Maritime background infrared imagery classification based on histogram of oriented gradient and local contrast features

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Abstract：In the complex and changeable sea environment，when using infrared imaging technology to search and rescue small and medium targets on the sea surface，it is necessary to classify the collected original images in order to facilitate the subsequent target processing in different scenes. According to different environmental conditions，the sea infrared images are divided into five kinds of scenes. The training set images are extracted from two aspects：one is to divide an image into basic layer and detail layer by the Gaussian filter，and use improved histogram of oriented gradient（HOG）method to extract the features；the other is to extract features by calculating local contrast of images. The extracted feature vectors are fused and input into the classifier，and the test set images are classified by support vector machine（SVM）. In this paper，a new feature descriptor combined with HOG and local contrast method（LCM）is used to classify the scene of sea infrared image. Compared with other methods，the results show that the accuracy of the improved method is 96. 4%，which reflects the feasibility and effectiveness.

Key words：background classification，feature descriptors，histogram of oriented gradient（HOG），local contrast method（LCM），infrared images

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基于方向梯度直方图和局部对比度特征的海面背景红外图像分类

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摘要:在复杂多变的海面环境下,应用红外成像技术对海面中小目标进行搜救时,为有利于后续针对不同场景的目标处理,有必要对采集的原始图像进行分类处理。根据不同的环境条件,将海面红外图像分为五类场景。从两个方面对训练集图像进行特征提取,一个是通过高斯滤波将图像分为基础层和细节层,然后使用改进的方向梯度直方图(HOG)方法提取特征;另一个是提取图像的局部对比度得到局部特征。将提取的特征向量融合并输入到分类器中,使用支持向量机(SVM)对测试集图像进行分类。文章使用了 HOG 和局部对比度方法(LCM)结合的新特征描述符对海面红外图像的场景进行分类,与其它方法相比,结果表明改进方法的准确率达到96.4%,体现了可行性和有效性。

关 键 词:背景分类;特征描述符;方向梯度直方图;局部对比度方法;红外图像

中图分类号:TP391   **文献标识码**:A

Introduction

With the development of the area of fast search and rescue for small and medium maritime targets for recent years，infrared target detection has been the main application method. Due to the complexity and change of the marine environment，it has brought certain difficulties to search and rescue targets. Therefore，it is necessary to classify the images of different scenes in order to improve the efficiency of target detection. It will facilitate subsequent image processing.

DONG Li-Li *et al*：Maritime background infrared imagery classification based on histogram of oriented gradient and local contrast features

5 期

651

In recent years，image scene classification including natural scene and artificial scene is also an important research direction in the field of computer vision. The key to scene classification is image features extraction. Aiming at the extraction of image features，many classical methods have appeared，which are mainly divided into three categories [1]. One is a low-level method to extract feature descriptors directly from images，such as scale-invariant feature transform（SIFT），color histogram and so on. The second is a mid-level method that continues feature extraction based on some underlying features of image block extraction，such as bag-of-visual-words（BOVW）and sparse coding. Thirdly，it is a high-level method to automatically extract features of images by training the network model of deep learning [2-3].

Each of the three methods have advantages and disadvantages. The first method has simple steps，but the description of low-level features has limitations. Compared with the first method，the second method improves the classification accuracy，while the process is more complicated. Deep learning is a method emerging in recent years. The advantage is that the feature descriptors are not extracted manually，and well-trained network classification works very well. However，a large amount of data is required for training，which takes a long time and a high storage space.

In this paper，we use the low-level features because the whole process does not have much time and space in actual situations. And classification is performed by extracting the features of the sea background of the entire images，not sea targets. Common feature extraction methods of scene classification are SIFT，speeded-up robust feature（SURF），local binary pattern（LBP），HOG，and gray level co-occurrence matrix（GLCM）and so on.

Qilong Li et al. used SIFT algorithm to extract feature points，all feature points extracted are clustered by K-means clustering algorithm，and then bag of word（BOW）of each image is constructed. The SIFT algorithm has a strong tolerance for scaling，rotation，brightness changes，and noise [4]. Qiqi Zhu et al. proposed a local-global feature BOVW scene classifier for high spatial resolution imagery [5]. Atreyee Sinha et al. proposed a novel set of image descriptors. This image descriptor encoded information in image features and improves the popular directional gradient histogram pyramid（PHOG）descriptor for object and scene image classification [6]. Haitao Lang et al. used co-occurrence matrix to implant the spatial relations between local features，and proved that the feature co-occurrence matrix（FCM）is a potential discriminative character for scenes classification [7].

At present，the infrared maritime target detection algorithms are relatively multiple and mature，but the background classification still has not received enough attention in the whole detection process. There is no single way to handle images with multiple situations. Therefore，it is necessary to study it carefully to improve the efficiency of search and rescue.

