Extracting targets from regions-of-interest in infrared images using a 2-D histogram

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Abstract. We propose an effective method of extracting targets from a region-of-interest (ROI) in infrared images by using a 2-D histogram, considering intensity values and distance values from a center of the ROI. Existing approaches for extracting targets have utilized only intensity values of pixels or an analysis of a 1-D histogram of intensity values. Because the 1-D histogram has mixed bins containing false-negative bins from the target region as well as false-positive bins from the background region, it is difficult to extract target regions effectively due to the mixed bins. In order to solve the problem of the mixed bins, we propose a novel 2-D histogram-based approach for extracting targets. Experimental results have shown that the proposed method achieves better performance of extracting targets than existing methods under various environments, such as target regions with irregular intensities, dim targets, and cluttered backgrounds. [DOI: 10.1117/1.3536471]

Subject terms: target extraction; thresholding; 2-D histograms; principal component analysis.

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1 Introduction

In infrared (IR) search and track systems, the data association algorithm is indispensable in order to track targets in cluttered environments. Two representative algorithms of the data association techniques are the strongest-neighbor filter (SNF) and the nearest-neighbor filter (NNF). Because of their simplicity, the SNF and NNF are the most widely used methods for target tracking in cluttered environments. In the SNF, the strongest intensity among the validated measurements in a gate is used for track update as if it were the correct measurement. In the NNF, the measurement that is the closest to the predicted measurement is used.[1–6] However, the selected measurement is not the correct one with some probability. Because these data association algorithms are based on the measurements that consider only the signal amplitude or distance information in order to distinguish the correct measurement from clutters, this could lead to a filter divergence. Therefore, if we can extract exact target regions from the measurements in IR images, we can utilize shape features of the target regions in combination with the data-association algorithms in order to improve the performance of the track update. However, the extraction of target regions from an ROI in IR images is a challenging task due to irregular intensities and background noises.

Many approaches for extracting targets have been proposed. Wang et al. proposed to segment targets by using Otsu's method[7] for IR ship recognition.[8] Methods of using normalized cuts have been proposed for segmenting objects.[9,10] The fuzzy c-means algorithm has been applied to image segmentation[11–13] Chen and Reed modeled the clutter and noise after local demeaning as a whitened Gaussian random process and developed a detector with a constant false alarm rate using a generalized maximum likelihood ratio.[14] Wang et al. presented a fusion detection method for small targets based on support vector machines in the wavelet domain.[15] Wu and Ji presented an algorithm based on the improved power law detector for the detection of small dim moving targets in IR image sequences.[16] Deng et al. proposed a method based on empirical mode decomposition (EMD), in order to detect small targets under complicated sea-sky backgrounds in infrared images.[17]

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However, these methods are very sensitive to irregular intensity environments. Furthermore, they are not suitable for real-time processing because the time complexity is very high. In order to solve these problems, we propose a novel target extraction method based on a 2-D histogram considering intensity values and distance values from a center of the ROI. The proposed method is composed of two steps. In the first step, the 2-D histogram is constructed by using intensity values and distance values between the corresponding pixel and the center of the ROI. In the final step, two decision functions that classify target regions are determined by combining the principal component analysis and Otsu's method.

Experimental results show that the proposed method achieves better performance than the existing methods.

The remainder of this paper is organized as follows. Section 2 describes the approach of constructing 2-D histogram using intensity values and distance information from the given ROI. The method of target extraction is explained in Sec. 3. Section 4 shows the experimental results, and Sec. 5 includes concluding remarks.

2 2-D Histogram Using Intensity and Distance Information

Generally, target regions in infrared images are brighter than backgrounds. However, the target regions tend to have irregular intensity values caused by emitting engine heat of the targets. Therefore, a 1-D histogram using only intensity values has mixed bins containing false-negative bins from the target region as well as false-positive bins from the background region. Owing to the mixed bins containing the target and background intensity values in the 1-D histogram, it is difficult to extract the target pixels by using a 1-D histogram. Therefore, in order to solve the problem of the mixed bins, we propose a novel 2-D histogram–based approach considering not only intensity values but also distance information for extracting targets. The 2-D histogram is defined as

