Signal Denoising of Multi Element Infrared Signal Based on Wavelet Transform

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Abstract. General target detection system is based on active detection method, which is usually of poor concealment and bulky. In order to improve the concealment and dexterity of airborne detection, an airborne infrared scanning imaging system for ground vehicles based on passive infrared detection is proposed. In order to solve the problem of false alarm and false recognition when the rotary airborne multi-element infrared detection is used to identify armored vehicles on the ground, based on the wavelet theory, the infrared signal output from the air to ground rotary detection system is denoised by wavelet. The denoising threshold function suitable for the rotating multi element infrared detection system is constructed. Through calculation analysis and experimental verification, the fours-layer coif wavelet basis function is the best. On the premise of not losing the infrared information of the original armored vehicle target, the output waveform is flat when there is no armored vehicle, and the output waveform is smooth when there is armored vehicle target. It provides a theoretical basis for the later realization of armored vehicle type identification.

1. Introduction
Infrared detection system uses the radiation difference between vehicle target and natural background to realize recognition[1]. Because the infrared detection depends on the infrared radiation received by the sensor, it is easy to be affected by bad weather conditions, such as fog, dust, haze, fireworks[2]. These interferences can contaminate the output signal of the sensor. In order to realize the recognition and detection of armored vehicles, it is necessary to get clean denoising signals. In this paper, the high-speed data acquisition card is used to collect and analyze the data of multiple infrared sensors. The common wavelet denoising methods include modulus maximum denoising method, threshold denoising method, translation invariant method and so on. Soft and hard threshold function is the most widely used denoising method. This method is based on the different wavelet coefficients of signal and noise after wavelet transform, but there are some disadvantages[3-4]. The hard threshold is discontinuous, which makes the reconstructed signal oscillate. Although the soft threshold function is continuous, it has a fixed deviation from the real wavelet coefficients, so the reconstruction accuracy decreases. According to the characteristics of multi element infrared scanning signal, a threshold function is proposed, and the experimental verification of infrared detection signal denoising effect is carried out[5-6]. The denoising effect is improved to a certain extent compared with the traditional soft and hard threshold, and the
signal-to-noise ratio and mean square error are greatly improved.

2. Air-ground rotary infrared scanning imaging model for ground vehicles
The principle of the rotary infrared scanning detection system is shown in Fig. 1. The ground vehicle is taken as the reference coordinate system, the forward direction of the ground vehicle is X-axis, and the moving speed is \( v_r \). The unmanned aerial vehicle rotary infrared scanning detection platform, it is detection distance of \( l \), infrared detector field center axis and the angle between the ground plumb axis \( \theta \), scanning angular velocity is \( \omega \), the unmanned aerial vehicle platform moves in the negative direction of the X-axis and the velocity is \( v_v \). The rotary infrared scanning detector receives the infrared radiation characteristics of the reflected environment from the body of the ground vehicle or the surface of the vehicle, which is \( S_1, S_2 \) and \( S_3 \).

\[
\begin{align*}
\sin \theta \cos \omega t + (v_r - v_v) t \\
\sin \theta \sin \omega t
\end{align*}
\]

In Eq. (1), relative velocity is \( V = v_r - v_v \), detection time is \( t \).

3. Wavelet denoising principle based on infrared radiation signal
In order to obtain the position information of armored vehicle, it is necessary to analyze the characteristics of the output signal of infrared sensor. The working principle of pyroelectric infrared sensor with normal temperature system is adopted. When the armored vehicle passes through the field of view, the detection unit will output the signal generated by the infrared radiation of the vehicle, which
is a kind of clock pulse signal. When the intrinsic radiation of ground vehicles and the radiation of reflected background reach the detector through atmospheric transmission and optical system conversion and generate the response voltage of radiation signal can be obtained as,

$$V_S = r_p^* (\lambda) r_{air}^* (\lambda) \int_{\lambda_1}^{\lambda_2} \left[ \frac{I^*}{L^2} - \Phi^* \times \omega \right] A_0 R (\lambda) d\lambda$$

(2)

In Eq. (2), $V_S$ is the signal voltage, the detection band of the infrared detection system is $\lambda_1 - \lambda_2$, $A_0$ is the area on which the target radiation area is mapped onto the detector sensitive surface. Because the frequency of jamming infrared signal is different from that of armored vehicle, the frequency of effective signal is often in low frequency band, while jamming noise signal is usually in high frequency band. Therefore, wavelet analysis can be used to process and analyze the signal. The signal polluted by white noise can be obtained as,

$$d_i = f_i + \varepsilon \times z_i \quad i = 1, 2, ..., N$$

(3)

In Eq. (3), $d_i$ is a noisy signal, $f_i$ is the real signal, $z_i$ is white Gaussian noise.

The basic step of wavelet de-noising is to carry out multi-scale wavelet transform on the output signal of the sensor, transform it from time domain to wavelet domain, and then extract the wavelet coefficients under different scales, remove or weaken the wavelet coefficients belonging to noise signal as far as possible, and then reconstruct the wavelet signal with inverse wavelet transform, so as to get the signal after denoising.