1 Image Characteristics Analysis

The sea background is complex and variable，and it will encounter various situations in the process of searching for targets，which may cause difficulty in target recognition and detection. Usually according to the actual needs of the sea rescue environment and target detection algorithms，marine background can be divided into five kinds of environment，namely，back-lighting environment（BE）[8]，large wind wave environment（LWWE）[9]，sea fog environment（SFE）[10]，sea-sky-line environment（SSLE）[11]，and calm sea environment（CSE）. Some images of each background are shown as Fig. 1. Gray distribution is shown in Fig. 2.

It can be seen from images that the overall brightness distribution of the BE image is uneven and has many spots. The background gray level of an image is unevenly distributed. LWWE texture information is irregular and clear，with stronger texture direction and weak correlation between gradients in different directions. The brightness distribution of the SFE image is not uniform. The difference between the foggy portion and the sea surface brightness is large，and the local background is smooth. The SSLE image is divided into sea surface part and sky part by sea-sky-line，including cloud，islands and so on. The sky part has high grayscale and clear texture information. Since images of different environments have different characteristics，they can be classified.

When multiple scenes appear in an image，we define the classification priority to these scenes. According to the actual situation，there are up to three situations. One is SSLE coexists with LWWE，one is both SSLE and BE exist simultaneously，and the other is both BE and LWWE exist side by side. The order for priority is SSLE，BE and LWWE. The image is shown as Fig. 3. It is classified as SSLE.

2 Algorithm

The targets include small and medium targets，mainly ships，and the application scenario is sea rescue search. Therefore，when the target exists in the background，the local characteristics of the background and the target position are less affected. There is no uniform influence rule，so the local features have less influence on global features. For the overall sea surface background，feature extraction is performed from two aspects.

The process of extraction of HOG and local contrast features are shown in Fig. 4. First，images are scaled to a uniform size（256*256 in this paper），and the HOG features and local contrast are extracted respectively. The features are merged as shown as Fig. 5. Then a new feature vector is constructed and input into the classifier to complete an image classification task.

The content of feature extraction includes geometric or arithmetic descriptions of its color，grayscale，texture，contour，region，special point or line. Based on infrared imagery，it can be considered mainly from two aspects of texture and grayscale. Therefore，the HOG method and LCM are selected and combined to represent
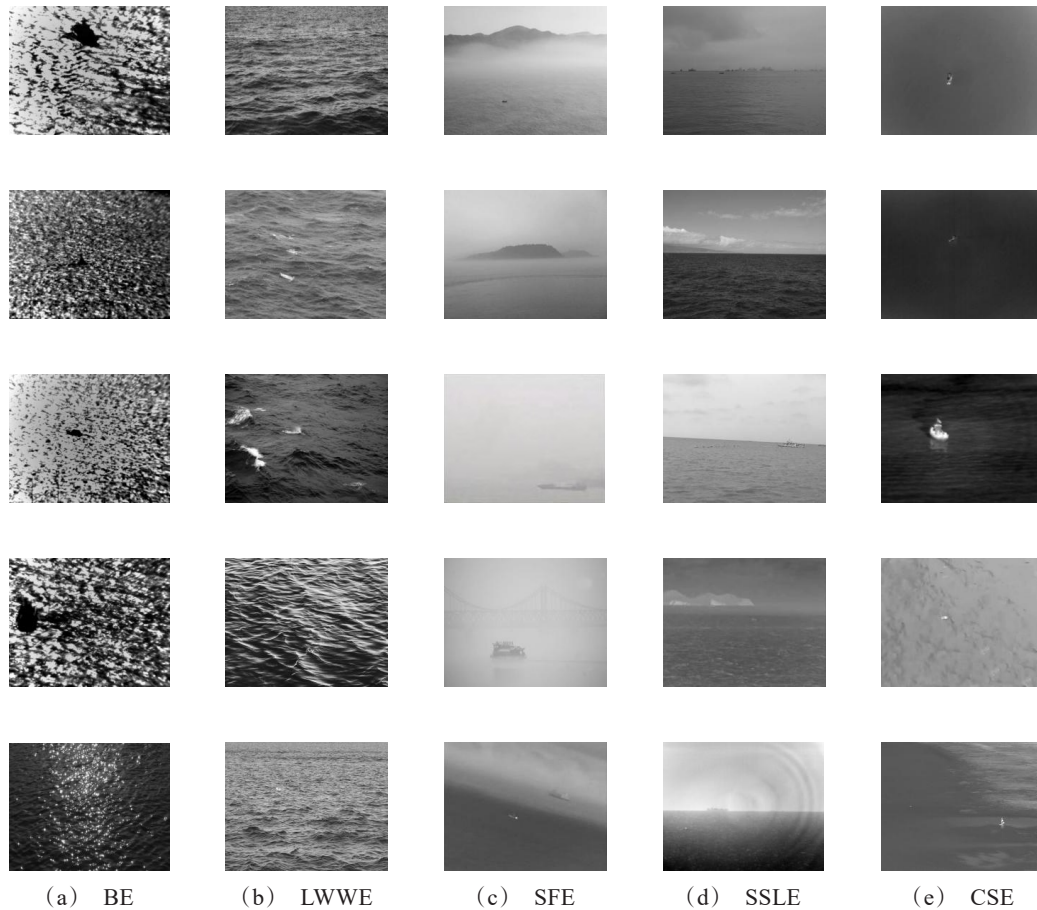
（a）　BE　　　　　（b）　LWWE　　　　（c）　SFE　　　　（d）　SSLE　　　　（e）　CSE

