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An infrared maritime target detection algorithm applicable to heavy sea fog

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HIGHLIGHTS

- An infrared maritime target detection strategy for heavy sea fog is proposed.
- Features of infrared maritime image taken in heavy sea fog are analyzed.
- We propose a novel target detection algorithm upon wavelet inter-subband correlation.

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ABSTRACT

Infrared maritime images taken in heavy sea fog (HSF) are usually nonuniform in brightness distribution and targets in different region have significant differences in local contrast, which will cause great difficulty for normal target detection algorithm to remove background clutters and extract targets. To this problem, this paper proposes a new target detection algorithm based on image region division and wavelet inter-subband correlation. This algorithm will firstly divide the original image into different regions by an adaptive thresholding method OTSU. Then, wavelet threshold denoising is adopted to suppress noise in subbands. Finally, the real target is extracted according to its inter-subband correlation and local singularity in original image. Experiment results show that this algorithm can overcome the brightness nonuniformity and background clutters to extract all targets accurately. Besides, target's area is well retained. So the proposed algorithm has high practical value in maritime target search based on infrared imaging system.

1. Introduction

Sea fog is a weather phenomenon caused by the gathering of a mass of liquid drops or ice crystals generated through vapor condensation in lower atmosphere above sea surface, with horizontal visibility less than 1000 m [1]. With the increase of liquid drops' or ice crystals' concentration, horizontal visibility will reduce further, even down to 500 m (HSF). Compared with normal weather condition, the high concentration of drops in the air will lead to faster growth of atmospheric path radiation and faster reduction of atmospheric transmissivity along with the distance increase, so that the imager will receive stronger self-emitted radiation of sea surface than the atmospheric path radiation in the vicinity, and in the distance, it will receive much stronger atmospheric path radiation than self-emitted radiation of sea surface. Under this condition, there will be a large bright region (BR) and a distinguishing dark region (DR) in the infrared maritime image (IMI, shown as Fig. 1), leading to the nonuniformity in global brightness distribution, besides, this condition results in that the contrast of target in BR will be much lesser than the target's in DR.

In this situation, maritime target search using infrared imaging system will be hard because it is difficult for normal target detection algorithms to self-adaptively deal with the brightness nonuniformity and big difference between targets' contrast, which means that it is hard to remove background clutters exactly and detect all real targets accurately. Besides, retaining more target's area to improve the positioning accuracy is also a difficulty for normal algorithms in this condition. In order to solve this problem, this paper proposes a new target detection strategy that consists of a region division algorithm based on adaptive thresholding and a novel target detection algorithm based on the wavelet inter-subband correlation and the local singularity of original image. Experimental results prove that this strategy is effective on target detection under this environment.

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Fig. 1. IMI taken in HSF.

This paper will firstly analyze characteristics of IMI taken in HSF, and then, the basic algorithm principles and algorithm flow will be introduced. Finally, experiment results will be shown and compared with two normal target detection algorithms to verify the effectiveness of the proposed algorithm.

2. Characteristics analysis for IMI taken in HSF

Fig. 1 shows an IMI taken in HSF with a medium-frequency wave infrared refrigeration thermal imager, which has an effective response band of 3.7–4.8 μm and a resolution of 320 × 256. Besides, the weather condition is as followed: wind speed is 6.3 m/s, mean wave height is 0.3 m, air temperature is 15.0 °C, and horizontal visibility is less than 500 m (according to meteorological data from China Meteorological Administration). In this figure, there are two targets: a fishing boat (marked by a box) and a freighter (marked by an ellipse). After further analysis, there are 3 obvious features that can be concluded.

(1) In terms of brightness distribution, the image can be divided into a bright region and a dark region. If a straight line shown in Fig. 1 is used as the boundary of these two regions, the mean grey value of BR is 157.04 and the mean grey value of DR is 88.86, which is a sharp contrast leading to difficulty for target detection based on grey value, such as binarization.

