. If the range is less than the areas average, it is judged as a image transmission signal, otherwise it is an interference signal. In Figure 2 (a), the values of the three areas are 8, 12 and 12 respectively, the average value of the area is $(8 + 9 + 9) / 3 = 10.7$, and the range is 4, which is less than the average value of the area, so there is a image transmission signal in this group; In the (b) figure, the three area values are 0, 9 and 0 respectively, the area average value is 3 and the range is 9, which is larger than the area average value, so it is judged as an interference signal.

The general flow chart is as follows:
3. Experimental Results And Analysis

3.1 Experiment 1
When the received signal involve a image transmission signal, WiFi and constant frequency interference. Firstly, Perform STFT on the received data to obtain the time-frequency matrix $S_1$. The time-frequency diagram is shown in Figure 4.

The sampling rate of the receiver is 128M/s, the bandwidth is 128M, the center frequency is 2.44GHz and the observation time is 25ms. The UAV model for the experiment is Dajiang spirit 3S. By performing short-time Fourier transform on the received signal, a time-frequency matrix can be obtained. The matrix has 128 rows and 96061 columns, The vertical axis is the normalized frequency, the 0 frequency represents the 2.44GHz center frequency, and the horizontal axis is the number of sampling points, with a total of 3200K sampling points. The figure indicates the image transmission signal, WiFi signal and fixed frequency signal. It can be seen that the fixed frequency signal exists in the whole time period in a fixed frequency band. The discontinuity of image transmission signal occurs within the observation time. WiFi signals only appear briefly for a period of time.

Perform adaptive threshold filtering on matrix $S_1$ to obtain matrix $S_2$, as shown in Figure 5(a). It can be seen that the fixed frequency signal in the figure has been filtered out. Binarize the matrix $S_2$ to obtain a new time-frequency matrix $S_3$, as shown in the Figure 5(b):
Divided the time-frequency matrix $S_3$ into groups every 10MHz, which can obtain Table 1.

| number | value | number | value |
|--------|-------|--------|-------|
| one    | 0     | seven  | 0     |
| two    | 0     | eight  | 3098  |
| three  | 203   | nine   | 64144 |
| four   | 177186| ten    | 12106 |
| six    | 6575  | twelve | 0     |

From Table 1, we can get twice group average value is 66712.5. Therefore, the fourth and fifth groups are suspected to be image transmission signals.

Table 2 the values of the fourth and fifth groups after area division

| Area number | Fourth value | Fifth value |
|-------------|--------------|-------------|
| one         | 46568        | 38705       |
| two         | 29988        | 17204       |
| three       | 30610        | 22987       |
| four        | 26575        | 18443       |
| five        | 43444        | 39604       |

The area range of the two groups is 19993 and 22400, and the area average value of each group is 35437 and 27388.6. The range of the fourth group and the fifth group is less than its regional average value, so it is judged as image transmission signal, and the bandwidth is about 2.446MHz-2.466MHz according to the number of groups.

3.2 Experiment II

When there is no UAV signal, but WiFi interference, perform this algorithm. The time-frequency diagram of the signal is shown below. It can be seen that there is obvious WiFi interference in the diagram.

![Figure 6 time frequency diagram when there is no UAV](image)

After adaptive threshold filtering and binarization, the time-frequency matrices $S_2$ and $S_3$ are obtained. The time-frequency diagram is shown in figure 7:
After grouping matrix $S_3$, the group value table of each group is obtained:

| number | value | number | value |
|--------|-------|--------|-------|
| One    | 0     | seven  | 3     |
| two    | 1     | eight  | 289   |
| three  | 0     | nine   | 59863 |
| four   | 59    | ten    | 7050  |
| five   | 14    | eleven | 0     |
| six    | 21444 | twelve | 0     |

The sixth group and the ninth group are larger than twice average value of the group. It is divided into 5 areas to obtain the value of each area, as shown in table 4. Obviously, the range between the two groups is larger than the average value of the area, so it is judged as an interference signal.

| number | Fourth value | Fifth value |
|--------|--------------|-------------|
| one    | 46568        | 38705       |
| two    | 29988        | 17204       |
| three  | 30610        | 22987       |
| four   | 26575        | 18443       |
| five   | 43444        | 39604       |

4. Conclusion

Due to the difficulty of detecting the UAV image signal in complex environment, this paper proposes a UAV detection algorithm based on the difference of power dispersion. This algorithm can detect the UAV image signal and its working frequency in the case of fixed frequency interference and WiFi interference. Simulation results show the effectiveness of the algorithm.

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