Fig. 1　Sea infrared images
图 1　海面红外图像

the characteristics of the image.

2.1　HOG

HOG is a feature descriptor used to describe local edge and shape information. It mainly calculates and counts the direction gradient histogram of the local region of the image. However, images of different backgrounds, such as SFE and SSLE, sometimes have similar grayscale distributions as shown in Fig. 6. Processing only the original image does not yield enough information, so dividing an image into a base layer and a detail layer allows for more comprehensive extraction of features such as Fig. 7. This paper uses Gaussian filtering to extract HOG features after layering the image. The size of the convolution kernel was determined to be 101 * 101 through multiple experiments, and σ = 20. Scan each pixel in the image in turn to perform a weighted average operation to obtain pixel values Q（x, y）at the corresponding position of the new image, which is a base image. Then a basic image is subtracted from an original image to obtain a detail image. Finally, the HOG feature of the whole image is obtained by tandem fusion.

The detailed process of extracting HOG features is as follows：

· Step 1：Calculate the gradient and direction angle of each pixel of the image.

The gradient of the horizontal and vertical directions of the image pixels are calculated differently as follows：

$$G_x(x,y) = f(x + 1,y + 1) - f(x,y), \quad (1)$$

$$G_y(x,y) = f(x + 1,y) - f(x,y + 1). \quad (2)$$

In the above equation, $f(x, y)$ represents pixel values, $G_x(x, y)$ and $G_y(x, y)$ represents the horizontal and vertical gradients at the pixel（x, y）in the input images. In this paper, the new one-dimensional central template operator is used to calculate the gradient values to reflecting local changes. Combined with the Robert operator, it is sensitive to curved edges. The gradient magnitude and gradient direction at the pixel（x, y）are as follows：

$$G(x,y) = \sqrt{G_x(x,y)^2 + G_y(x,y)^2}, \quad (3)$$

$$\alpha(x,y) = \tan^{-1}\left(\frac{G_y(x,y)}{G_x(x,y)}\right). \quad (4)$$

The square root operation makes the process similar to what happens in the human visual system. The angle is divided into nine directions, and the corresponding gradient values are calculated respectively which are normalized as the feature vector of the gradient direction.

· Step 2：Divide cell units and take the gradient di-

5 期

DONG Li-Li *et al*：Maritime background infrared imagery classification based on histogram of oriented gradi-
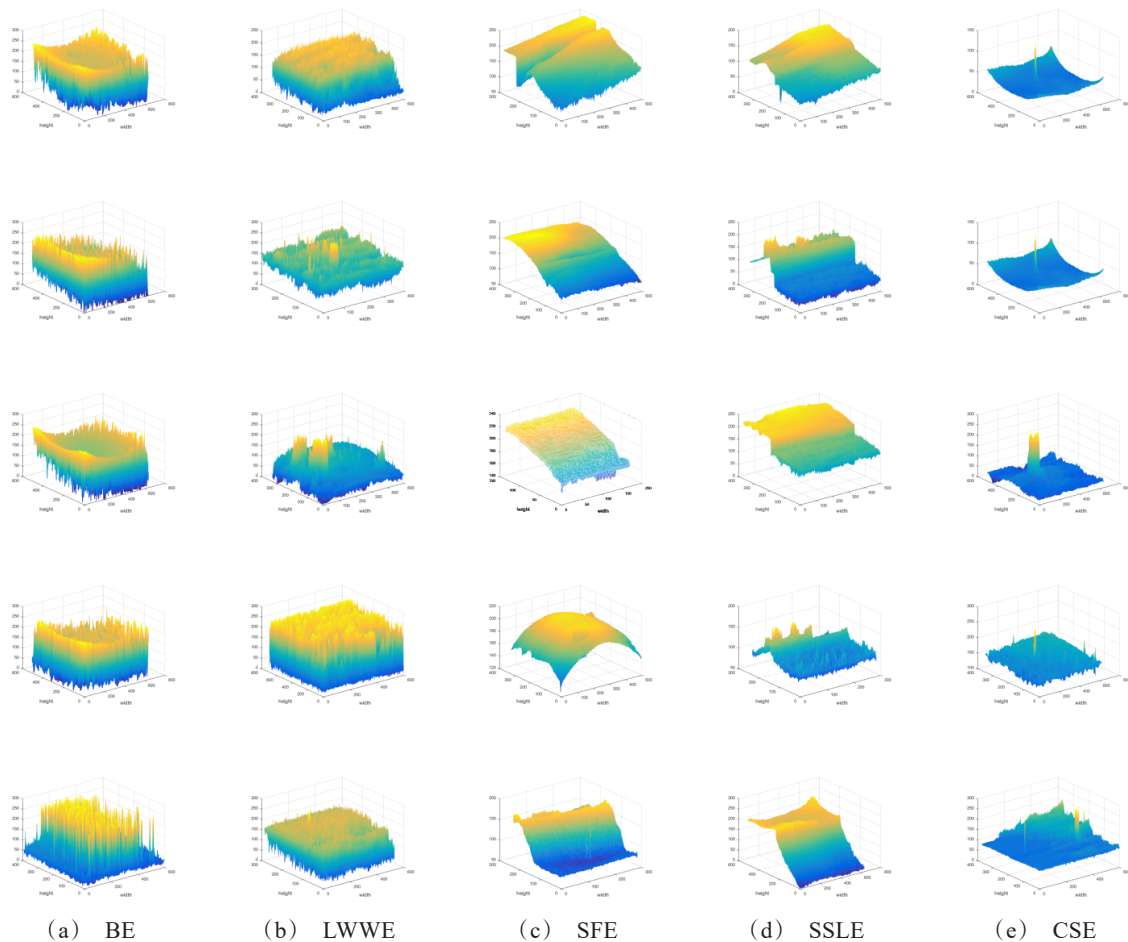ent and local contrast features

