Weak Moving Target Detection Based on Improved Wavelet De-noising

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Abstract. When the weak moving target is far away, the signal of the detecting system is very weak, and the background noise has a great influence on the detection results. In this paper, a method based on kernel theory is proposed, this method can distinguish target signal from background noise signal. To suppress background noise, a new threshold function based on wavelet packet decomposition is proposed. In the high-speed camera, the above two methods are used to detect weak moving targets. The experimental results show that the method has great advantages in the detection of small moving targets.

1. Introduction

When the target is detected in a long distance, the image of the target takes up very few pixels, and when the target move at a low speed, the target spans few pixels. With the influence of the complex background, the target is almost annihilated in the image.

Summarizing the previous detection methods of small targets, we find that they mainly use two methods, one is to detect through a single image, the other is to detect through the relationship between image frames. Moreover, previous scholars have successfully applied a large number of spatial filtering techniques in image de-noising preprocessing, mainly including mean filtering, weighted average filtering, median filtering and dilatory operation. Top-Hat filtering (top hat) and two-dimensional least mean square (TDLMS) are common and easy to use filtering methods. In many cases, time-domain filtering technology will be chosen to deal with image processing based on frame sequence. The optical flow method, background subtraction method and frame difference method are the classical common target tracking algorithms. Another detection method is multi-filter combination and time multi-scale segmentation detection.

Time information and space information are two important dimensions of video sequence. There are many ways to use these two aspects of information at the same time, such as STLCF filter based on neighborhood information. In simple background such as sky and ocean, although these methods have achieved good detection results in image sequence tracking, but in a slightly complex background, the above methods are there are many limitations.

Reasonable use of the wavelet analysis method can effectively remove the noise in the signal and retain the real signal value. The basic principle of de-noising with wavelet analysis method is that the basic idea of wavelet threshold de-noising is to set a critical threshold value λ first, if the wavelet coefficient is less than λ, it is considered that the coefficient is mainly caused by noise, and this part of
coefficient is removed; if the wavelet coefficient is greater than $\lambda$, it is considered that this coefficient is mainly caused by signal, keep this part of coefficient, and then carry out wavelet inversion for the processed wavelet coefficient[1]. Get the de-noised signal. So we should focus on the selection of appropriate threshold and threshold function, which are very important for the application of wavelet de-noising. In the research of other scholars, two kinds of methods are mainly used, one is the soft threshold method, and the other is the hard threshold method. When we choose a suitable threshold for wavelet analysis, many methods are involved, such as unbiased risk estimation criteria, minimax criteria, fixed threshold criteria and hybrid criteria, and some threshold determination methods, such as top threshold, SUREShrink threshold and adaptive threshold [2].

2. System Architecture
This system is used to detect weak moving targets in long distance. The system block diagram is shown in Fig.1. When the target is moving, the system sensor collects the signal and the signal reaches the de-noising module. The de-noising method is improved wavelet de-noising, which aims to remove part of the background noise. Then the signal enters the detection module. The detection method is kernel method, which aims to find the moving target.

3. Methods and theories

3.1. Improved threshold function for wavelet analysis
In wavelet analysis, there is a big difference between the coefficients of noise and the coefficients of the target signal. Set a reasonable threshold value, the signal where the coefficient is smaller than the threshold value can be considered as noise, and the signal where the coefficient is larger than the threshold value can be considered as an effective signal [3]. Use the threshold value to divide the signal and noise, and then distinguish the noise and effective signal, so a reasonable threshold value function can achieve a better de-noising effect. There are many methods to set the threshold value of wavelet function, but these linear or approximate linear threshold functions must have limitations, and they cannot effectively segment the signal and noise in many cases. This linear function has the problem that selecting a small threshold value cannot effectively remove the noise. When the threshold value is too large, some signals will be mistaken as noise, which will lead to signal distortion.

Given above problems, a new threshold function based on wavelet packet decomposition is proposed.

$$I_j(k) = \lambda_j + \alpha_j \left| I_j(k) - \lambda_j \right| e^{\frac{I_j(k) - \lambda_j}{M_j - \lambda_j}} - e^{\frac{I_j(k) - \lambda_j}{M_j - \lambda_j}}$$

(1)

$$\alpha_j = \frac{kq_j}{2^j + 1}$$

(2)
Among them, $\alpha$ is the relevant factor. From the publicity, we can see that the information factor has a great influence on the threshold function. In this paper, the correlation factor $\alpha$ is adjusted by using kurtosis, which is a numerical statistic reflecting the distribution characteristics of random variables. After the kurtosis of the signal is estimated, $\alpha$ is calculated by the formula.

