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Research of the Space-Borne Infrared Ship Target Recognition Technology Based on the Complex Background

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***Abstract*—Space-based detection of ship targets is a significant way for fishery management, naval warfare, vessel traffic services today. Now the algorithm of ship target detection based on SAR and visible light is very mature, while the research of infrared ship target detection develops slowly as the resolution of infrared payload on orbit is relatively low. With the development of infrared technology, ship recognition based on infrared band becomes possible. As the space-borne infrared images have the characteristic of low SNR, low contrast and is easily influenced by the weather, light, sea, cloud background, a satellite-borne infrared target recognition realization is expected to develop to provide the guidance for the engineering applications. In this paper an innovative method of sea land segmentation by the statistics of power spectrum based on block combined with region growing method, background suppression by the revised TOP_HAT filter operator united with saliency map method is adopted. The measured long-wave infrared images are employed to verify the relevant method and the results show that the method proposed can detect the ship targets clearly.**

***Index Terms*—target characteristic, sea-land segmentation, infrared ship recognition, background suppression**

I. Introduction

With the improvement of the strategic position of ships in civil and military affairs, the research on ship target recognition will become more and more important. Ship target recognition in remote sensing images has become a hot topic in the field of remote sensing image processing and pattern recognition. As an important method of maritime transportation, it is of great theoretical significance and practical value to conduct a deep research on the automatic detection and recognition of ships. At present, the technology of space-borne ship recognition based on SAR and visible light images is relatively mature. The development of ship recognition based on infrared images is relatively lagging behind. With the development of infrared technology, the resolution of remote sensing images is gradually improved, which makes it possible for space-based system to recognize the ships on orbit. However, infrared sensors are affected by factors such as atmosphere, ocean thermal radiation and detector noise, which makes the ship appear as a small target with low signal-to-noise ratio. It is required that the infrared ship recognition technology can overcome the influence of various adverse factors in various complex background environments and has better real-time performance and higher detection rate, which is also an urgent problem to be solved in the infrared ship target recognition technology [1].

This paper introduces the method of space-borne infrared ship target recognition in the cluttered background ,which aims at modeling and analysis of ship target characteristics, study of the theory and method including ship target imaging model, pre-processing, image segmentation and recognition the remote sensing infrared images based on complex background. An innovative method of sea land segmentation by the statistics of power spectrum based on block combined with region growing method, background suppression by the revised TOP_HAT filter operator united with saliency map method is adopted. And the measured infrared images are employed to verify the relevant method and provide the guidance for the applications.

Ship detection is performed according to the following steps, as shown in Fig. 1. Infrared remote sensing image may contain terrestrial and cloud disturbances. In addition to the sea background, there may be some small islands, and the sea background itself may contain certain noises such as blur, bright spots, and so on. The sea-land segmentation and cloud detection are first performed and the noise is filtered out.

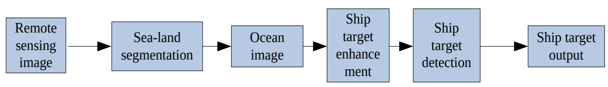

Figure 1. Procedure of ship detection algorithm

After removing the land background and cloud background, the image is the ocean background image containing the ship target. Then the target enhancement of the ocean image is normalized to eliminate the effects of

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different phases. Then the target is identified according to the threshold segmentation, and the image is output after the recognition according to a certain rule.

II. Modeling and Analysis of Ship Target Characteristics

Due to the reflection and thermal characteristics of ship target in infrared images, the detection of ship target in complex background becomes difficult due to the weather, illumination, sea conditions and many other factors. Therefore, it is the premise of target recognition to study the target characteristics of marine ships under various complex backgrounds. The target characteristic analysis should take into account the sea background and the emissivity model of ship target, the atmospheric attenuation model of infrared radiation, and the energy loss caused by optical systems and sensors. According to the infrared imaging radiance distribution data of target and background, the infrared images of target and background are obtained by quantifying the image temperature distribution [2].

A. Radiation Brightness of Object

Firstly, the emissivity model of sea background is established. There are three commonly used models, namely grey body model, empirical model and theoretical model. As the zenith angle of infrared sea background imaging ranges from 0 degrees to 50 degrees, empirical model can be selected as the sea surface emissivity model in this paper. The empirical model expresses the sea surface emissivity as a function of the emission direction, and considers that the sea surface emissivity is only related to the emission direction. The formula for calculating the sea surface emissivity is as follows:

$$\varepsilon_\theta = 0.98\left[1-\left(1-\cos\theta\right)^5\right] \tag{1}$$

ε is the sea surface emissivity, θ is the zenith angle.