653

Fig. 2　Three-dimensional map of sea infrared images
图 2　海面红外图像三维图

Fig. 3　SSLE
图 3　海天线场景图像

rection histogram of each cell.

　　An image is divided into cells that each cell is 32*
32 pixels，and the gradient information is counted by the
histogram of 9 bins. The gradient size is used as the
weight of the projection. It is obtained a 9-dimensional
feature vector corresponding to the cell，that is，the gra-
dient direction histogram of a cell.

　　If the size of the input image is 256 × 256，the
small target will occupy less than 0. 15% of it. This stan-
dard is usually independent of the size of the input im-
age[12]. It is not necessary to extract more detailed fea-
tures and reduce redundant information. Table 1 shows
the comparison of different cell size under the same con-
dition. It can be seen that small size takes a long time.

　　· Step 3：Combine cell units into blocks and normal-

ize gradient histograms within blocks.

　　Each cell is combined into a large，spatially con-
nected interval，and the feature vectors of all cells in
each block is concatenated and normalized to obtain the
HOG feature of the block. The normalization method
used is L2-Hys，which is obtained by first performing L2-
norm，then clipping the result，and normalizing. L2-
norm formula is setting as follows：

$$L2-\mathrm{norm:}\alpha = \frac{\beta}{\sqrt{\left\|\beta\right\|_2^2 + e^2}}. \tag{5}$$

In this equation，β denotes a no normalized vector con-
taining histogram information for a given block，e is a
small constant，and the purpose is to avoid the denomina-
tor being 0；$\left\|\beta\right\|_k$ is the k-order norm of β.

　　· Step 4：Get the HOG feature of the whole image.

　　The feature vectors of all the blocks in the detection
window are concatenated to obtain the overall HOG fea-
ture vectors，which are combined into the final feature
vector for classification.

2. 2　Local Contrast Method

　　Local contrast features are used to describe the gray-
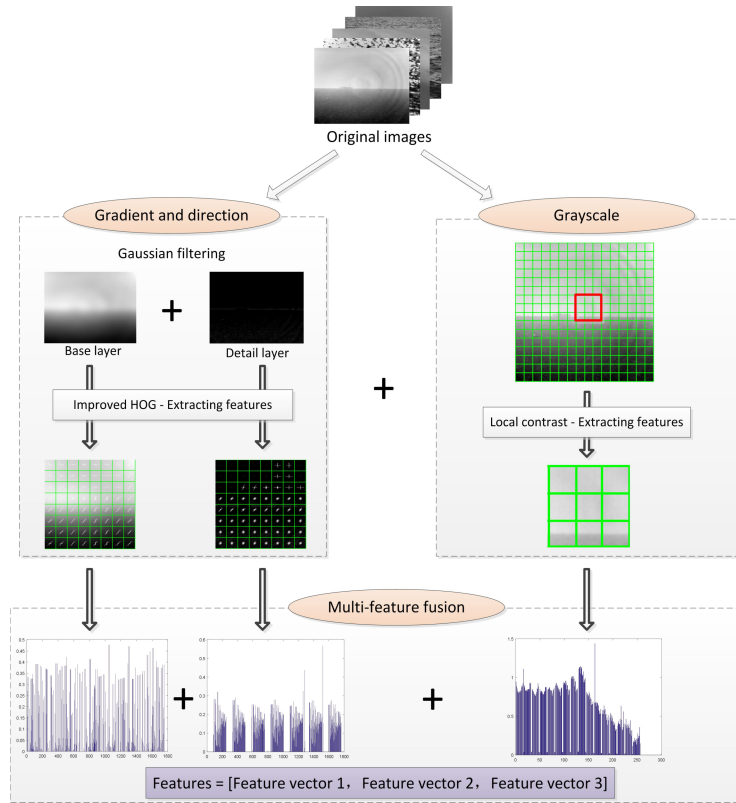scale variation of an image. Divided an image into blocks