3.2. Detection of target signal based on kernel function

Kernel method is widely used in machine learning and pattern recognition. Its main purpose is to measure the similarity between two feature vectors. Usually, the problem of data analysis we are faced with is to separate two eigenvectors of different classes in a certain Eigen space by the nonlinear method. After using the positive definite kernel corresponding to a dot product in the feature space, we can express everything by the kernel formula. So we can calculate in low dimensional feature space, but the dimension of point product feature space is very high.

The definition of the kernel is given by input space and feature space, which is represented by a function. It should be emphasized that in our application, the similarity between two signal segments is the significance of kernel function [4]. The signal similarity between the background and the background is certainly different from that between the target and the background. With this feature, we can analyze the image sequence in the video in the time domain, and then detect the signal, even the weak signal, that is, the weak target motion.

When we apply kernel method to weak signal detection, the signal of time series is mapped to another high-dimensional feature space. In this space, the target signal we need is amplified, and the noise signal we don't need is weakened, which is more helpful to detect the weak motion of the small targets.

A weak signal detector is designed based on kernel function, so it must meet the following three conditions [5].

- The first is the one-to-one correspondence between the characteristic space $f$ and the amplitude.
- The second is that the mapping in eigenstate $f$ is independent of the value of signal or noise.
- The third condition is that the detector can effectively weaken the noise signal and enlarge the target signal.

The detection model is described as follows:

When the target appears and moves,

$$ P_0 : Y = x(r,t) + p(r,t) $$

When the target does not appear or is moving,

$$ P_1 : Y = x(r,t) $$

$p(r, t)$ is the signal of the target.

When we choose a correct kernel function, the value of the kernel function satisfies the following two formulas.

$$ E[k(x(r,t)+p(r,t),x(r,t))] \neq E[k(x(r,t),x(r,t))] $$

$$ E[k(x(r,t)+p(r,t),x(r,t)+p(r,t))] \neq E[k(x(r,t),x(r,t))] $$

4. Experiment result

At the beginning of the experiment, the data with complex noise and weak signals are used to simulate the signal and compared with other de-noising methods to verify the effectiveness of the de-noising method.

The traditional de-noising method is used to process the analog signal, and the experimental results are shown in Fig. 2. The experimental results of the de-noising method described in this paper are shown
in Fig. 3. The experimental results show that this method can improve the signal-to-noise ratio of the signal to 15dB, while the signal-to-noise ratio of other methods to 5dB.

![Figure 2. The results of traditional wavelet analysis](image)

By adding moving objects to the image sequence collected by Phantom-V641 camera, the simulation data can be obtained at the frame rate of 2000 FPS. Then this method is applied to the moving object detection in image, and compared with other detection methods.

In our subsequent experiment, the high-speed came ra was placed on the top of our experimental building, with a height of about 20 meters. The camera pointed axially to a road under the experimental building. On the road, a colleague rolled out a basketba ll to make it roll slowly along the road. At this time, we recorded a video with high-speed photography level, which contains the picture of a basketball rolling along the road.

![Figure 4. STLCF](image)
The processing results of the improved method proposed in this paper are as shown in Fig. 8.
Using the traditional target detection method, the experimental results are as follows. Fig. 4 is the result of STLCF and you can see the unclear track. Fig. 5 is the result of Wavelet Transform, and you can see the track, but there is a lot of noise. Fig. 6 is the result of Top-Hat, with a little more noise, you can't see the track. Fig. 7 is the result of TBD, with a lot of noise, you can't see the target track at all.

To verify the effectiveness of the proposed de-noising method, we use other methods to process the video. Through table 1, we can see that different methods have different false alarm rates and correct rates. We can see that the best one is the combination of kernel method and the improved wavelet transform in this paper.

Table 1. Comparison of different methods

| Method     | False Alarm Rate | Detection Probability |
|------------|------------------|-----------------------|
| kernel function Improved wavelet transform | 1.24% | 77.37% |
| Improved wavelet transform | 7.32% | 51.52% |
| Traditional wavelet transform | 8.54% | 59.54% |
| STLCF      | Improved wavelet transform | 18.56% | 47.78% |
| Top-Hat    | Improved wavelet transform | 64.38% | 35.48% |

Compared with the above results, the method proposed in this paper has the best effect. It can see the track of the moving target, and other noises are also suppressed, to achieve the purpose of detecting the weak moving target, and get a significant effect.

5. Conclusion
A detection method of weak moving target based on kernel theory and a de-noising method based on wavelet packet transform are proposed. This method is suitable for detecting weak moving target. Simulation and experiment verify the effectiveness of the method, which can improve the signal-to-noise ratio from -8dB to 15dB, and the clarity of the image obtained from the experiment is also significantly improved. In the future research, not only the time information of image sequence can be used, but also the spatial correlation of pixels can be used.

References
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