Ship Detection for Complex Background SAR Images Based on a Multiscale Variance Weighted Image Entropy Method

Xiaolong Wang and Cuixia Chen

***Abstract*— Ship detection from complex background synthetic aperture radar (SAR) images is a challenging task. Due to varying local clutter and low signal-to-clutter ratio, the most conventional methods fail to yield satisfactory results. An effective ship detection approach for complex background is developed in this letter. The approach measures the local dissimilarity between target and its neighborhood by using the variance weighted information entropy (VWIE) method. In order to enhance targets, an optimal window selection mechanism based on the multiscale local contrast measure is used in the local VWIE calculation. Experiments indicate that the proposed approach can effectively detect ship targets from the complex background SAR images by using the optimal selection mechanism.**

***Index Terms*— Multiscale local contrast measure (multiscale LCM), ship detection, synthetic aperture radar (SAR), variance weighted information entropy (VWIE).**

I. Introduction

SHIP detection from synthetic aperture radar (SAR) images is an important technique in maritime surveillance [1]. Owing to the corner reflection from ship structures, ships are usually bright in SAR images. When ocean surface is relatively quiet, it is easy to detect these ships. Whereas, when the wind is fierce, large waves will be stirred. Ships will be submerged in background clutter or heavy noise, the detection becomes an extremely challenging task.

Many researchers have paid much attention to the study of SAR ship detection, especially for those images that are against complex and noisy backgrounds [2]–[6]. Conventional detection methods, such as the constant false alarm rate methods and adaptive threshold algorithms, are usually based on a prior detection window [7], [8]. The strong dependence of the window initialization on prior knowledge about ships and background observation limits their application. A self-adaptive detector based on the local variance weighted information entropy (VWIE) has been applied to the detection of ship targets from SAR images and was proven to be a simple and effective method for the relatively complex background detection task [6]. The local VWIE can enlarge the original brightness difference between targets and their neighboring areas and effectively suppress background clutter and noise, while the background is consistent with their neighboring areas. However, things are complex when different sizes of targets occur in heterogeneous or strong noise backgrounds. Its ability is weakened because the identical window is used throughout the whole local VWIE calculation. In order to deal with this problem, an effective way for the varying local backgrounds is to use multiple scales of windows. Recently, a new trend toward imitating robust human visual system (HVS) to promote the performance of target detection has emerged [9]–[11]. HVS-based methods have shown great potential in various target detection tasks. Of those methods, target detection methods based on the local difference/mutation have attracted much attention. A representative is local contrast measure (LCM) [12], which is presented to measure the dissimilarity between the target region and its surrounding areas. The method adopts multiple scales of windows to calculate the multiscale LCM and is proved to be efficient in dealing with small targets and the complex background.

As a new contrast measuring method, the existing researches about the multiscale LCM mainly focus its applications on the target extraction [11]–[14]. In practice, we found that the multiscale LCM has great potential in determining the local optimal detection windows. Inspired by this idea and the local entropy concept, a multiscale LCM-based VWIE (MVWIE) detection approach has been designed in this letter aiming to solve the problem of ship detection in complex background SAR images. Experimental results show that the proposed approach has better detection performance compared with the existing LCM and WIE-based methods, and it is an effective method for detecting ship targets from the heterogeneous or strong noise background SAR images.

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X. Wang is with the Institute of Electronics, Chinese Academy of Sciences, Beijing 100190, China (e-mail: xiaolong-wang@163.com).

C. Chen is with the National Institute for Communicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention, Beijing 102206, China (e-mail: cxchen1@163.com).

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II. Description of Algorithm and Method

A. Multiscale LCM

LCM describes a pixel (position) by generating a signal value [12]. According to LCM, local contrast in an image can be measured by a hierarchical architecture. As shown in Fig. 1(a), if the target cell u is different from its neighborhood, the target in the central of the image patch v can be enhanced. When the window v moves on the whole image w,

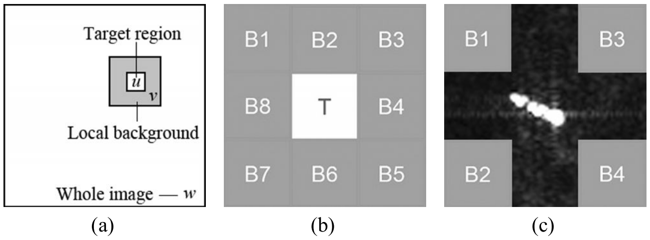


Fig. 1. Calculation windows of multiscale LCM. (a) Multiple windows. (b) Eight neighboring cells scheme. (c) Four neighboring cells scheme.