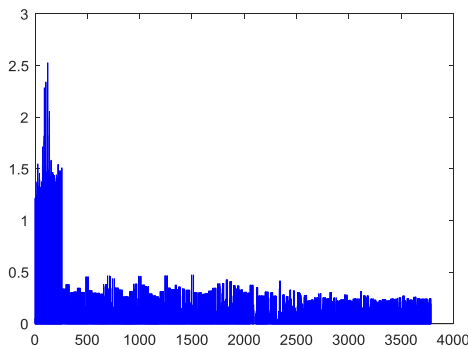Fig. 4   The process of extracting features
图 4   ．特征提取过程

Fig. 5   Fused features
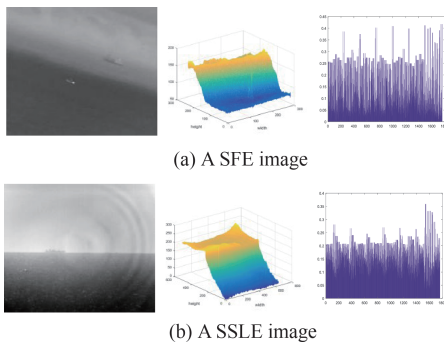图 5   融合后的特征

(a) A SFE image

(b) A SSLE image

Fig. 6   Two similar gray distribution of different background images
图6   两张不同场景图像相似灰度分布

and analyzed the relationship between the central block and the surrounding blocks as shown in Fig. 8. And Fig. 9 shows the specific values of the matrix. An image is divided into n*n blocks，each block is composed of m*m pixels，and the maximum value and the average value of each block is calculated separately. Then each block is compared with the 8 surrounding blocks to form a 3*3 image window，which will slide sequentially to calculate the contrast of each block.

The local contrast is calculated as follows：

$$C_n = \frac{\max_n(M_0)}{mean_n(M_i)}. \tag{6}$$

In the equation，C_n represents the contrast of nth image block，and $\max_n(M_0)$ indicates the maximum value of the nth block as the intermediate block，$mean_n(M_i)$ （i=1，2，…，8）means the average of the surrounding blocks of the nth block.

The calculated values of each block form a 16*16 matrix，which is then arranged to obtain a one-dimensional feature vector of the entire image of 256×256 size. Fig. 10 calculates the local contrast of five different backgrounds. It can be seen that each category has different characteristics. The values of BE and LWWE fluctuate greatly，but they have no obvious rules of change. So，it is necessary to combine the HOG method mentioned above extracting more features. The values of SFE and SSLE have a trend from high to low that SSLE changes significantly from high to low and SFE is relatively flat. However，there is also a case where the difference
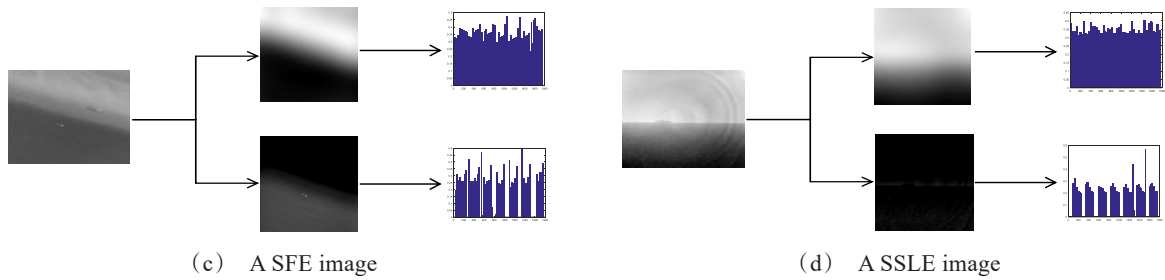
DONG Li-Li *et al*：Maritime background infrared imagery classification based on histogram of oriented gradient and local contrast features

5 期

655

（c） A SFE image （d） A SSLE image

Fig. 7　Gray distribution of base layer and detail layer of different background images
图 7　不同场景图像的基础层和细节层的灰度分布

Table 1　Comparison of different cell sizes
表1　不同cell大小的比较

Cell size	8*8	16*16	32*32
Feature vector dimension	34596	8100	1764
Time cost(s)	48.119	15.653	12.515

in brightness between the sky and the sea surface is not obvious as shown in Fig. 8 SSLE-④. For example, Fig. 8 also shows the trend of SFE-⑤ and SSLE-⑤ which is less consistent with the normal law than the respective identical backgrounds. At this time, the simple local features are not sufficient to reflect the background difference. The value of CSE is generally lower and smoother.