Then the emissivity model of ship target is discussed. Taking an axisymmetric pipeline ship as an example and we suppose it is 200 m long and 30 m wide. Its structure is complex, mainly including the hull, deck and superstructure. The ship hull is made of alloy shipbuilding steel with emissivity ranging from 0.8 to 0.85. The deck material is generally made of steel with emissivity ranging from 0.8 to 0.82. The upper building material is generally made of aluminium alloy with emissivity ranging from 0.5 to 0.6. For the simplified ship model, the average emissivity of the ship is 0.8.

The band with high transmittance of the atmosphere in infrared radiation is called atmospheric window. In infrared imaging of ship target, the working band of infrared images is 8-12 um atmospheric window with zenith angle. During the daytime, we suppose the sea surface temperature is 296K and the ship's temperature is 312K. In the night the temperature of sea surface is 283K and that of ship is 278K. The radiance of sea surface and ship is shown in Table I.

From Table I, it can be seen that the infrared ship image is bipolar. In daytime, the ship's radiance is greater than that of the sea background object, but at night it is opposite. At the same time, the difference between the radiation values of ship and sea surface is small, and the contrast is low.

TABLE I. Radiance of Objects in Infrared Images

	Sea surface	ship
Daytime	0.0035	0.0037
Night	0.0028	0.0021

B. Atmospheric Transmission Attenuation

Infrared radiation from ship targets and ocean background will be selectively absorbed by some gases in the atmosphere and scattered by suspended particulate clouds, rain and snow before reaching infrared sensors. According to the atmospheric model, atmospheric transmittance and path radiance are obtained as shown in Fig. 2 and Fig. 3.

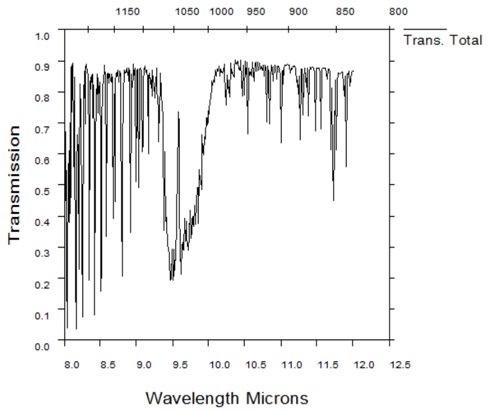


Figure 2. Atmospheric transmittance in cloudless and rainless weather

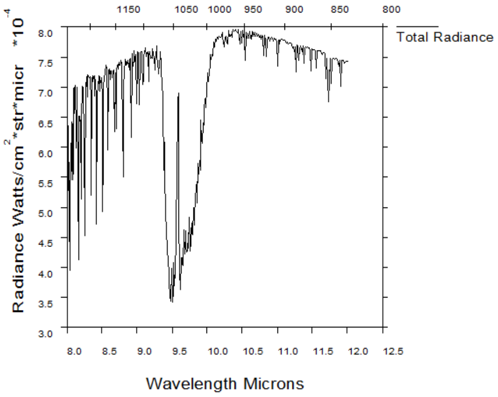


Figure 3. Range radiance in cloudless and rainless time

The radiance of the image received by the satellite infrared payload located outside the atmosphere is equal to the sum of the object radiance attenuated by the atmosphere and the radiation of the transmission path. The following formula is shown as follows:

$$N_1 = \frac{\varepsilon_\theta}{\pi}\int_{\lambda_1}^{\lambda_2} \rho(\lambda)\cdot e_\lambda(T)\,d\lambda + N \tag{2}$$

The optical attenuation of infrared lens is mainly related to the optical transmittance, that is, the ratio of the emergent luminous flux to the incident luminous flux of the optical system. Considering the low transmittance of infrared long-band mirror materials, the number of lenses in the whole infrared imaging system is about 5-8. After comprehensive design, the transmittance of the optical system is about 0.5.

