Detection of small targets with adaptive binarization threshold in infrared video sequences

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Received July 4, 2005

An additive discussion for the validity of using the weighted information entropy to evaluate the complex degree of infrared (IR) backgrounds is given. Since small targets can be temporarily lost in actual infrared video sequences, an adaptive binarization threshold for small targets detection is presented. Experimental results show the robustness of our method.

OCIS codes: 100.0100, 110.3080, 040.7290.

There are many methods for detecting small targets in sea-sky infrared (IR) images. The spatial high pass filters are usually used to detect small targets in mild backgrounds[1,2], but they do not have good performances in the sea clutter. Some researchers have analyzed and confirmed the chaotic nature of radar sea clutter signal[3,4]. Leung and Lo presented an approach to signal detection in the sea clutter based on prediction of chaotic characteristics[5]. We proposed an adaptive method for detecting IR small targets in sea-sky complex backgrounds[6] (the dashed block in Fig. 1). This method does not need to know models of backgrounds. The filtering property of the Butterworth high pass filter (BHPF) can be adaptively conducted according to the complex degree of different backgrounds. Thus, its filtering effect is better than the one achieved through using a filter with fixed parameters. In this letter, an additive discussion for the validity of using the weighted information entropy (WIE) to evaluate the complex degree of IR backgrounds is given. To handle the condition that small targets are temporarily lost in actual video sequences, an adaptive binarization threshold for small targets detection is presented (Fig. 1). Experimental results show the robustness of our method.

In Ref. [6], the problem of detecting small targets under sea-sky complex backgrounds is described by how to separate the middle frequency from the high frequency effectively. Through regulating the cutoff frequency D_0 of a BHPF, the filtering property can be changed to meet different filtering requirements. In order to describe the information of gray-values and our subjective judgment about IR images (for example, to emphasize the contribution of high gray-values), a method for evaluating the complex degree of IR backgrounds has been proposed in Ref. [6]. Let S denote the set of gray-values in an IR image with 256 gray-levels, and p_s be the probability of gray-value s occurred in the set S, the WIE of the image can be defined as

$$H(S) = -\sum_{s=0}^{255} s \cdot p_s \log p_s,$$

$$\text{when } p_s = 0, \quad \text{define } p_s \log p_s = 0. \tag{1}$$

The complex degree of different IR backgrounds can be effectively evaluated by Eq. (1). Then, a simple piecewise linear interpolation method is put forward to relate the WIE $H(S)$ with the prior cutoff frequency D_0 of a BHPF. Experimental results show that it is an effective method for detecting IR small targets in sea-sky complex backgrounds. We have concisely discussed the validity of using the WIE to describe the complex degree of IR backgrounds in Ref. [6]. Here we will give an additive discussion for the validity.

For an image which includes r ($1 \le r \le 256$) kinds of known gray-values $s_1, s_2, \cdots, s_r$, relationship between the WIE and probabilities of different gray-values of the image can be derived as follows. Let $\alpha > 0$ be an undetermined constant. An auxiliary function is defined as

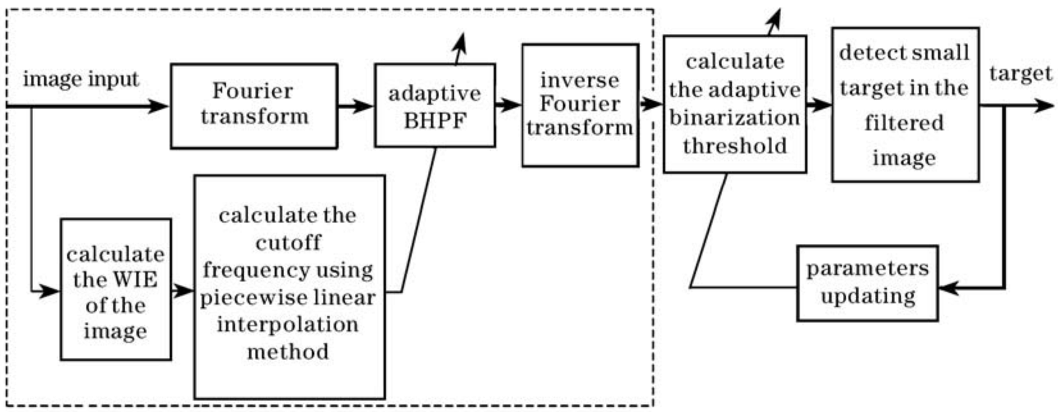

Fig. 1. Block diagram of small targets detection in IR video sequences.