In general, local contrast can be distinguished under normal conditions by four categories. BE and LWWE are considered one type because it is difficult to distinguish between the two. Therefore, the features of an image are jointly extracted in combination with the HOG features above.

2.3　SVM

Through the learning algorithm, the support vector machine（SVM）can automatically find the support vector with good discrimination ability. The constructed classifier can maximize the class-to-class interval, so it has better adaptability and higher classification accuracy. Combined with the image classification of this experiment, it has a good classification effect.
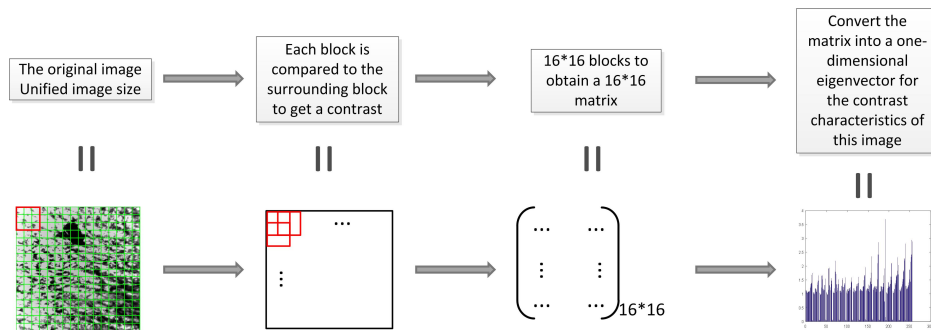

Fig. 8　Local contrast calculation diagram
图8　局部对比度算法
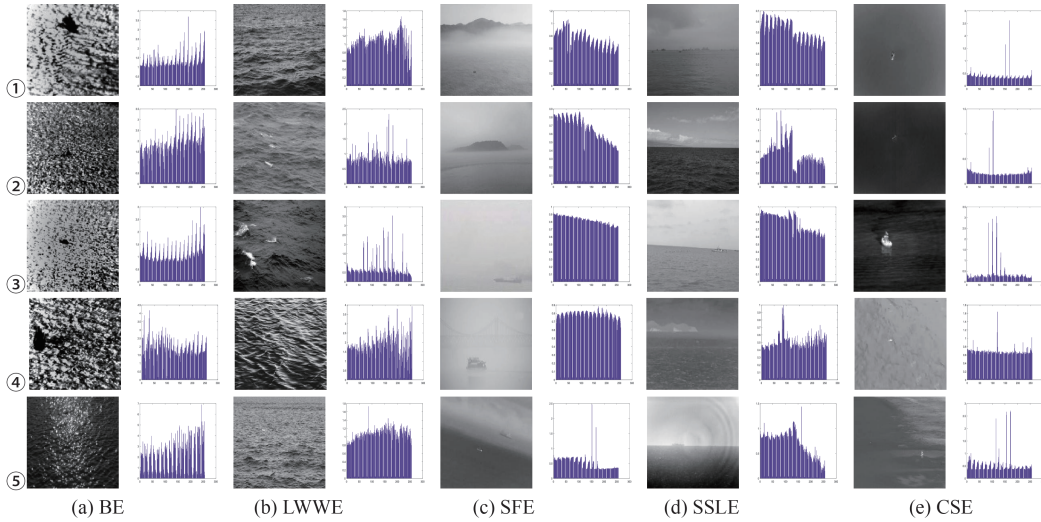

Fig 9　16*16 matrix
图9　16*16矩阵

Fig. 10　Local contrast calculation diagram based on different sea backgrounds：
No obvious change regularity: (a), (b); have a certain change regularity: (c), (d) and (e)

图 10　基于不同海面背景的局部对比度计算 没有明显变化规律：(a)，(b)；有一定变化规律：(c)，(d)和(e)

Usually，"one vs. rest" or "pair-wise" strategy [13] is used to solve multi-class SVM，and one-to-one model is used in experiments which is simplified into multiple binary classifiers（SVMs）for multi-class learning. The N categories are paired in pairs，and a total of $N(N-1)/2$ classification tasks are performed. The test samples are input into $N(N-1)/2$ classifiers to obtain $N(N-1)/2$ results. The category with the smallest distance after comparison is the final result. Divided into 5 categories in the experiment，and N = 5 is substituted into a total of 10 classifiers. It is determined by calculating the Euclidean distance.

