Small Target Detection with Clutter Rejection using Stochastic Hypothesis Testing

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ABSTRACT

The many target-detection methods that use forward-looking infrared (FLIR) images can deal with large targets measuring 70×40 pixels, utilizing their shape features. However, detection small targets is difficult because they are more obscure and there are many target-like objects. Therefore, few studies have examined how to detect small targets consisting of fewer than 30×10 pixels. This paper presents a small target detection method using clutter rejection with stochastic hypothesis testing for FLIR imagery. The proposed algorithm consists of two stages; detection and clutter rejection. In the detection stage, the mean of the input FLIR image is first removed and then the image is segmented using Otsu's method. A closing operation is also applied during the detection stage in order to merge any single targets detected separately. Then, the residual of the clutters is eliminated using statistical hypothesis testing based on the t-test. Several FLIR images are used to prove the performance of the proposed algorithm. The experimental results show that the proposed algorithm accurately detects small targets (less than 30×10 pixels) with a low false alarm rate compared to the center-surround difference method using the receiver operating characteristics (ROC) curve.

Keywords: IR Image, Target Detection, Hypothesis Testing

1. INTRODUCTION

Military vehicles, such as tanks, reconnaissance vehicles and aircraft, use automatic target recognition (ATR) systems with electro-optical sensor imagery to find and identify targets on the battlefield. However automatic target detection and identification using FLIR images are very challenging tasks because a number of factors can affect thermal images, including range, location, time of day, aspect angle, and meteorological conditions [1-3].

A typical ATR system consists of three stages: target detection, clutter rejection, and target classification. The region containing target candidates is extracted in the detection stages. True targets are identified in the clutter-rejection stage. Finally, the type of target is determined in the classification stage. This paper focuses on the detection and clutter-rejection stages of an ATR system.

Many researchers have developed target-detection algorithms for FLIR images. Typical methods are thresholding [4-6], hit-miss transform [7], morphological wavelet [8], and directional wavelet [9]. Recently, Rizvi et el. proposed a neural network approach using region-based principal component analysis (PCA) [10] and Chan et el. used Eigenspace separation transform (EST) to reject potential targets [11]. These method deal with very

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large targets containing about 70×40 pixels. By contrast, we are interested in small distant targets that measures 30×10 pixels. In such case, target detection is difficult, since the image contains a lot of target-like clutter and target shapes are obscured. In our experience with a variety of detection methods, one weakness of the above approaches is that they can miss small targets or miss targets when the appearance of the target or background changes. So, we propose a small-target-detection method that uses stochastic hypothesis testing[12] based on the *t*-test in the clutter rejection stage.

This paper is organized as follows. In section Ⅱ, target detection and clutter rejection is proposed. In the detection stage, 1) the mean removed image is first generated using a spatial filter and target candidates are segmented using Otsu's method. 2) A closing operation is performed in order not to separate a single target. 3) Candidate targets larger or smaller than the expected target size are removed. In the clutter-rejection stage, the residual clutter is removed by statistical hypothesis testing using the *t*-test with the mean and standard deviation of the inner windowed target and outer windowed background in the FLIR image. Finally, a decision is made based on the p_α values using the *t*-table[13] with (1− α)×100 % confidence. In section Ⅲ, experimental simulation results show that the proposed algorithm works well in a cluttered environment. Finally, concluding remarks are given in section Ⅳ.

2. PROPOSED TARGET-DETECTION METHOD

As shown in Fig. 1, the proposed target-detection algorithm consists of two stages: detection and clutter rejection. In the detection stage, candidate targets are extracted, while real targets are selected in clutter-rejection stage.
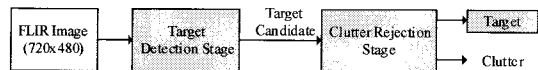

Fig. 1. Block diagram of target detection.

2.1 Target-Detection Stage

Target candidates are detected in the detection stages, which consist of four steps: 1) mean rejection of the FLIR image 2) segmentation of target candidates using Otsu's method 3) a closing operation to prevent target separation in the binary image 4) the rejection of target candidates larger and smaller target candidate than expected target size.

