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A new infrared small and dim target detection algorithm based on multi-directional composite window

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HIGHLIGHTS

- Gray characteristic analysis is used in infrared dim small target detection.
- Gray characteristic of different structure is investigated and acquired through a detection window.
- We introduce a detection window with eight directions and three levels.
- A novel detection pretreatment is adopted for reducing the runtime.
- Parameters optimization method based on fuzzy control theory is designed.

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ABSTRACT

This work presents a new method based on gray characteristic analysis for infrared dim small target detection under complex backgrounds. Firstly, an improved detection window with eight directions and three layers is introduced to investigate the gray distribution characteristic of different structure in an infrared image. Secondly, we adopt a pretreatment process based on morphology filter and mean filter to reduce the running time and propose a detection rule on characteristic analysis for infrared targets. Meanwhile a new parameter optimization algorithm based on fuzzy control theory is employed so that the detection rule could be independent of the initial parameters. Finally, experimental results indicate that the proposed method can effectively detect the dim small targets and has better tracking performance.

1. Introduction

Infrared dim small target detection has been extensively studied and used in several areas such as infrared target tracking, precise guidance and distant early warning. However, infrared targets have their own characteristics which make the detection and tracking work quite difficult. As imaging distances of targets are always far, they only occupy several pixels in the image. In addition, due to noises introduced by atmospheric radiation and background noises of imaging sensors, the targets are easily drowned by them and have no concrete shapes and textures. Hence we know it is rather difficult to detect targets exactly from infrared image.

In the past decades, many target detection algorithms have been put forward. Common typical algorithms of target detection are as follows:

Background prediction algorithm [1,2]: Background prediction algorithm, also named as background suppression algorithm, is a single frame target detection algorithm. From this algorithm we can conclude that infrared radiation spatial distribution has a strong relevance in background area instead of the target area. According to this conclusion, we obtain a prediction image by predicting infrared image and then employ the difference of the original image and filtered image to represent a residual image where SNR (signal-to-noise ratio) could be improved through suppressing background and enhancing infrared target. Algorithm achieves the purposes by segmenting the residual image. The selection of prediction template, when predicting the original infrared image, is key factor for the algorithm performance. Median filter [3] template, a kind of typical spatial filter template based on nonlinear smooth technology, is used to set gray value as the median of all

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the pixels in neighborhood window. Other filter templates also are used widely, such as high-pass filter and mean filter [4]. This kind of algorithm is easy to be implemented in real-time hardware system and has been successfully employed to detect the infrared dim target. However, there are still some key problems such as the detection rate, false alarm rate, especially under the conditions of heavy clutter.

Morphological filtering algorithm [5,6]: As a form of nonlinear filter, morphological filter has been widely applied in the field of image processing and it is an effective method for infrared dim small target detection. A morphology filtering image is obtained through morphology open operation, where the infrared dim small targets can be removed by some pre-defined structuring morphological elements in respect that the target area is lesser. Then a residual image, in which the signal-to-noise ratio is enhanced, is represented by the difference of the original image and the filtered images. Detection results can be presented by segmenting the residual image. Among the morphological filtering algorithm, Top-Hat [7] algorithm is a representative algorithm, which morphology open operation and morphology close operation are adopted simultaneously. However, algorithms based on morphological filter perform well only when SNR is relatively high after the infrared image has been preprocessed.

Wavelet transform algorithm [8,9]: The basic idea of wavelet transform algorithm is that the infrared image has a large area continuous distribution state and the intensity of the infrared radiation presents a gradual transition state in background area. Therefore the infrared image has a strong relevance for gray distribution and constitutes a 2-D stationary random process. The intensity of the infrared radiation in target area has nothing to do with the intensity in background area and it is generally higher than that in background. Therefore, the infrared image can be categorized into two sub-bands: one contains high frequency components and the other contains low frequency components. Infrared dim small targets can be detected by extracting the high frequency components from infrared image after wavelet transform and analyzing the high frequency data. Target detection, based on the wavelet transform to image segmentation, is adopted in infrared detection system widely. But these algorithms are so complex that the performance of real-time capability is disappointed owing to their heavy computation and high capacity memory demand.