The linear support vector machine learning model is a separated hyperplane $\omega^T x + b = 0$. This plane can be used to distinguish between positive and negative samples without error and the distance to the two types of samples are maximum. The discriminant model is calculated as follows.

$$f(\omega) = sign(\omega^T x + b). \tag{7}$$

The linear support vector machine learning is to minimize the objective function and transform it into an optimization function for a n-dimensional input x_i（i = 1, 2, ..., N）with labels y_i as shown below. The first term is the loss function. The loss function is shown as follows. In the equation，the response range is y ∈ {-1, 1}，and 1 for the positive class，and -1 otherwise.

$$\min_{\omega,b} \sum_{i=1}^{N} L\left(y_i, f(x_i)\right) + \lambda \|\omega\|^2, \tag{8}$$

$$L\left[y_i, f(x_i)\right] = \max\left[0, 1 - y_i f(x_i)\right] i = 1, 2, \cdots, N. \tag{9}$$

Combined with the idea of the optimal classification straight line to be found，which is the straight line with the largest distance to the two types of class point sets，the objective function at this time can be abstracted：

$$\max_{\omega,b} d = \max_{\omega,b} \frac{1}{\|\omega\|}, \tag{10}$$

$$\min_{\omega,b} \|\omega\| = \min_{\omega,b} \frac{1}{2} \omega^T \omega. \tag{11}$$

The constraints satisfy the inequality constraint as follows.

$$y_i\left(\omega^T x + b\right) - 1 \geqslant 0 \quad i = 1, 2, \cdots, N. \tag{12}$$

Construct a Lagrange function，where a_i is the Lagrangian coefficient，find the partial differential of ω, b, a_i，and find the optimal classification function. x_i represents the support vector，and x_j represents the vector to be discriminated.

$$f(x) = sign\left((\omega^*)^T x + b^*\right) = sign\left(\sum_{i=1}^{N} a_i^* y_i \varnothing(x_i) \varnothing(x_j) + b^*\right). \tag{13}$$

When the complexity of the data becomes large and cannot be separated linearly，the data is mapped into a high-dimensional feature space so that the data is linearly separable in the feature space. This mapping is denoted as $\varnothing(x)$. Since the inner product $\varnothing(x_i) \varnothing(x_j)$ has a very large calculation dimension，a kernel function is introduced.

The number of samples in the experiment is 330 images，and the total feature dimension extracted is 3784. According to the prior knowledge of the experts，the ratio of the feature dimension to the number of samples is greater than 10，and usually a linear kernel function is used. The expression of the linear kernel function is as follows.

$$K(x_i, x_j) = x_i^T x_j. \tag{14}$$

The inner product in the classification decision function can also be replaced by a kernel function，and the classification decision function becomes the form shown below.

$$f(x) = sign\left(\sum_{i=1}^{N} a_i^* y_i K(x_i, x_j) + b^*\right). \tag{15}$$

DONG Li-Li *et al*：Maritime background infrared imagery classification based on histogram of oriented gradient and local contrast features

5 期

657

Table 2　Classification accuracy of different background images
表2　不同类别的背景图像的分类精度

	Number of misjudged images	Classification error rate
Total images	9	3.6%
Classification of different types of background images	2	0.8%
Classification accuracy of multiple types of backgrounds in the same image	7	2.8%

3　Discussion

3.1　Data Set Description

This paper selects image captured by the actual shooting and qualified images found online. The data set consists of 5 categories. The training set contains 330 images，all of which are measured to 256*256 pixels in size. 250 images are kept for testing. Combining with SVM classifier，a one-to-one model is used for classification test. The operating environment is window7 operating system and the memory is 2G. The simulation platform uses matlab2016b version. The test was repeated 10 times，and the randomness was eliminated on average.

3.2　Result

The results of using the new method are shown in the Table 2. There are 250 test images. Nine images were misclassified，and seven of them contained multiple scenes. It can be seen that the classification error rate of multiple types of backgrounds in the same frame of images accounts for 77.8% of the total misjudged images. Images containing multiple types of scenes are misjudged，such as Table 3. Multiple types of scenes are in the same image，including SSLE and SFE. However，the characteristics of SSLE are more obvious than those of SFE. It is easy to misclassify it by a classifier.

Some common feature extraction methods have been selected for comparison. Other methods for comparison with the new method include circular LBP（r=2，neighbor =8），HOG，BOF，circular LBP（r=2，neighbor=8）+ HOG [14]，Gaussian filter +HOG. The comparison of the correct rate and time of algorithms by many experimental data statistics is shown in Fig. 11. It can be seen that the accuracy of the improved feature is effective than the single feature extraction and the traditional combination methods. The accuracy of the new method reached 96.4%. At the same time，the method has good working performance in combination with accuracy and time cost.