Step 1 : the mean removed image is obtained by subtracting the local mean from the input image using Eq. (1).

$$I_{MeanRemove}(i,j) = I_{InImage}(i,j) - \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N}I_{InImage}(i,j)$$

(1)

Where $I_{InImage}$: Input Image
$I_{MeanRemove}$: Mean Removed Image
N   : N×N spatial Filter size

Step 2 : Otsu's method is used for target segmentation [4]. An optimal threshold t* is chosen to maximize the between-class variance (target class and clutter class). $\sigma_B^2(T)$

Step 3 : as a single target candidate may be detected as multiple targets, a closing operation is used to eliminate multiple target candidates that are actually the same, single target.

Step 4 : target candidates larger or smaller than expected target size are removed.

2.2 Clutter Rejection Using Stochastic Hypothesis Testing

Clutter rejection is needed to identify true targets by discarding the clutters from the target candidate images provided in the detection stage. The clutter-rejection stage consists of two steps. 1)

find stochastic characteristics from the region of interest (ROI) of target candidates; and 2) apply the clutter-rejection step using stochastic hypothesis based on the t-test.

The center of the inner window is calculated from the ROI and the inner window is located at that position. Then, the outer window is positioned over the outer part of inner window, as shown Fig. 2. The area of the outer windows can equal that of the inner window. Then, the stochastic characteristics of the windows are compared using t-test and the p value for $(1-\alpha) \times 100\%$ confidence. Typically, a standard t-test is performed when the sample group has the same variance characteristics. A modified t-test can use when the variance characteristics differ. Consequently, we decide whether the variance of the sampled group has the same variance characteristics using the F-test before the t-test. If they have the same variance characteristics, we use standard t-test; otherwise, Modified t-test is used.

Step 1 : The center coordinates of the ROI (R$_{cent}$) are selected using the centers of target candidates from binary images, as shown Fig. 2. The position of the inner window is calculated from the ROI and the expected target size. The position of outer window is selected; it can have the same area and outer position as the inner window. Then, the mean and variance of the inner and outer windows are calculated.

Step 2 : After performing the F-test using the inner and outer windows, as shown Eq. 2, the value of the t-statistic (t_{val}) is calculated using Eq. 3 - 5. When the variance differs, Eqs. 3 and 4 are used to determine t_{val} otherwise, Eq. 5 is used.

$$F = \frac{s_1^2}{s_2^2} \qquad (2)$$

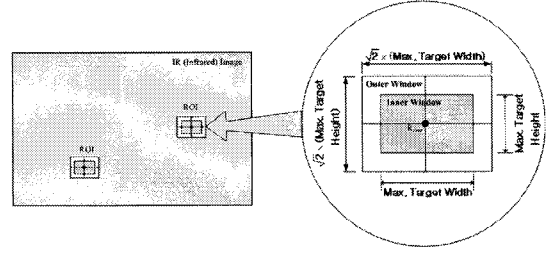$$t_{val} = \frac{\overline{x_1} - \overline{x_2}}{S_p \sqrt{(\frac{1}{n_1} + \frac{1}{n_2})}} \qquad (3)$$

Fig. 2. Target ROI selection method.

$$S_p = \frac{(s_1^2(n_1-1) + s_2^2(n_2-1)}{n_1 + n_2 - 2} \qquad (4)$$

where n_1, n_2 are the pixel populations of inner and outer window, respectively, $\overline{x_1}, \overline{x_2}$ are the means of the respective windows, and s_1^2, s_2^2 are the respective variance.

