Infrared Physics & Technology 77 (2016) 440–450

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

Regular article

A fast-saliency method for real-time infrared small target detection

Shengxiang Qi *, Guojing Xu, Zhiying Mou, Dayu Huang, Xueli Zheng

Science and Technology on Avionics Integration Laboratory, Shanghai 200233, China
China National Aeronautical Radio Electronics Research Institute, Shanghai 200233, China

HIGHLIGHTS

- Small targets could be well detected by a gradient enhancement operation.
- A 5×5 facet operator holds the key for separating small targets from backgrounds.
- A fast-saliency method is proposed to meet the requirement of real-time detection.
- Both the detection accuracy and computation efficiency are respectable.

ARTICLE INFO

Article history:
Received 15 May 2016
Revised 19 June 2016
Accepted 19 June 2016
Available online 25 June 2016

Keywords:
Infrared image
Small target
Real-time detection
Visual saliency
Computation efficiency

ABSTRACT

Infrared small target detection plays an important role in applications including military reconnaissance, early warning and terminal guidance. In this paper, we present a fast method, called *fast-saliency*, with very low computational complexity, for real-time small target detection in single image frame under various complex backgrounds. Different from traditional algorithms, the proposed method is inspired by a recent research on visual saliency detection indicating that small salient signals could be well detected by a gradient enhancement operation combined with Gaussian smoothing, which is able to delineate regions of small targets in infrared images. Concisely, there are only four simple steps contained in *fast-saliency*. In order, they are gradient operation, square computation, Gaussian smoothing and automatic thresholding, representing the four procedures as highpass filtering, target enhancement, noise suppression and target segmentation, respectively. Especially, for the most crucial step, gradient operation, we innovatively propose a 5×5 facet kernel operator that holds the key for separating the small targets from backgrounds. To verify the effectiveness of our proposed method, a set of real infrared images covering typical backgrounds with sea, sky and ground clutters are tested in experiments. The results demonstrate that it outperforms the state-of-the-art methods not only in detection accuracy, but also in computation efficiency.

1. Introduction

Infrared small target detection, with its capability to locate regions covering valuably thermal target, is one of the most significant techniques in the automatic target recognition (ATR) system [1,2]. It has attracted lots of research interest benefiting from its wide applications in military reconnaissance, early warning, terminal guidance, etc. [2–4]. Because of the long distance imagery, the targets only occupy very few pixels in infrared images and typically suffer from random noises and nonstationary clutters, resulting in lack of adequate structure information for detecting or matching [5,6]. Relying on the infrared imagery characteristics, large amounts of methods have been carried out for extracting the targets from backgrounds. However, many of them just concern specific scenes such as the sky [7] or sea-sky [8,9] clutters. Although numerous attempts [2,10–12] are made in recent years aiming at variously complex situations, they require relatively long run time at the cost of computation efficiency. In fact, algorithms with high computational complexity could not meet real-time requirements for most practical projects. Up to now, infrared small target detection techniques desiring both high detection accuracy and computation efficiency are still challenging with respect to various complex scenes.

In a general way, the essential phase is to highlight the targets while suppress the backgrounds as much as possible, in order to improve the signal-to-clutter ratio (SCR) [10]. Since targets with high SCR could offer an aggressive assistance for the final target

* Corresponding author at: Science and Technology on Avionics Integration Laboratory, Shanghai 200233, China.
E-mail address: shengxiang.qi@gmail.com (S. Qi).

http://dx.doi.org/10.1016/j.infrared.2016.06.026
1350-4495/

segmentation, most approaches elaborate their work on how to "pop out" the targets and "neglect" background regions [12,13]. Towards the goal, existing algorithms could be roughly classified into four categories: spatial processing, frequency analysis, morphological operation and saliency computation.

On the whole, most detection approaches belong to spatial processing, by which targets are enhanced via direct target filtering or indirect background prediction. For target filtering, Wang et al. [14] present a cubic facet model-based [15] extremum filter to detect infrared small targets. Similarly, Wang et al. [13] also formulate the task as a problem of finding extreme points from images and construct the extremum filter by least squares support vector machine (LS-SVM). Kim [16] puts forward a novel spatial filter called the min-local-LoG filter, which is designed through decomposing the 2D Laplacian of Gaussian filter into several 1D filters. Deng et al. [17] compute the self-information maps to improve SCR of infrared images under the guidance of information theory. Chen et al. [18] present a local contrast method for detection inspired by the contrast mechanism of human vision system and derived kernel model. Yang et al. [19] suggest the directional support value of Gaussian transformation. A novel multiscale facet model is also put forward by Yang et al. [20]. On the other hand, by the indirect way, the residual map between the original image and its predicted background image is computed to highlight targets. In this sense, the background of the image must be well estimated while the real target area would be replaced by intensity of the nearby background regions. Deshpande et al. [21] make early attempt to provide max-mean and max-median filters for background expression. Bae [22] propose a bilateral filter to predict backgrounds. Gu et al. [12] predict and eliminate background clutters by a kernel-based nonparametric regression model. The similar idea on the kernel technique is also adopted by Xie et al. [23]. In essence, background modeling is hard to work well due to the unknown target positions.