4　Conclusion

This paper proposes an improved infrared images classification method based on improved features，which facilitates subsequent processing of different backgrounds and has practical significance. Combined with the new features，the infrared images of sea surface can be divided into 5 backgrounds. The image features are combined with the HOG feature extraction method of the improved extraction template and LCM. Under the same condition，the classification effect of the new features is better than that of single-use HOG features. At the same time，it is also compared with some common feature extraction methods. Experimental results show that this method has a good consequent to meet practice requirements.
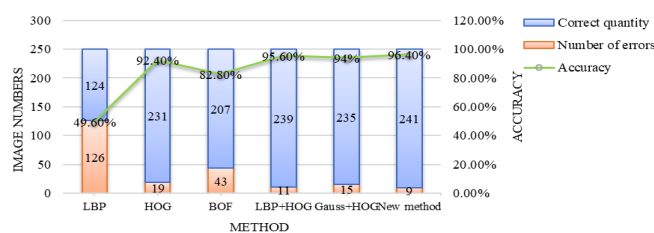
（a）　Accuracy of different classification algorithms
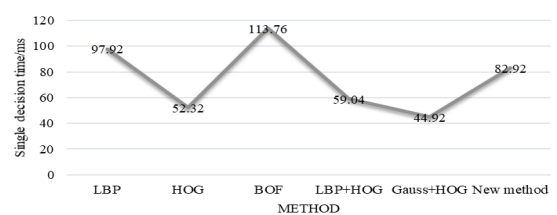
（b）　Time cost of different classification algorithms

Fig. 11　Accuracy and time cost of different classification algorithms
图11　不同分类算法的准确率和时间花费

Table 3　A misclassified image
表3　分类错误的图像

Image	Expected classification	Actual classification
	SFE	SSLE

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2020年10月20-22日　南京

https://b2b.csoe.org.cn/meeting/IR2020.html

主办单位：中国光学工程学会

承办单位：南京理工大学、昆明物理研究所、中国兵工学会夜视技术专委会、中国光学工程学会红外与微光技术产业联盟、南京波长光电科技股份有限公司、武汉高德红外股份有限公司

大会主席：陈良惠院士、褚君浩院士、刘永坚院士、王建宇院士

大会共主席：陈钱副校长（南京理工大学）、朱颖峰副所长（昆明物理研究所）、蒋亚东院长（电子科技大学）、张山总师（中国航天科工飞航技术研究院）、史泽林副所长（中国科学院沈阳自动化研究所）

会议日程：10月20日报到；10月21-22日报告交流。

会议地点：南京长江之舟华邑酒店，地址：南京市江北新区滨江大道504号

投稿网址：https://b2b.csoe.org.cn/submission/IR2020.html

截稿时间：2020年10月10日（最后一轮）

会议注册：网址：https://b2b.csoe.org.cn/registration/IR2020.html

会议费：会议费2808元/人，9月10日前汇款优惠为2608元/人

汇款时请务必注明"姓名或稿件编号"，非作者请注明"红外+姓名"，以便核对。

汇款信息：

账号：0200296409200177730；开户行：工行北京科技园支行；户名：中国光学工程学会

组委会：

学术交流：刘艳，022-58168510，liuyan@csoe.org.cn

会议赞助：孙萍，022-58168877，sunping@csoe.org.cn

DONG Li-Li *et al*：Maritime background infrared imagery classification based on histogram of oriented gradient and local contrast features

5 期

659

第七届国际新型光电探测技术及其应用研讨会

2020年11月5-7日 昆明

https://b2b.csoe.org.cn/meeting/NDTA2020.html

主办单位：中国光学工程学会、微光夜视技术重点实验室

承办单位：云南大学、西安工业大学、北方夜视技术股份有限公司、中国宇航学会光电技术专业委员会、红外与微光技术应用产业联盟

大会主席：苏君红院士、褚君浩院士、于起峰院士、姜会林院士

大会共主席：曾桂林所长（昆明物理研究所）、张力副校长（云南大学）、陈钱副校长（南京理工大学）、刘卫国党委书记（西安工业大学）、苏建忠所长（天津津航技术物理研究所）

大会执行主席：朱颖峰副所长（昆明物理研究所）、苏德坦总经理（北方夜视技术股份有限公司）

会议日程：11月5日报到；11月6-7日专家报告和海报交流。

会议地点：连云宾馆，云南省昆明市五华区圆通街58号，0871-65156661。

投稿网址：http://events.kjtxw.com/tougao/NDTA2020.html

截稿时间：2020年10月10日（最后一轮）

会议注册：网址：https://b2b.csoe.org.cn/registration/NDTA2020.html

会议费：2808元/人，2020年9月5日前汇款优惠为2608元/人。

汇款时请务必注明"姓名或稿件编号"，非作者请注明"探测+姓名"，以便核对。

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组委会：

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