The typical orbital altitude of 500 km is selected for infrared remote images detection. According to the manufacturing level of space-based infrared sensors, the F number of sensors is less than 6. Suppose the following parameters are adopted, including 8-12 um of infrared band, 0.75 of F number, 1 meter of aperture, 30 um of single pixel size, 1516 of pixel number, 9×10^{-4} mm^2 of detector photosensitive surface area, 10 m of resolution, 0.1k of equivalent noise temperature difference of camera, 0.7 of response efficiency of infrared detector. The response voltage of infrared detector can be obtained. The corresponding voltage value as shown in Table II.

TABLE II. DETECTOR VOLTAGE VALUE (V)

	The voltage of sea surface	The voltage of ship
Day time	0.00019	0.00022
Night	0.00018	0.00011

By simulating the voltage value, the daytime infrared image is obtained as shown in the Fig. 4 and Fig. 5.

Figure 4. Simulated infrared image in daytime

Figure 5. Simulated infrared image during Night

III. METHOD OF SEA-LAND SEGMENTATION

Ocean and land area segmentation is the second step of ship target detection. Analysis of the distribution characteristics of water and land can be summarized as follows: the water-containing area is relatively smooth, there is no excessive fine texture information, and the gray level changes smoothly. Based on this idea, the water-bank separation algorithm is designed [3].

First of all, the image roughness is judged because the seawater area is relatively smooth and is one of the basis for land-water separation. Because the image roughness is a statistical concept, it needs to be calculated in a certain range, so the image is to be cut. The image is divided into 50 × 50 small blocks and the spectrum of each block area is calculated. And the cumulative frequency of the spectrum of the image in the range of 4 to 20 is to determine the flatness of the image. In the Fig. 6 to Fig. 9, the images which was cut into small pieces are respectively listed and the distribution of their power spectrum with frequencies of 4 to 20 is shown.

The frequency of an image is an index characterizing the degree of intensity change in the image, and also a gradient of the gray level in the plane space. In the image, the grayscale of the areas changes slowly and the corresponding frequency value is very low. For the edge area where the grayscale changes drastically in the image is a region with a relatively high frequency value. The Fourier transform transforms an image from the spatial domain to the frequency domain.

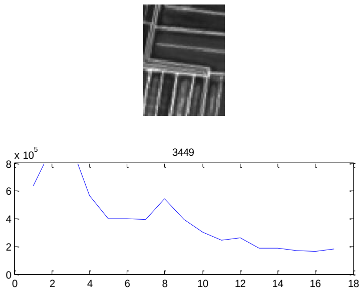


Figure 6. Farmland

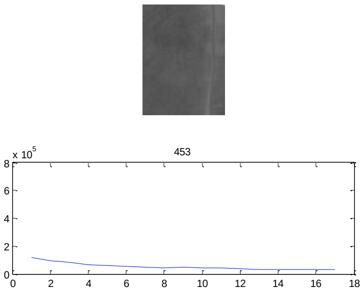


Figure 7. Seawater

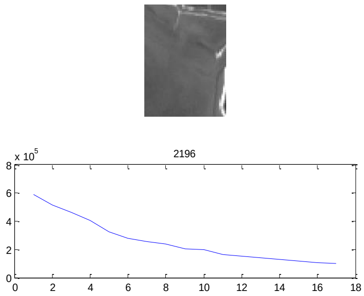


Figure 8. Water's edge

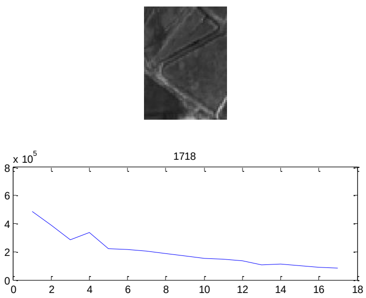


Figure 9. Vegetation

From the power spectrum of the image, it can be clearly seen that the power spectrum is smaller in the completely water area, and the power spectrum is larger in the non-water area of the image even if it is smooth, for example, the spectrum of the field also clearly exceeds the spectrum of water. The image is roughly divided into two categories. Then the edge is extracted where the two parts are transferred, and the edge is extracted as a seed point for area growth.

The image (Fig. 10) is subjected to an area growth treatment to eliminate small holes in the interior, and the black areas covered by large lands are filled with white. After the expansion and erosion algorithm, the interference in the shallow sea area is removed. After applying a median filter to the binary image, an edge extraction algorithm is used to outline the coastline.