The hypothesis is examined using the t-test to compare the two population means, as shown below:

$$\begin{aligned} H_0 &: \overline{x_1} = \overline{x_2} \quad (t_{val} \le p_\alpha) \\ H_1 &: \overline{x_1} > \overline{x_2} \quad (t_{val} > p_\alpha) \end{aligned} \qquad (5)$$

$\overline{x_1}$: mean of the target candidate (inner window)

$\overline{x_2}$: mean of the background (outer window)

p_α : p-value in t-table with the $(1-\alpha) \times 100\%$ confidence level

α : significance level

The null hypothesis H_0 indicates that the mean $\overline{x_1}$ of the target candidate (inner window) equals the mean $\overline{x_2}$ of the background (outer window). This means that target candidate (inner window) is clutter. The alternative hypothesis implies that target candidate (inner window) is a target.

3. SIMULATION AND ANALYSIS

To demonstrate the performance of the algorithm, various Infrared (IR) images obtained from a military infrared thermal sight installed on an army vehicle were tested. The IR images of targets were taken under different conditions, such as a riverside with a stone dike and natural field with

a small stream and mountain, in different seasons year round. The image measured 720×480 pixels and the range between the target and FLIR sensor was 1200m~1700m. We selected 202 images for the simulation and each image contained from one to three targets.

Fig. 3 and Fig. 4 show two of the images used for the simulation. Fig. 3(a) and Fig. 4(a) show raw IR images with three and one target, respectively. The images were trimmed for appearance (720x480 pixels -> 215×170 pixels). Fig. 3(b) and Fig. 4(b) show mean removed images. Fig. 3(c) and Fig. 4(c) show thresholded (binary) image using Otsu's method. Fig 3(d) and Fig. 4(d) show binary image after closing operation. Fig. 3(e) and Fig. 4(e) show target candidates with windows for the t-test . Fig. 3(f) and Fig. 4(f) shows the final image the detected targets are marked with rectangular boxes.
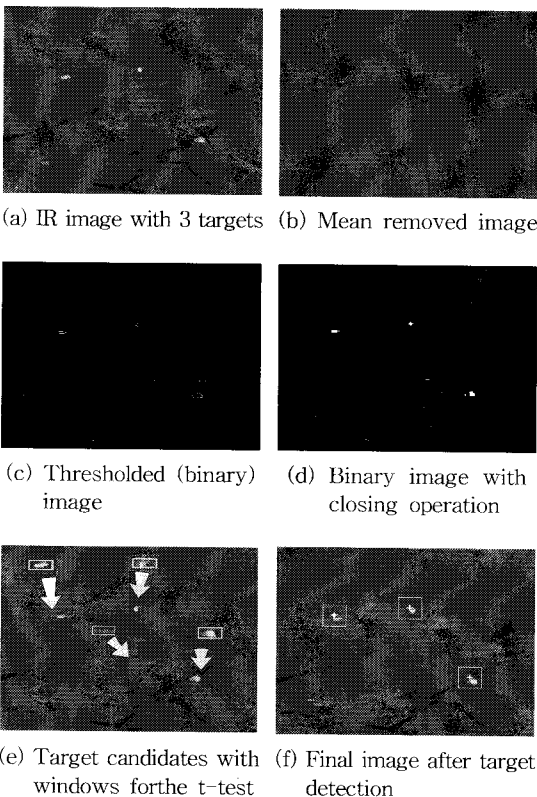
(a) IR image with 3 targets (b) Mean removed image

(c) Thresholded (binary) image (d) Binary image with closing operation

(e) Target candidates with windows forthe t-test (f) Final image after target detection

Fig. 3. Clutter rejection result using the t-test (I) (These figures show that small targets are detected well).