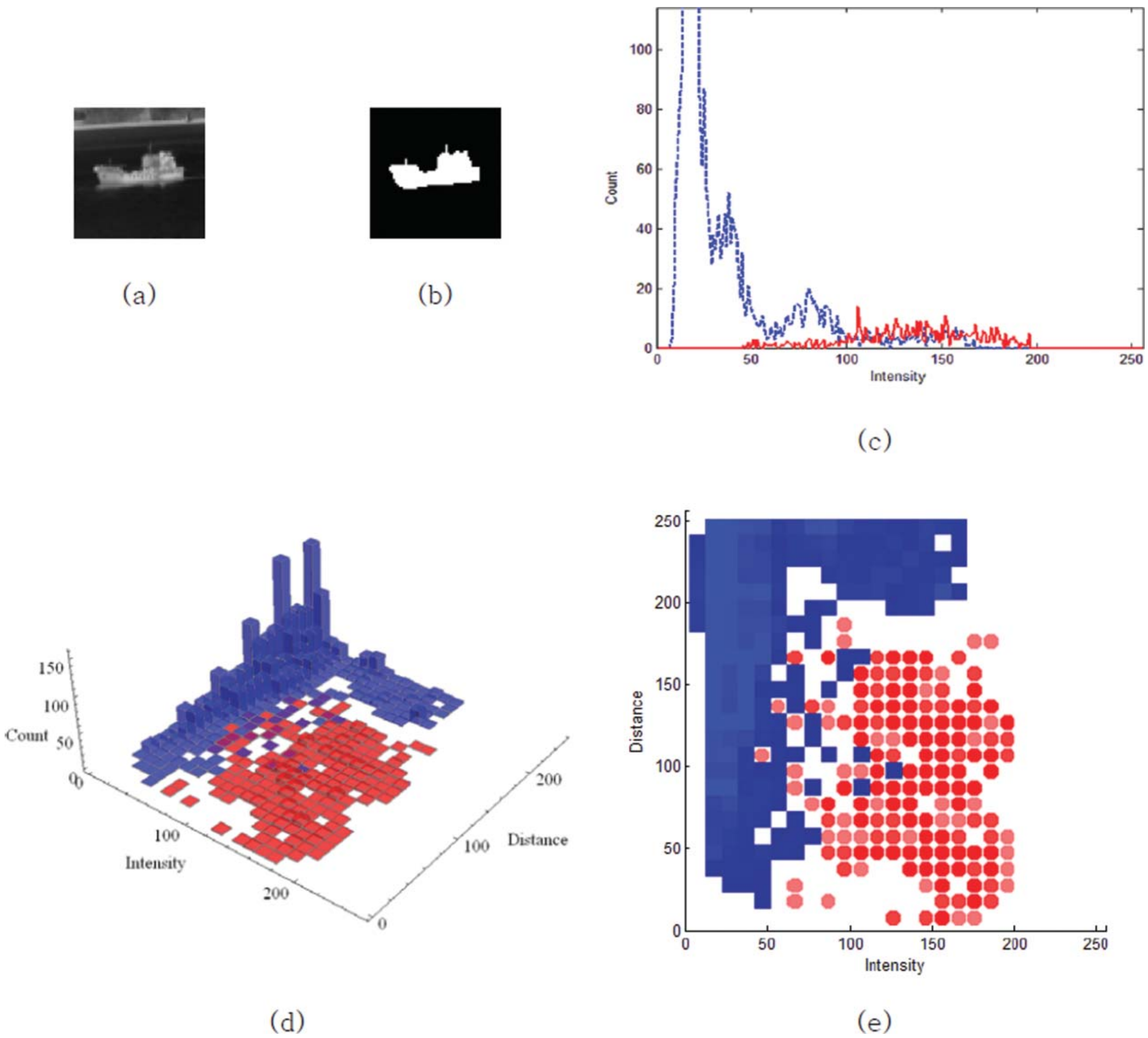

Fig. 1 (a) Test image, (b) ground truth of image (a), (c) 1-D histogram of image (a) where the solid line and the dashed line denote the target region and the background region, respectively, (d) 2-D histogram of image (a), and (e) 2-D histogram represented as 2-D projection profile, where the dot regions denote the target regions and the square regions denote the background region.

follows:

$$v = I(x, y),$$
$$d = \frac{L}{D}\sqrt{(W/2 - x)^2 + (H/2 - y)^2}, \quad (1)$$
$$f(v, d): \text{ 2-D histogram,}$$

where v is the intensity value at pixel $I(x,y)$ in the input ROI. W and H are the width and the height of the input ROI, respectively. L/D is a normalizing coefficient. L and D denote the maximum intensity and maximum distance, respectively. d denotes the distance between (x,y) and the center of ROI. $f(v,d)$ denotes the frequency of pair (v,d) appeared in the input ROI image. A sample image and its manually extracted ground truth are shown in Figs. 1(a) and 1(b), respectively. Fig. 1(c) shows a 1-D histogram of the sample image using only intensity values, where the solid line is the target region and the dashed line is the background region. It is noted that the 1-D histogram has mixed bins containing false-negative bins from the target region as well as false-positive bins from the background region. Owing to the mixed bins containing the target and background intensity values in the 1-D histogram, it is difficult to distinguish the target pixels from background pixels. Figure 1(d) shows that the 2-D histogram $f(v,d)$ generated from Fig. 1(a). By the visual observation of the scattered data pattern including