different image patches of size v can be obtained. For each image patch v, the target cell u is encircled by eight surrounding cells [see Fig. 1(b)]. The gray mean of the ith cell is denoted by m_i $(i = 1, 2, \ldots, 8)$, that is

$$m_i = 1/N_u \sum_{j=0}^{N_u} I_j^i \tag{1}$$

where N_u is the number of the pixels in the ith cell and I_j^i is the gray level of the jth pixel in the ith cell. The width and the height of the window v are usually both three times those of window u. Consequently, the contrast between the central cell and the ith surrounding cell is defined by

$$c_i^n = L_n/m_i \tag{2}$$

where L_n represents the maximum of the gray value of the central cell in the nth image patch of size v. In order to enhance the small, faint even hidden targets, the LCM is defined as follows:

$$C_n = \min_i L_n \times c_i^n = \min_i L_n \times L_n/m_i = \min_i L_n^2/m_i. \tag{3}$$

The definition means that the larger C_n is, the more likely a target appears. For a given scale, an LCM map can be obtained once the window v moves across the whole image w.

As a matter of fact, the sizes of targets are different. In the ideal case, the closer the size of window u is to the target size, the larger the local contrast between target and its neighborhood is. In order to obtain the maximum contrast C_n, a series of LCM maps is computed by using enough scales of windows $(u = 1, 3, 5, \ldots, 2k+1)$. Based on this, a maximum operation for each point is implemented on these maps, and then, the final multiscale LCM map can be achieved.

B. VWIE

Information entropy is a statistical form of characteristics, which reflects how much information there is an information source [15]. Similar to the information entropy, image entropy is constructed based on the image histogram. For an image with L gray levels, its entropy is

$$E = \sum_{i=0}^{L-1} p_i \log(p_i) \tag{4}$$

where p_i is the probability of the ith gray level in the image.

Image entropy can reflect the degree of difference in the gray values of pixels. However, it cannot reflect the complex degree of image background, since it ignores the importance of gray information. VWIE is explored to emphasize the contribution of high gray value components to the information entropy of an image [16]. Assume that I is the gray value at the point (x, y), and its neighborhood (local window) includes m kinds of gray values $I_1, I_2, \ldots, I_m$. Then, the VWIE of the point (x, y) can be expressed as

$$E(x, y) = -\sum_{i=0}^{m} (I_i - \overline{I})^2 p_i \log(p_i) \tag{5}$$

where $\overline{I}$ is the mean value of the image patch in the local window.

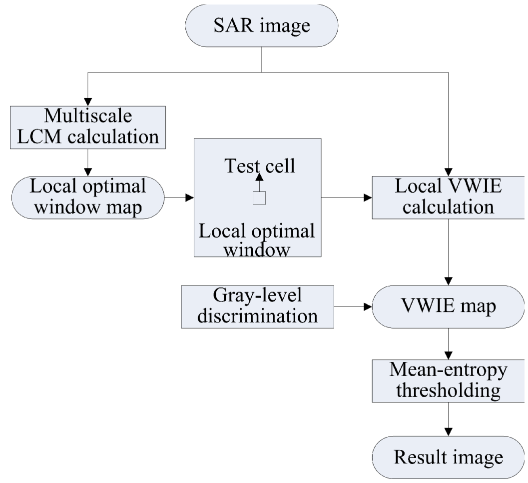


Fig. 2. Block diagram of MVWIE detection framework.