(a) IR image with single target (b) Mean removed image

(c) Thresholded (binary) image (d) Binary image with closing operation

(e) Target candidates with windows for the t-test (f) Final image after target detections
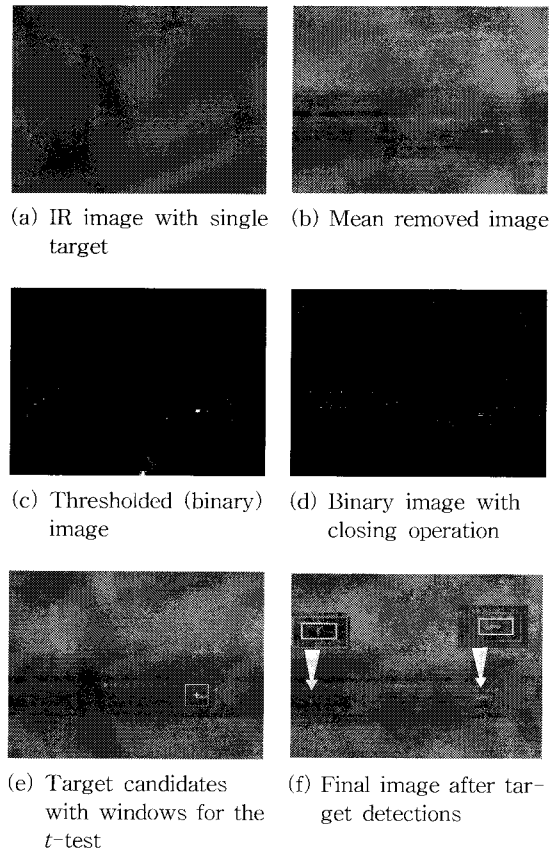
Fig. 4. Clutter rejection result using t-test (II) (These figures show that target is detected well under target-like clutters in Background).

In simulation, 5×5 spatial filter is used for mean rejection. And Otsu's method is used for target segmentation. After closing operation, target candidates which are less than half of expected target size or larger than twice of expected target size are removed. The thresholding value(p_α) for t-test, 1.645 is used when α is 0.05.

In addition, we evaluated the performance of the proposed method in terms of received operation characteristic (ROC) curves. For each target candidate, two events can be defined: either the potential target is a real target (event "T") or it is not a real target (event "C"). When a potential target image is presented to the target detection system (or the clutter rejection system), the system responds by answering "yes"(Y) meaning it is a real

target; or "no" (N) meaning that is not a real target (it is a clutter) The hit rate is the probability of responding "yes" given an event "T" has occurred (the probability of correct target detection) and the probability of responding "yes" given an event "C" has occurred is called the false alarm rate [14]. Thus,

$$\text{Hit Rate} = P(Y|T) \tag{6}$$
$$\text{False Alarm Rate} = P(Y|C)$$

To evaluate the performance of the proposed detection algorithm, we compared our method with center-surround difference method, which uses a template to reject clutter [3] using Matlat, a commercial simulation tool used for performance evaluation.

The trade off between the probability of target detection and the number of false alarms is varied by tuning p_α. The test results are plotted in the ROC curve in Fig. 5. For the center-surround difference method, the detection rate was 77.2% detection rate with 2.0 false alarms per image. With our target detector, the detection rate was 86.1% with 2.0 falses alarm per image.

4. CONCLUSIONS
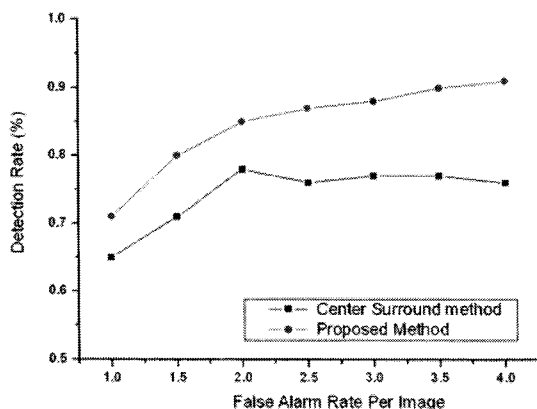
This paper proposed a small-target-detection

Fig. 5. Comparison of ROC performance with different false alarm rates.

algorithm using clutter rejection with statistical hypothesis testing. The mean removed image, target segmentation, and a closing operation are used for detection. Hypothesis testing using the t-test is used to reject residual clutter. The simulation results using Matlab showed that the proposed algorithm works well in a cluttered environment. To evaluate our proposed algorithm, our method was compared with center surround difference method, which uses a template to reject clutter. The comparison showed that our algorithm is better than center-surround difference method, with high target detecting rate and a low false alarm rate.

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