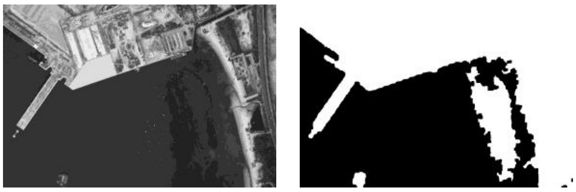


Figure 10. Waterside separation results

The extracted coastline is disturbed by sea waves and other clutter. Ship targets are detected at the edges of their seawater and coast.

IV. Ship Target Detection

When detecting a target in the sea, we must first suppress the influence of ocean background noise; highlight the target of the ship, and then extract the ship by the feature.

A. Suppression of Ocean Background Noise

The classical Top-Hat filtering applies structure operator with special shape and size to compare and measure the object image by mathematical morphology theory. Image characters are detected with operation as that the open operation is usually applied to detect the maximum and the close operation is usually applied to detect the minimum domain. Suppose that F is the infrared remote-sensing image, B is the structure operator, then the eroding operation Θ and dilating operation $\oplus$ are expressed as:

$$\begin{aligned} F\Theta B &= \min_{i,j}(F(x+i, y+j) - B(i,j)) \\ F \oplus B &= \max_{i,j}(F(x-i, y-j) + B(i,j)) \end{aligned} \tag{3}$$

where (x, y) is the coordinate of object image pixel.

The open operation $\circ$ with eroding operation firstly and the close operation $\bullet$ with dilating operation firstly are expressed as:

$$\begin{cases} F \circ B = (F\Theta B) \oplus B \\ F \bullet B = (F \oplus B)\Theta B \end{cases} \tag{4}$$

On the basis of open and close operation, the open and close operators are defined as the white Top-Hat operation WTH and the black Top-Hat operation BTH each [4], [5]. WTH and BTH are expressed as:

$$\begin{cases} WTH(x, y) = F - F \circ B \\ BTH(x, y) = F \bullet B - F \end{cases} \tag{5}$$

The structure operator is the most important factor which infects balance between real time effect of the transformation and background suppression effect of the image. The study shows that the integrated effects on balance will be the best when the shape of structure operator is similar to that of the input signal. So that a 3×3 squared structure operator is designed to simulate the rectangle structure of infrared remote-sensing image.

The improved Top-Hat operator with two nested parts are shown in formula 6. Where B_i is the inner structure operator, and B_o is the outer one. They are satisfied as $B_i \subset B_o$. The edge structure operator is expressed as:

$$A = B_o - B_i \tag{6}$$

With the inner and edge structure operators, Wth and Bth are:

$$\begin{cases} WTH(x, y) = F - (F\Theta A) \oplus B_i \\ BTH(x, y) = (F \oplus A)\Theta B_i - F \end{cases} \tag{7}$$

Ship targets are dim and small, and the background is a wide area changing slowly. There is strong relationship between pixels and the near lines in the background which takes up low-frequency domain while ship targets occupies the high-frequency domain. So that the WTH operation is the universal tool to detect the maximum value of the object image so as to realize the complex background suppression. In Top-Hat filter, the close operation has advantage on filtering minimum value of the object image. Both superiorities of the WTH operation and the BTH operation are utilized together with linear combination to enhance image contrast degree by suppressing background noise and making targets distinct.

$$J(x, y) = WTH(x, y) + BTH(x, y) \tag{8}$$

The contrast between ship targets and sea background is also enhanced. The improved method gets rid of the frequency spectrum range between background low-frequency and targets high-frequency so as to sharpen the contrast while the high-frequency area is protected to meet the request of the target recognition.

Background suppression based on the improved Top-Hat filtering enhances the targets, it also has some shortage such as object loss detection and land false alarm. Such shortage will affect the appliance of background suppression and cause the incorrect ship detection severely afterwards. The visual attention mechanism is utilized to detect the interesting area by intensifying prominent image, decreasing false alarm rate and making ship targets salient. The classic Itti-Koch model is chosen because of its advantage at cognizing small signal. The saliency map is generated from attention selecting procedure. And the salient domain is built by the area with strong contrast.

Aiming at color image, the intensity character I is expressed as:

$$I = (r + g + b)/3 \tag{9}$$

where r, g, b are red, green, blue components relatively.

Color characters are expressed as:

$$\begin{aligned} R &= r-(g+b)/2 \\ G &= g-(r+b)/2 \\ B &= b-(r+g)/2 \\ Y &= (r+g)/2-|r-g|/2-b \end{aligned} \tag{10}$$

where R, G, B, Y are red, green, blue, yellow channels relatively. Since the infrared image dealt with is the gray image which has no color, the value of intensity character is the same as that of image gray-level.