$$G(p_{s_1}, p_{s_2}, \cdots, p_{s_r}) = H(S) + \alpha \left[1 - \sum_{m=1}^{r} p_{s_m}\right]$$
$$= -\sum_{m=1}^{r} s_m \cdot p_{s_m} \log p_{s_m} + \alpha \left[1 - \sum_{m=1}^{r} p_{s_m}\right]. \quad (2)$$

Calculating the first-order partial derivative for the variables p_{s_m} $(1 \leq m \leq r)$ in the function $G(p_{s_1}, p_{s_2}, \cdots, p_{s_m})$, we get r stable-point equations

$$\frac{\partial}{\partial p_{s_m}} G(p_{s_1}, p_{s_2}, \cdots, p_{s_r}) = -s_m(1 + \log p_{s_m}) - \alpha = 0. \quad (3)$$

So, we get probabilities of different gray-values which make the WIE reach the maximal value as

$$p_{s_m} = \exp\left(-\frac{\alpha}{s_m} - 1\right), \quad m = 1, 2, \cdots, r,$$
$$\text{when } s_m = 0, \quad \text{define } p_{s_m} = 0. \quad (4)$$

Calculating the first order derivation for the variable s_m in Eq. (4), we obtain

$$\frac{\mathrm{d}p_{s_m}}{\mathrm{d}s_m} = \frac{\alpha}{s_m^2} \exp\left(-\frac{\alpha}{s_m} - 1\right) > 0, \quad (5)$$

where the probabilities p_{s_m} making the WIE reach the maximal value is a monotonic increasing function in domain of variables s_m. In other words, if gray-values of the IR image are known and the WIE of an image reaches the maximal value, probabilities of different gray-values are proportional to the size of their gray-values. It is the basic motivation for using the WIE to indicate our subjective judgment about IR images. In addition, we notice that the high gray-values should be controlled in some ranges. Equation (4) indicates that $p_{s_m} < \mathrm{e}^{-1} \approx 0.368$ is an important condition that should be met to get the maximal value of the WIE. It means that the joint distribution of different gray-values, such as the sea clutter in real world, is the condition which makes the WIE reach the maximal value.

In Ref. [6], we simply chose a number which was 0.95 time of maximal gray-value as the binarization threshold in the filtered images. It is not practical to detect maneuvering targets in actual IR video sequences. For example, influenced by some uncertain factors such as emergent refraction of sunlight or the vibration in missile operational sequences, small targets can be lost in some frames temporarily. It is evident that many false alarms will be inevitably caused by the method present in Ref. [6]. In addition, backgrounds of consecutive two frames usually have a little random changes, so the WIEs and the corresponding cutoff frequencies of the BHPFs of these two frames will also be changed. It leads general gray intensity of the filtered images to increase or decrease in different degree. Thus, we cannot detect small targets by a fixed binarization threshold. To solve these problems, an improving method is proposed as follows.

Adaptive Binarisation: Two filtered images of consecutive two frames are observed, supposing that small targets have been detected in the kth frame, the mean gray-value of the target region in the kth frame is M_k, and the mean gray-values of these two filtered images are E_k and E_{k+1} respectively. Since property of small targets in consecutive two frames varies little, an adaptive binarization threshold of the $(k+1)$th frame Θ_{k+1} can be formulated as

$$\Theta_{k+1} = (1 - \varepsilon) \cdot M_k + E_{k+1} - E_k, \quad (6)$$

where ε $(0 \leq \varepsilon \leq 1)$ is a factor for keeping some gray-values margin. It can be selected to avoid losing targets in multiple targets cases. Commonly, this factor is a little number, or else the false alarms will be caused. For example, we set $\varepsilon = 0.1$ in our system. Because the new information of the small target, i.e. the mean gray-value of the target region M_k has been introduced into Eq. (6), thus, this binarization threshold can adapt the change of the property of small targets during the period of system running. In addition, because small targets of the first frame can be captured artificially in real applications, the mean gray-value of the target region M_1 and the mean gray-values of the frame E_1 can be initialized easily.