However, this brightness nonuniformity is a common phenomenon in HSF, which can be generally explained by the analytical model of infrared atmospheric radiation transmission (shown as formula (2.1)) [2].

$$L = L_t \times \tau + L_b \times \tau + L_{path} \tag{2.1}$$

In this formula, L represents total infrared radiation that thermal imager receives, L_t represents target radiation, L_b represents background radiation, L_{path} represents the atmospheric path radiation which will increase with the increase of distance between imager and background, τ represents atmospheric transmissivity which will reduce with the increase of distance between imager and background [3]. With the growth of particles concentration in atmosphere, the increase rate of L_{path} and the reduction rate of τ will also increase, so that in certain distance (distance threshold), $L_b \times \tau$ will be exceeded by L_{path}, resulting in the transition from DR to BR in IMI [4].
In other words, when the pitch angle of imager optical axis is in a certain range, the field range of imager will cover the distance threshold, leading to the nonuniformity in image's brightness distribution, so it's a common phenomenon for IMI taken in HSF.

(2) The contrast of target in BR is lower than the contrast of target in DR. Due to rapid reduction of atmospheric transmissivity along with distance increase in HSF, the radiation of target in the distance is weakened a lot to be close to the atmospheric path radiation, so that the contrast of target in BR is lower.

If we adopt formula (2.2) to calculate target contrast, the contrast of target in BR is 0.089 and 0.61 is the contrast of target in DR. In this situation, it's hard for algorithms based on local contrast to accurately detect all targets with so distinguishing local contrast.

$$\text{Contrast} = \frac{\bar{g}_t - \bar{g}_b}{\bar{g}_b} \tag{2.2}$$

In this formula, $\bar{g}_t$ represents the target's mean grey value and $\bar{g}_b$ represents the mean grey value of background.

(3) The background is smooth and there is no strong clutter interference both in DR and BR. In DR, the background is sea surface, it can be seen from Fig. 1 that there is no strong wave interference. In BR, the background is sea surface and sky, but their radiation is all exceeded by the atmospheric path radiation so this region is shown in uniformly white. According to the sea fog formation mechanism [5,6], when HSF occurs, low-altitude wind speed is usually less than 10 m/s. However, one of necessary conditions for waves developing is continuous strong wind above sea surface (usually it is more than 10 m/s) [7,8], so that HSF cannot occur along with strong waves. Namely, smooth background is also a common characteristic for IMI taken in HSF.

However, because the atmosphere turbulence and sea surface are not absolutely stable in actual, there is still some mild background clutter interference which can be observed in wavelet subbands (WS) (just as shown in Fig. 2). But compared with real targets, background clutters in WS are weak and can be easily removed by wavelet threshold denoising (see Section 3.2 for detail).

Based on the above analysis, it is difficult for normal target detection algorithms based on brightness distribution or local contrast to extract targets both in BR and DR accurately without leak detection or false detection. However, it can be found from Fig. 2 that, in terms of high-frequency subbands, the correlation between target's horizontal WS (HWS) coefficients and vertical WS (VWS) coefficients is strong. It is obvious that the strongest coefficients correspond to targets both in HWS and VWS. Besides, the coordinates of strongest coefficient in HWS of target in BR are (99,52) and the corresponding coordinates in VWS are (104,50), the coordinates of strongest coefficient in HWS of target in DR are (79,75) and the corresponding coordinates in VWS are (80,75). It can be seen that there is only 1 pixel offset between the strongest HWS coefficient and VWS coefficient of target in DR, however, there are 5 pixels horizontal offsets and 2 pixels vertical offsets between the strongest HWS coefficient and VWS coefficient of target in BR. By contrast, the high-frequency WS coefficients of background are weak so that most of them can be removed by the wavelet adaptive threshold denoising and the residual background WS coefficients have overall weaker inter-subband correlation compared with targets (see Section 3 for more details).

Hence, the strong inter-subband correlation of targets provides feasibility for target detection. Besides, the experiment shows that the area of original targets can be retained better if the original image is divided firstly according to brightness distribution.