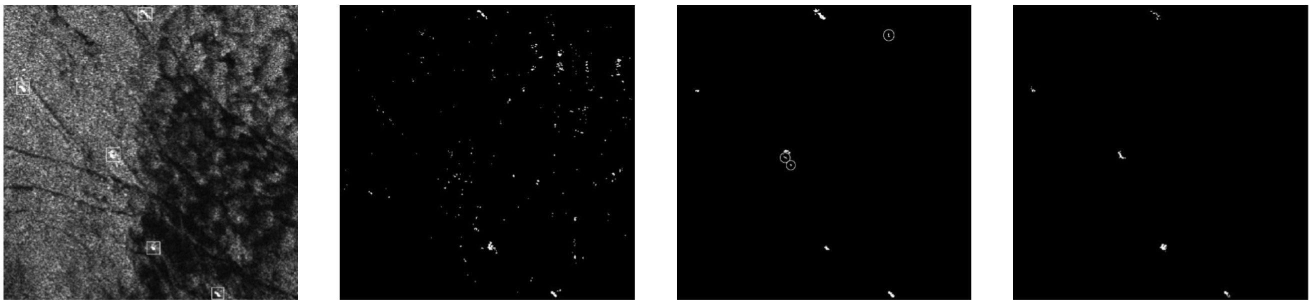
C. MVWIE Ship Detection Approach

As mentioned in Section I, the concept of multiscale LCM provides an ideal selection mechanism for the local optimal windows, while the VWIE gives a simple and effective way in improving the signal-to-clutter ratio (SCR) of the image. With these considerations in mind, an MVWIE ship detection approach for complex background SAR images has been designed in this letter. The block diagram of the proposed detection framework is shown in Fig. 2. The detection process can be summarized as follows.

1) Local optimal window map calculation. For inputted SAR image, multiple scales of LCM maps are calculated by using different scales of windows. Based on this, a local optimal window map can be obtained by using the maximum operation, since the optimal window size for each local area generally corresponds to the local maximum LCM. In order to reduce the computation cost and eliminate the effect of strong scattering target on its neighboring cells in both the range and azimuth directions, a four neighboring cells scheme as shown in Fig. 1(c) is used in the LCM calculation.
2) VWIE map calculation. Based on the calculated local optimal window map, the local VWIE for each local area can be calculated by using its corresponding window. When each point in the image is calculated, a VWIE map can be obtained. Considering that the VWIE algorithm

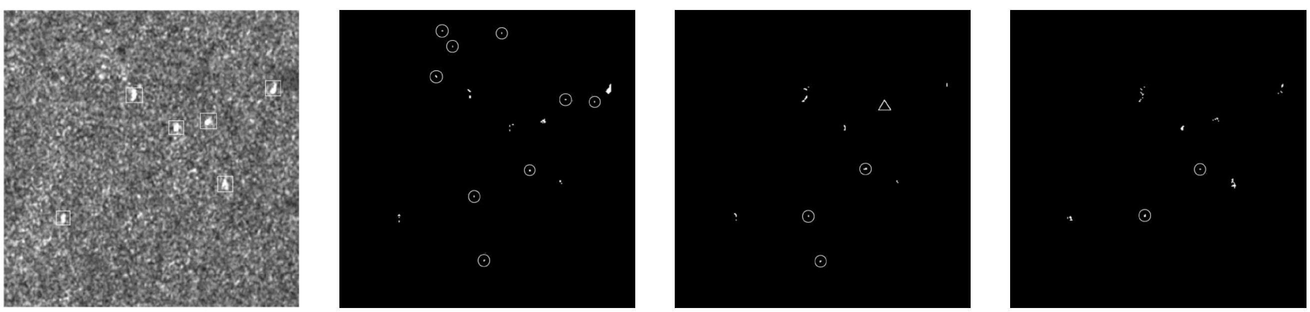
(a) (b) (c) (d)

Fig. 3. Ship detection in homogeneous background situation. (a) Original SAR image. (b) Multiscale LCM result. (c) VWIE result. (d) MVWIE result.



(a) (b) (c) (d)

Fig. 4. Ship detection in heterogeneous background situation. (a) Original SAR image. (b) Multiscale LCM result. (c) VWIE result. (d) MVWIE result.



(a) (b) (c) (d)

Fig. 5. Ship detection in strong noise background situation. (a) Original SAR image. (b) Multiscale LCM result. (c) VWIE result. (d) MVWIE result.

has some difficulties in defining the target boundaries, an auxiliary gray-level discrimination based on the image mean is added in this process. The corresponding VWIE value is set to zero if the intensity of a point is smaller than the mean value.