The Gabor filter is always used at edge detection. The filter frequency and orientation characteristic are comparable with human visual system [6]. As the Gabor filter is good at texture separation, it is utilized to determine orientation character O in Itti-koch model. The filter centered by origin point circumrotates with some orientation is to cover all spectrum space. Choose orientation as $\{0, 45^\circ, 90^\circ, 135^\circ\}$. After Gaussian filtering separately, the difference operator of center-surround method is applied to normalize multiple feature maps. The color, intensity, orientation saliency maps C', I', O' are normalized later. The whole saliency map S is

$$S = \frac{1}{3}(\mathrm{N}(C') + \mathrm{N}(I') + \mathrm{N}(O')) \tag{11}$$

where $N(\cdot)$ is normalized operator. The WTA(Winner-take-all, WTA) neural network technology is utilized.

Fig. 11 shows the result of background suppression based on improved Top-Hat and saliency map.

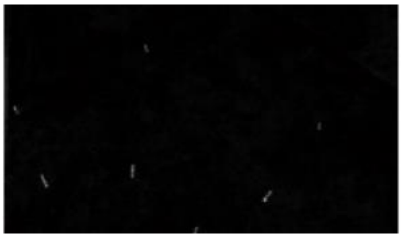
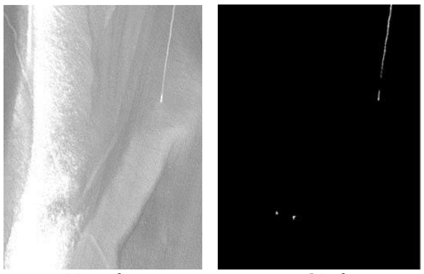


Figure 11. The background suppression based on improved Top-Hat and saliency map

B. Ship Target Segmentation

The area of the ship's target on the sea surface is relatively small, and sometimes they interfere with the background, so the histogram of the image does not appear bimodal as previously stated. This requires a grayscale morphological reconstruction of the Top-hat processed image [7].

Gray-scale morphology reconstruction is based on morphological gradient images, using morphological opening and closing reconstruction operations to reconstruct the gradient image and preserve important regions. This effectively preserves important information and suppresses background areas that are not of interest. This greatly reduces the difficulty of segmentation [8]. The result of binary segmentation of the image is as follows (Fig. 12):



(a) Before (b)after

Figure 12. Target segmentation results

C. Ship Target Confirmation

Through the skeleton, the information of the ship is extracted, and the aspect ratio of the ship is calculated. The false alarm condition is removed, then the image judgment is made according to its gray value [9], [10].

Before the confirmation of the ship's target, a series of processing is required. First, the segmented image needs to be inflated, the main information of the target such as the ship is extracted (Fig. 13). The Unicom region which is larger than 15 pixels is extracted, while the areas less than 15 pixels are deleted. It is etched (Fig. 14) and then the skeleton image of the area is extracted (Fig. 15).

Figure 13. Expansion

Figure 14. Corrosion

Figure 15. Skeleton

The commonly used ship target features are: grayscale, size, shape, texture features, including grayscale, area, length, width, length-width ratio, eccentricity, contour, constant distance, statistical characteristics. However, due to the limitation of image resolution, fewer features can be used. In this project, the length-width ratio, gray-scale distribution and length were selected for selection. It is designed using the long and short axes and circumscribed rectangle processing methods in image processing [11].

V. Conclusion

The ship's target detection is mainly based on the ship target candidate area or the ship's suspected target extraction, combined with the ship's own characteristics, further analysis and confirmation, removal of false alarms, and extraction of real ship targets.

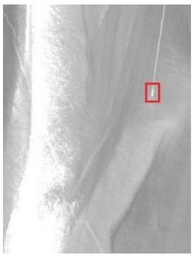


Figure 16. Recognition results

The above Fig. 16 is the detection result. As can be seen from the above, the small boat and wake disturbances are all eliminated, and the target information with the pixel value of not less than 40 pixels is retained. It can be detected the ship target effectively . Further research is to be studied under the complex and diverse imaging conditions, such as weather conditions, solar angle, imaging perspective, sea surface conditions, ship motion characteristics and other factors.

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