From the perspective of statistics, the energy of backgrounds is mainly concentrated in components with low frequency while small targets possess middle or high frequency [2]. For this reason, frequency analysis is applied to detect infrared small targets as well. One of the milestone techniques is proposed by Yang et al. [8], who suggest an adaptive Butterworth highpass filter to suppress background clutters. Afterwards, Qi et al. [3] argue that the phase spectrum of Fourier transform has a desired property of standing out salient signal, and accordingly propose to enhance small targets by a novel method on phase spectrum of quaternion Fourier transform which could achieve good detection results.

In decades, another widely-used technique on small target detection is based on mathematical morphology. This kind of methods arise to the well-known top-hat operator proposed by Tom et al. [24], who perform the closing operation on infrared images to predict backgrounds by reserving high frequency contents. Bai and Zhou [25] use two different but correlated structuring elements to reorganize the classical top-hat transformation by which the difference information between the target and surrounding regions is taken into account. In order to improve the performance, large amounts of modified algorithms derived from mathematical morphology, including the toggle contrast operator [26], multiscale center-surround top-hat transform [27], hit-or-miss transform [28], and adaptive morphological top-hat transform [29], are further put forward. Although methods based on morphological analysis could effectively ameliorate the quality for detection, as discussed by Guo and Chen [30], the results are too sensitive to the given structure elements which should be consistent with the shapes and sizes of targets.

Recently, with the development of study on visual attention mechanisms [31], visual saliency computation, which simulates the biological brain and vision system to identify salient regions, has been gradually employed in object detection and recognition [32]. Shao et al. [33] exploit the Laplacian of Gaussian filter to deal with the input image according to the contrast mechanism of human visual system. Wang et al. [34] design the Difference of Gaussian filters to compute the saliency map in which potential targets are then extracted through a control mechanism of winner-take-all competition and inhibition-of-return. Zhao et al. [1] highlight target area via combining both the frequency-tuned based saliency extraction technology and morphological theory. Dong et al. [35] integrate contrast mechanism, visual attention and eye movement simultaneously to detect and track dim targets. Wang et al. [36] incorporate the template filtering and saliency detection method for the task. Qi et al. [10] put forward a robust method based on directional saliency for small target detection in complex scenes. Furthermore, a novel approach inspired by the Boolean map visual theory is also proposed by Qi et al. [2]. Numerous study on relevant researches indicates that algorithms based on visual saliency computation could offer better results compared to traditional methods [1,2,10]. Nevertheless, most saliency models have high computational complexity. That is, they often require long run time relative to traditional methods. Such a fact leads to a problem that many existing small target detection techniques based on visual attention mechanisms could not meet the real-time requirements for practical projects.

Aiming at the real-time applications like the onboard early warning and terminal guidance, we elaborate on providing a fast method, called *fast-saliency*, with very low computational complexity, to detect small targets in single image frame under various complex backgrounds. It derived from a well-known visual saliency detection model called the phase spectrum of Fourier transform (PFT-saliency) method [37–39]. By the recent study [3], Qi et al. demonstrate that PFT-saliency could benefit enhancing small targets in infrared images. However, as is known to all, image processing in frequency domain would decrease the computation efficiency. To this end, an operation on spatial domain suggested by Li et al. [37] shows the considerable performance with PFT-saliency, inspiring our fast-saliency model. That is, a gradient enhancement operation combined with Gaussian smoothing is able to detect small salient regions well, which is very helpful to enhance small targets because these targets could often attract attention of human eyes in infrared images [8]. Concisely, only four simple steps are contained in the proposed method, in order, they are gradient operation, square computation, Gaussian smoothing and automatic thresholding. These steps represent four procedures as highpass filtering, target enhancement, noise suppression and target segmentation, respectively. Especially, in the step of gradient operation, the most crucial procedure, we innovatively propose a facet kernel operator deduced from the facet model [15]. This operator is a 5×5 template holding the key for highlighting targets while suppressing backgrounds since the infrared small targets are brighter than their nearby regions due to the thermal imagery at a very far distance [2]. Intuitively, the proposed method has very low computational complexity with only about twice image convolution and once square computation (for which our automatic thresholding step could be neglected in computational complexity analysis), so that it is easy to perform and fast enough on various platforms.

The remainder of this paper is organized as follows. Section 2 introduces the PFT-saliency method. Section 3 details our fast-saliency method based on two different kernel operators, the traditional Laplacian kernel and the proposed facet kernel, and then analyzes their computational complexity. Experiments carried on a set of real infrared images covering typical backgrounds with sea, sky and ground clutters are shown in Section 4. Finally, the paper end ups with a conclusion in Section 5.