3) Mean-entropy thresholding. In the calculated VWIE map, some salient regions in the scene are likely target regions. In order to extract the potential targets, a simple threshold operation is applied to the VWIE map. The threshold E_{th} is defined as follows:

$$E_{\text{ship}} > E_{\text{th}} \text{ with } E_{\text{th}} = k \times \text{meanEntropy} + 3000 \quad (6)$$

where meanEntropy is the mean of the VWIE value of the whole image, k is an adjustment parameter, and 3000 is a fitting constant. In our experimental work, k ranges from 1.05 to 1.50, which has been tested to be suitable for the most situations. Then, if the VWIE value $E(x, y)$ of a pixel is larger than the threshold, the pixel would be selected as the pixel of a target.

III. Experiments and Results

To demonstrate the performance of the proposed approach, three different background SAR images as shown in Figs. 3(a), 4(a), and 5(a), respectively, are used. Fig. 3(a) is a homogeneous background image containing eight ships (TerraSAR-X SAR image, 1600×1200 pixels, 3-m pixel size), Fig. 4(a) is a heterogeneous background image containing five ships (ERS C-band SAR image, 500×500 pixels, 12.5-m pixel size), and Fig. 5(a) gives a strong noise background image containing six ships (Radarsat C-band SAR image, 332×334 pixels, 30-m pixel size). In the experiments, the size of the window u ranges from 3 to 13, and k is set as 1.05 for Figs. 3 and 4 and 1.30 for Fig. 5.

A. Ship Detection

To test the effectiveness of the proposed approach, we compare it with the recent methods of multiscale LCM [12] and VWIE [6]. The results are shown in Figs. 3–5, respectively. The true targets are labeled by rectangles, the false targets are signed by circles, and the missed targets are signed by triangles.

As can be seen, due to the uniform background and the higher SCR, all methods produce similar results for the homogeneous background situation in Fig. 3(a), which highlight all the ships without causing any false alarms or with only one false alarm [Fig. 3(b)]. However, things are different for

TABLE I
FoMs OF DIFFERENT METHODS

	LCM	VWIE	MVWIE
Homogeneous background(Fig.3)	0.889	1	1
Heterogeneous background(Fig.4)	<0.100	0.625	1
Strong noise background(Fig.5)	0.400	0.556	0.750

the heterogeneous and strong noise background situations. Due to excessive sensitivity to gray difference, the multiscale LCM method can detect ships with large numbers of false alarms as shown in Figs. 4(b) and 5(b), whereas the VWIE method can detect the true targets with relatively few false alarms, but when the sea clutter is complex and strong noise, it presents an increasing number of false alarms and missing alarms. In comparison, the proposed approach can detect the true targets successfully. Although little noise or clutter in strong noise background in Fig. 5(a) is mistaken to be ships, compared with those of the other methods, the detection results are acceptable.

B. Performance Evaluation

The figure-of-merit (FoM) [17] is used to assess the detection performance. It is the ratio of the correctly detected target number to the sum of the actual target number and the false alarm number. The higher value of FoM means higher detection rate and lower false alarm rate. FoM is defined as

$$\mathrm{FoM} = N_{\mathrm{tt}}/(N_{\mathrm{fa}} + N_{\mathrm{gt}}) \quad (7)$$

where N_{tt} is the number of correctly detected targets, N_{fa} is the number of false alarms, and N_{gt} is the number of true targets that existed in image.

Table I lists the FoM values of the three methods. It is clear that the proposed approach has much better adaptability than the other methods for the complex background situations, which indicates that it is an effective way in enhancing targets and suppressing background clutter and noise significantly. Furthermore, the variance analysis reveals its robustness. The variance of the FoM is 0.014 for the MVWIE method, which is significantly smaller than those of the LCM and VWIE methods (0.106 and 0.038, respectively). In addition, the higher FoM values of the MVWIE method than those of the VWIE method suggest that the proposed optimal selection mechanism can improve the performance of the window-based detectors. Hence, it is particularly suitable for the window-based detectors.

IV. CONCLUSION

In this letter, a new approach for ship detection from the complex background SAR imagery is proposed. The contributions can be summarized as: 1) an effective selection mechanism for local optimal detection windows is proposed inspired by the multiscale LCM method and 2) a ship detection framework for complex background is designed based on the proposed mechanism. Experimental results show that the proposed approach achieves satisfying performance on the aspects of detection rate and false alarm rate, which means that the proposed mechanism is helpful in enhancing the local dissimilarity between target and its neighborhood, especially for the complex background SAR images.

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