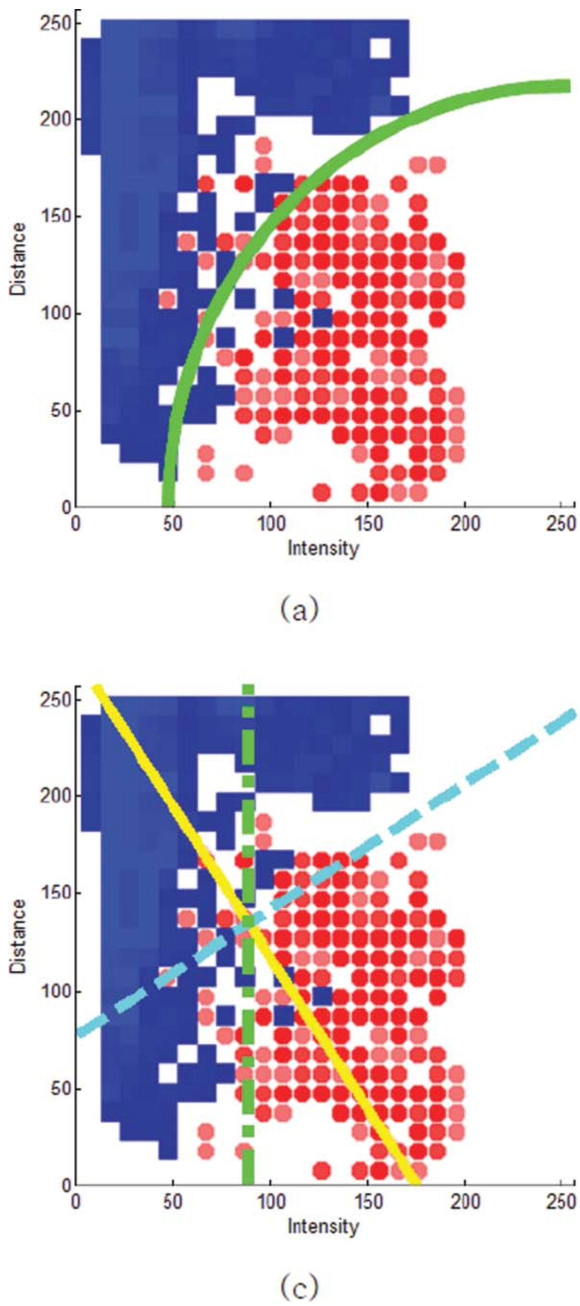

Fig. 2 (a) The green curve is a manually selected optimal decision curve in the 2-D histogram (intensity-distance domain), (b) line is the principal component axis corresponding to the largest eigen-value by principal component analysis, (c) dashed line, and the dashed-dotted line are decision functions, and (d) the background and the target region. (Color online only.)

target and background regions, it is noted that the proposed 2-D histogram method effectively distinguishes the target bins from many mixed bins. By analyzing the 2-D histogram, the target pixels have high intensity values and are relatively closer to the center of the ROI, whereas the background pixels have low intensity values and are relatively further from the center of the ROI. Therefore, more accurate target regions can be separated from the background region by using optimal decision functions. Figure 1(e) shows that the scattered data of the proposed 2-D histogram is represented as a 2-D projection profile, where the brightness values represent the frequency of each bin of $f(v,d)$.

3 Decision Functions

Through the observation of the scattered data pattern on the 2-D histogram, it is noted that the problem of mixed bins can be solved by an optimal decision curve for extracting targets, as shown in Fig. 2(a). However, it is a complicated task to define the criterion of an optimal decision curve and a large amount of processing time is required to determine an optimal decision curve. Thus, in this paper, through visual inspection of the scattered data patterns on the 2-D histogram, we select two linear decision functions, simplifying the optimal decision curve, by using the principal component analysis[18] and Otsu's method.[7] The procedure for determining the decision functions is composed of two steps. In the first step, the scattered points on the intensity-distance domain of 2-D histogram are analyzed by principal component analysis in order to reduce the dimension of the 2-D histogram. Then, as shown in Fig. 2(b), the scattered data are projected onto the first principal axis corresponding to the largest eigenvalue in order to obtain a 1-D histogram that contains information of a reduced dimension subspace on the intensity-distance domain. From the 1-D histogram, we calculate a reference point for determining two linear decision functions by carrying out Otsu's method.[7] In the final step, the first decision function perpendicular to the principal axis at the reference point is obtained, as shown in Fig. 2(c) superimposed by a dashed line. The second decision function perpendicular to the intensity axis at the reference point is obtained, as shown in Fig. 2(c) superimposed by a dashed-dotted line. As shown in Fig. 2(d), by eliminating background pixels that are on the left-hand side of the first and second decision functions, the target is properly extracted.