Image segmentation algorithm [10,11]: This kind of algorithm divides the infrared image into two parts after obtaining the optimal class variance and adaptive threshold by calculating the gray difference between dim small targets and background. However, this algorithm is inappropriate for complicated background, which is difficult to be described using one model.

Principal component analysis [12,13]: This algorithm has been developed with blind resources separation of signals, that is, correlation of multi-channel observed signals is removed, and principal components hidden in mixed signals are received. Since the target is independent of background in infrared image sequence, target and background can be regarded as principal components from mixed signals. Through analyzing these principal components, we can remove correlation of infrared image sequence and finally complete the separation of target and background respectively.

Detection algorithm based on entropy [14,15]: Entropy is an expression of capacity that signal contains information. The acuteness degree for area gray is reflected by area information entropy in an infrared image. There are many different categories area which have different quantity of information in infrared image, while the information entropy is different in various areas. Since there are great differences in quantity of information between target area and background area, namely the information entropy, it can be used to realize the detection algorithm.

Detection algorithm based on the analysis of the pixels [16,17]: The key of this algorithm is to utilize the change of image pixel patterns to realize the infrared target detection. The simplest one is to use the information obtained from the adjacent frames difference to detect the infrared small targets. This method is simple and has good adaptability to dynamic environment, but it is not easy to split out the infrared target completely, which leads to the target overlap between the two frames and causes false detection, that means it only detect part of the target.

In addition to the algorithms mentioned above, there are many other algorithms adopted broadly, such as higher-order statistics [18], dynamic programming [19], local binary patterns [20], and genetic algorithm [21]. Most of the target detection algorithms have lower detection accuracy and robustness under various complex backgrounds. Their performance relies heavily on the initial parameters. In order to improve the detection accuracy and robustness, a novel algorithm based on gray characteristic analysis [22,23] is put forward in this paper. The idea of gray characteristic analysis algorithm is that infrared image under complex background is considered as an image composed of different category structures. Various area category models are established after classifying the infrared image, which are based on gray value characteristic or direction characteristic. Firstly, we observe and investigate the gray characteristic distribution of different structures in an infrared image such as the target area, clean-sky area, middle-cloud area, edge-cloud area and broken-cloud area. To make a distinction between object and background, the algorithm proposed in this paper introduces a detection window with eight directions and three layers to calculate the gray mean respectively. Then, a pretreatment process based on morphology filter and mean filter is introduced to reduce running time. In the following, a further comparative analysis on gray characteristic is applied to detect targets precisely, including designing a detection rule and searching optimal arguments based on fuzzy control theory simultaneously. At last, experiments are conducted under normal infrared image and infrared image with additional noise and the results validate that the proposed method can significantly improve the accuracy and robustness of dim small target detection and tracking under complex backgrounds.

The rest of the paper is organized as follows. Section 2 analyzes the gray characteristic of different structure in an infrared image; Section 3 describes an infrared dim small target detection algorithm based on the gray characteristic analysis; Section 4 elaborates experimental results and conclusions.

2. Gray characteristic analysis

In this work, based on analyzing the gray distribution characteristics, infrared image can be divided into five gray structures: clean-sky area, middle-cloud area, edge-cloud area, target area and broken-cloud area. The gray structure models and analysis are illustrated in Fig. 1 and Table 1.

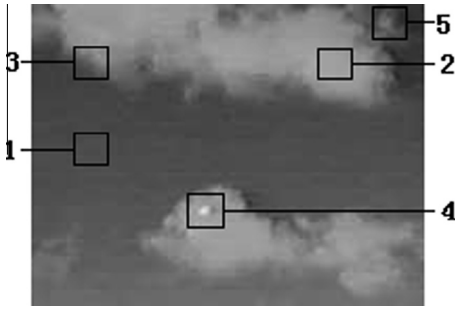

Fig. 1. Infrared image contains different gray structures.