4. Response analysis of ground vehicles radiometric projection size to infrared signal

The infrared detection system is installed on the mechanical turntable with adjustable elevation angle to form the rotary infrared detection system. The rotating infrared detection system is placed on a high platform, and the scanning angle is adjusted to scan the ground area. The high-speed data acquisition card is used to collect the output signal of the sensor, and the parameters such as sampling frequency and sampling length are set in the upper computer interface. When all parameter settings are adjusted to the appropriate state, start to collect the sensor output signal, and save the data to the local hard disk. After the detection experiment is completed, the saved signal data is imported into Matlab, and the signal processing and analysis are realized by Matlab programming[7-8]. Fig. 2, gives a schematic analysis of infrared radiation signal broadening under uncertain conditions.

![Fig. 2 Radiation area principle of armored target](image-url)
The infrared signals with and without targets are shown in Fig. 3. When there is no target passing through the field of view of the infrared sensor, the detector outputs only the background signal, which is a high-frequency signal with a constant amplitude. When the detector's field of view sweeps the target, the detection unit circuit outputs the signal generated by receiving the vehicle target radiation, that is, the signal mutation point appears at the moment of the field of view sweeping the target, and its waveform is similar to a bell shaped pulse.

![Infrared signal contrast map with or without target](image)

Fig. 3 Infrared signal contrast map with or without target

5. The simulation and experimental analysis

5.1 Simulation analysis

According to the rotating scanning detection mechanism, when the infrared detector flies in one direction with velocity along one direction through the flight platform, its scanning line intersects with the ground. Suppose the maximum detection interval is $\Delta R \leq 2m$, the diameter of detection area is $40m$, the detection altitude is $H = 30m$, the detection angle is $\theta = 30^\circ$, the rotary speed is $\omega = 4r/s$, and the flight speed is about $v = 12m/s$. The scanning trajectory of an independent single element detector is obtained as shown in Fig. 4.

![Multi element infrared rotary scanning system](image)

Fig. 4 Multi element infrared rotary scanning system

In Fig. 4 the black arrow represents the flight direction and the blue track represents the scan trajectory. When the armored vehicle exists in the main detection area of the front end indicated by the
enlarged image, the detector will capture the infrared characteristic area of the armored vehicle. The threshold method is used to process the infrared signal. The restoration effect of reconstructed signal is closely related to the selection of threshold value[9]. If the threshold value is too large, some useful information of signal will be lost, which is unfavorable to armored vehicle recognition. If the threshold is too small, the noise can not be effectively suppressed, and it is not conducive to the identification of armored vehicles.

The noise signal of infrared sensor is decomposed by fours-layer wavelet can be obtained as,

\[ S = cA_4 + cD_4 + cD_3 + cD_2 + cD_1 \]  \hspace{1cm} (4)

In Eq. (4), \( cA_4 \) is the fourth level approximate signal of the signal, \( cD_4 \sim cD_1 \) are the detailed information of each layer of the actual signal. Noise often exists in these details. The threshold method adapted to the detection system is used to filter the signal, so as to reconstruct the low noise signal without losing the signal characteristics[10].

5.2 Experimental analysis

The traditional soft and hard threshold function and the new threshold function proposed in this paper are used to denoise the infrared signal of the detection system. The processing results are shown in Fig. 5 and the denoising effect is shown in Table 1. In Fig. 5, the traditional hard threshold function has oscillation phenomenon in the denoising process, but when the soft threshold function is used for denoising, there is always a small fluctuation of the signal at no target time, which is caused by the fixed deviation between the soft threshold wavelet coefficient and the real wavelet coefficient.

![Fig. 5 Results of wavelet analysis](image)

The new threshold function proposed in this paper is used to process and analyze the infrared signal, which ensures the smoothness of the waveform without losing the detailed information, which is conducive to the compilation of armored vehicle recognition algorithm through de-noising waveform. According to the data analysis in Table 1, the SNR of the new threshold denoising function is 34.50% higher than that of the traditional soft threshold function, and 17.52% higher than that of the soft threshold function, while MSE is reduced by 16.15% and 20.77% compared with the traditional soft threshold function.
Table 1: Comparison of denoising effects of three threshold functions

| Threshold        | SNR   | MSE  |
|------------------|-------|------|
| Hard threshold   | 5.2892| 0.157|
| Soft threshold   | 6.0535| 0.151|
| Proposed threshold | 7.1140| 0.130|

The traditional soft and hard threshold function and the new threshold function proposed in this paper are used to denoise the infrared signal of the detection system.

6. conclusions
In this paper, wavelet analysis and threshold de-noising theory, the detection data of multi-element infrared scanning detection system are processed by wavelet decomposition and threshold denoising. The denoising effect of the new custom wavelet threshold function is compared with that of the traditional soft and hard threshold function. The results show that the threshold function proposed in this paper is better than the traditional denoising function in signal-to-noise ratio and mean square error. It can be used to design target detection and recognition algorithm in the later stage, realize the detection and recognition of vehicle targets by infrared detection system, and do a good job of data support, which is conducive to improve the recognition rate of the system.

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