Parameters Updating: If small targets are also detected in the $(k+1)$th frame, the mean gray-values of the target region in the filtered image M_{k+1}, and the mean gray-value of the filtered image E_{k+1} should all be saved to detect the target in the $(k+2)$th frame. If no target has been detected in the $(k+1)$th frame, the parameters of the $(k+1)$th frame should be replaced by that of the kth frame, i.e. let $M_{k+1} = M_k$, $E_{k+1} = E_k$. The replacement can be applied not only to keep continuity of targets detection, but also to avoid false alarm when small targets are temporarily lost in real scenes.

To confirm the validity of our improvement, two IR video sequences in which small targets are temporarily lost are demonstrated in Fig. 2, and relative parameters

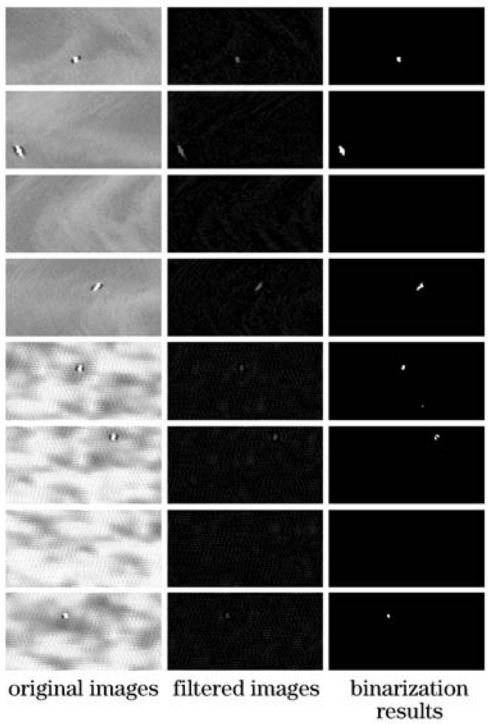

Fig. 2. Two IR video sequences.

Table 1. Relative Parameters of the Two IR Video Sequences

Frame No.	Parameter				
	$H(S)$	D	Θ	M	E
36	606.16	4.32	87.57	97.00	3.70
37	630.56	4.81	87.06	102.13	3.46
38	606.78	4.34	92.02	102.13	3.46
39	598.53	4.17	92.17	96.36	3.71
65	954.06	15.24	60.57	70.13	6.59
66	967.37	15.97	62.58	70.00	6.17
67	962.50	15.86	62.56	70.00	6.17
68	952.93	15.20	62.89	65.98	6.06

are listed in Table 1. Here "$H(S)$" is the WIEs of original images, "D" is the cutoff frequencies of the BHPFs, "Θ" is the adaptive binarization thresholds in the filtered images, "M" is the updated mean gray-values of target regions in the filtered images, and "E" is the updated mean gray-values of the filtered images. In Fig. 2, the rows 1—4 are the frames 36—39 of experimental sequence 1. Their backgrounds are mild sky. Assuming that a small target has been detected in the frame 35 (it is not listed), in this frame, the mean gray-value of the target region in the filtered image is 97.58, the mean gray-value of the filtered image is 3.95. We can see that the small target is temporarily lost in the frame 38. Experimental results show that our method can adapt this sudden change effectively. Similarly, the rows 5—8 are the frames 65—68 of experimental sequence 2. Their backgrounds are the sea clutter. Assuming that a small target has been detected in the frame 64 (it is not listed), in this frame, the mean gray-value of target region in the filtered image is 67.00, the mean gray-value of the filtered image is 6.32. Experimental results exhibit the good performance of our method again. All these experiments indicate that our method can effectively handle the condition that target is suddenly lost. Correspondingly, here if we use the binarization method presented in Ref. [6], many false alarms will be inevitably caused in the frame 38 of experimental sequence 1 and the frame 67 of experimental sequence 2, respectively. Because our binarization threshold can be adaptively conducted according to the differences of the gray-values in the filtered images of consecutive two frames, it is more robust than the binarization method presented in Ref. [6]. In addition, compared with approaches of small targets detection proposed in Refs. [1,2], the robustness of adaptive BHPF has been demonstrated in Ref. [6]. Our improvement is based on the method proposed in Ref. [6], so it is obvious that our adaptive binarization method is more effective than approaches proposed in Ref. [1,2].

In this letter, we give an additive discussion for the validity of using the WIE to evaluate the complex degree of IR backgrounds. To solve the problem that when detecting small targets in actual IR video sequences, many false alarms will be inevitably caused by the method presented in Ref. [6], an adaptive binarization threshold for detecting IR small targets is proposed. Experimental results show the robustness of our improvement.

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