4 Experimental Results

By using a test set composed of 300 IR images containing aircraft, ship, and vehicle targets under cluttered background environments, the proposed method has been tested and its performance has been compared to the existing methods. The test images with pixel resolution of 640×480 are obtained from a midwave infrared camera of FLIR systems. Input ROI images are presented with a size of 64×64.

Figure 3 shows the experimental results of the proposed and existing methods. Figure 3(a) shows input ROI images obtained from infrared images, and Fig. 3(b) shows the manually extracted ground truth. From Fig. 3(c) to 3(d), the results are obtained by using existing methods, including Otsu's method,[7] normalized cuts, and fuzzy c-means. Figure 3(e) shows the results of the proposed method. As shown, results of the proposed method are more robust against irregular intensity environments compared to the existing methods. However, as shown in the last two images in Fig. 3(e), some results of the proposed method have shown that the target regions are over- or undersegmented caused by image degradations, such as heavy noises, dim targets, and sea and sun glints.

In order to quantitatively evaluate the target extraction performance, we utilize the pixel-based quality measure[19] to calculate the extraction error rate, as follows:

$$e\left(B_{\mathrm{img}}, B_{\mathrm{gt}}\right) = \frac{\sum_{(x,y)} B_{\mathrm{img}}(x,y) \otimes B_{gt}(x,y)}{\sum_{(x,y)} B_{\mathrm{gt}}(x,y)}, \qquad (2)$$

where B_{img} and B_{gt} are the binary image for the extracted target and the manually extracted ground truth, respectively, and $\otimes$ denotes the exclusive OR operation.

Table 1 shows the performance comparisons in terms of the extraction error rate calculated from the results of Otsu's method,[7] normalized cuts, fuzzy c-means, and the proposed method. By evaluating the experimental results, the proposed method achieves much better performance than the existing methods. In the Table 1, "Avg." and "Std. Dev." are the average value and the standard deviation of the extraction error rate, respectively. "Min" and "Max" are the

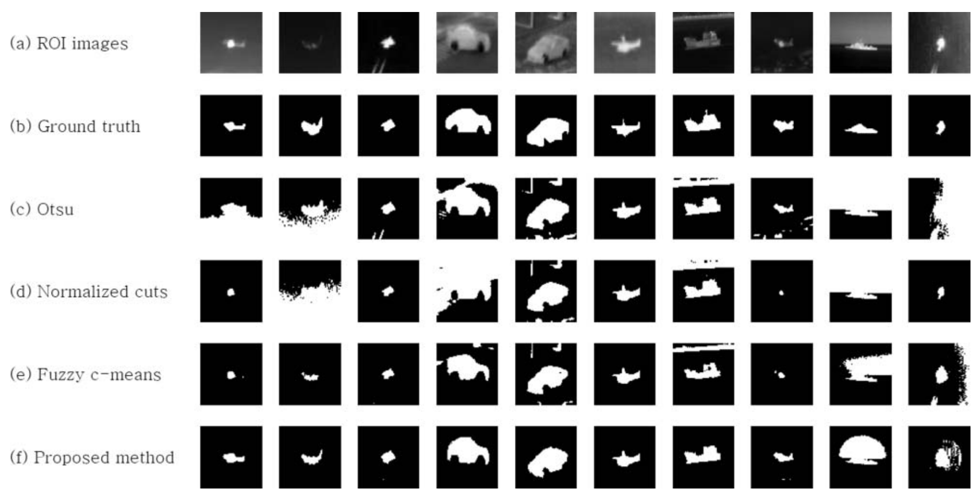

Fig. 3 Experimental results of target extraction.

Table 1 Performance comparison in terms of extraction error rate.

	Extraction error rate			
	Avg.	Std. Dev.	Min	Max
Proposed method	**0.48**	**0.46**	**0.09**	**4.99**
Otsu	2.97	6.09	0.13	35.22
Normalized cuts	1.61	2.79	0.1	19.93
Fuzzy c-means	1.3	2.91	0.09	24.58

minimum and the maximum value of the extraction error rate, respectively.

5 Conclusion

In this paper, we proposed a novel method for extracting targets in infrared images by using a 2-D histogram. Through the analysis of a 1-D histogram, we realized that the 1-D histogram has the problem of mixed bins containing false-negative bins from the target region along with false-positive bins from the background region. Therefore, in order to solve the problem of the mixed bins, we proposed a target extraction method based on the 2-D histogram considering intensity values and distance values between corresponding pixels and the center of the ROI. Experimental results have shown that the proposed method achieves better performance of extracting targets than the existing methods under various environments, such as target regions with irregular intensities, dim targets, and cluttered backgrounds.

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