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Infrared small target detection based on relevance vector regression

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Abstract

It is the core task of space combat operations to detect and track targets, and the infrared target detection technology has an immediate impact on the performance of combat systems. So, the infrared target detection has been one of the emphases in military research. With the accelerated development of modern high-tech, combat systems are required more in their abilities of long-range target detection and tracking. It needs us to explore much more precise infrared target detection methods to achieve better target detection performance. To complete this challenging task, an infrared small target detection method based on Relevance Vector Regression (RVR) is proposed in this paper according to the characteristics of infrared target and related theories of RVR. Firstly, the basic theories and related techniques of RVR are introduced. Secondly, the specific method of infrared target detection based on RVR and nonlinear kernel correlation coefficient is reviewed. Thirdly, we proposed the new detection method based on RVR. In the last part, the experiment results which compared the new method with other methods are shown. The final experiment results prove that the proposed method has validity and better performance than the classical compared methods.

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1. Introduction

We know that infrared detection, tracking and other observation facilities are widely used in the field of military.

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It is critical to find and confirm the targets in time to provide adequate defense time in the war. And therefore, the infrared target detection is one of the key technologies for modern weapon equipments. As early as possible to find targets means to detect the targets that are far away from the detection system. From the image point of view, infrared targets present the characteristics of smaller geometry size, lack of texture information and low contrast in an image. Infrared small targets present only a few pixels or even smaller, so its signal-to-clutter ratio (SCR)¹ is too low to be detected accurately. The detection of infrared small targets is a challenging task due to above factors. The performance of target detection algorithms is very critical to the operating range and intelligence of infrared detection systems.

Many target detection methods have been proposed by researchers at home and abroad. The traditional detection methods are mainly based on filter like two-dimensional least mean square (TDLMS) filter method^{2,3} and Top-hat filter method^{4,5}, in most of which the infrared targets are treated as high frequency signals. The anti-interference ability of filter method is poor because the image noise is also high frequency signal and always be detected as targets improperly. Then some novel target detection algorithms appeared with the development of pattern recognition theory, such as template matching method⁶ and support vector machine (SVM) method⁷. The essence of target detection methods based on pattern recognition are classified the image data as target data and the non-target data. A large number of target and background training samples are needed for pattern recognition, and they have a great influence on target detection performance.

In recent years, the research on relevance vector machine (RVM)^{8,9} emerges gradually. It is mainly used in fields like face recognition and object detection at present. In this paper, an infrared small target detection method based on Relevance Vector Regression (RVR) is proposed. As far as we know, there is no infrared small target detection algorithm based on RVR has been proposed yet. In order to get better performance of target detection, nonlinear kernel correlation coefficient and image binary-conversion are used as post-processing methods in this paper. Furthermore, the comparison experiment and result analysis are executed to validate the detection performance of the proposed method. The final results proved that the proposed method is effective, and has a certain superiority than other detection methods.

2. Relevance Vector Regression

Relevance vector machine (RVM), a new supervised learning^{10, 11} method based on Bayesian Framework, was proposed by Michal e. Tipping in 2000. RVM is divided into two cases: Relevance vector regression (RVR) and Relevance vector classification (RVC). RVM has the same performance with SVM, but the difference is that RVM is sparser with less number of relevance vectors and parameters. In addition, RVR can obtain the probability output and its kernel functions are not restricted by Mercer conditions. In view of all these strengths, we propose the infrared small target detection algorithm based on RVR. The mathematical model of RVR is based on a function $y(x)$ defined in the input space, and its model is obtained by training sets $\{x_i, t_i\}_{i=1}^N$. The training sets are constituted of a given input vectors $\{x_i\}_{i=1}^N$ and the corresponding object vectors $\{t_i\}_{i=1}^N$. The model can be formulated as

$$y(x; \omega) = \sum_{i=1}^N \omega_i k(x, x_i) + \omega_0 \quad (1)$$

where ω_i is the weight that corresponds to x_i , N is the length of the vector, and $k(x, x_i)$ is the kernel function.

The objective function meets the condition

$$t(x; \omega) = y(x; \omega) + \varepsilon_i \quad (2)$$

where ε_i is the noise contained in samples.

We assume that t_i is independent, and ε_i follows the Gaussian distribution with zero mean and variance σ^2 . So the probability density distribution function of t_i is

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