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Feature based fuzzy inference system for segmentation of low-contrast infrared ship images

Xiangzhi Bai[a,b,*], Miaoming Liu[a], Tao Wang[a], Zhiguo Chen[a], Peng Wang[a], Yu Zhang[a]

[a] Image Processing Centre, Beijing University of Aeronautics and Astronautics, Beijing 100191, China
[b] State Key Laboratory of Virtual Reality Technology and Systems, Beihang University, Beijing 100191, China

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ABSTRACT

Segmentation of infrared ship target is important for sea surveillance system. However, as a result of the deficiencies of infrared images, the segmentation of infrared ship image becomes a challenge. For the purpose of addressing this problem, a feature based infrared ship image segmentation method utilizing the fuzzy inference system is proposed. Firstly, the intensity feature is extracted by applying unimodal threshold, which could preserve the low-contrast pixels in the infrared images. Secondly, the local spatial feature is extracted by employing saliency detection, region growing and morphology processing, which could express the shape of the target. Thirdly, the global spatial feature is extracted by utilizing partial region growing and weighted distance transformation, which could suppress the background. Then these features are fuzzified using accommodative ways and prior knowledge. And in light of the fuzzy rules based upon expert knowledge, these fuzzified features are integrated in fuzzy inference system. Finally, the complete target could be directly segmented from the output of the fuzzy inference system. Experimental results illustrate that the proposed method could effectively extract more intact targets from the low-contrast infrared ship images. Additionally, the proposed method outperforms some existed segmentation methods.

1. Introduction

Infrared thermography technology could transform the infrared radiation emitted from objects to imaging sensor [1–3]. The emitted radiant intensity mainly depends on the temperature, the emissivity and the infrared wavelength interval [4]. In the condition of inadequate light, infrared imaging systems could effectively detect the target. Therefore, they are widely applied in secure surveillance, military reconnaissance, missile guidance and other fields. Segmentation of ship target in infrared image is a significant step for automatic target recognition in the surveillance system [5–8]. As a result of poor imaging circumstances in sea surface, the infrared image usually has low-contrast and may be affected by sea clutters and noises [9]. And sometimes the infrared ship target even submerges in the sea background after imaging by infrared thermal imaging system. Hence, segmentation of the ship target in low-quality infrared images becomes a challenge.

A large amount of methods have been proposed to settle the problem of image segmentation, such as threshold based methods [10–13], clustering based methods [14–16], active contour based methods [17], and so on. The Otsu's method [10], entropy based method [11] and minimum error thresholding [13] are popular thresholding strategies for segmentation, which manage to look for an optimal segmenting threshold through the statistical information of an image. Whereas the intensity difference between the ship target and background in the infrared ship images with low contrast is unobvious. And, generally, there is no optimal threshold since the infrared ship target is small comparing with the background in most cases. In addition, the spatial information in infrared ship images is not applied in the threshold based methods. Besides, the Otsu's method usually under-segments the small target and the entropy based method is easy to be interfered by the intricate ambient noises. These make the segmentation result unsatisfying. And the minimum error thresholding is sensitive to the noises and the ratio of area between the target and background. Since the low-contrast infrared images are mostly very complex, the good segmentation results cannot be obtained when only using a threshold. In a word, the Otsu's method [10], entropy based method [11] and minimum error thresholding [13] would be affected by the noises and cannot obtain satisfying

* Corresponding author at: Image Processing Centre, Beijing University of Aeronautics and Astronautics, Beijing 100191, China.
E-mail address: jackybxz@buaa.edu.cn (X. Bai).

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segmentation results for low-contrast infrared images. The 2D maximum entropy method [12] considers both the distribution of gray information and the spatial neighbor information. Nevertheless, it is sensitive to the contrast of the ship target and background regions. Similar to the entropy method, it is difficult for the 2D maximum entropy method to find a proper threshold when processing the low-contrast images. In addition, this method is sensitive to the ratio of the pixel numbers between the target and background. If the ship target is much smaller than the background, this method may regards the target as background. As a result, the 2D maximum entropy method [12] may fail to extract the target from the low-contrast infrared ship images. As we all know, the mean shift [14] and fuzzy *c*-means method (FCM) [15] are clustering based methods for image segmentation. Nevertheless, these methods are easily affected by noises, thus the segmentation results of these methods might produce bad effects because of the complexities of the infrared ship images. Moreover, these methods might wrongly regard the background as ship target when the spatial information is not appropriately used. Consequently, the segmentation results of mean shift [14] and fuzzy *c*-means method (FCM) [15] may not be satisfying due to noises and low contrast. The spatial fuzzy *c*-means method (SFCM) [16] integrates spatial information into the membership function on the purpose of clustering. However, SFCM is also sensitive to the contrast and the ratio of pixel number between the target and background. The Chan–Vese model [17] is accommodative to the topology structure of segmented target and is frequently-used in image segmentation, which is a method grounded on active contour. But it is difficult to extract the topology structure of the target, because both the target and background regions are inhomogeneous in the infrared ship image with low contrast and there is no obvious difference between the intensities of them. The level set method [18] is robust to noises and independent to the initial contour. Moreover, the level set method obtains good results in segmenting the images with inhomogeneous intensity. Nevertheless, the ship target may not be segmented from the infrared image when the target is small or the background is complex in the low-contrast infrared images. The marker based watershed method [19–22] uses the makers generated to acquire the contour between the target and background, which could produce good segmentation results. However, the marker based watershed may not segment some detail parts of ship target from the infrared ship images with low contrast, such as the masts. To extract the ship target, an iterative technique is taken to efface background and enhance the infrared ship target [4]. Nevertheless, since the target is not very bright at most cases and the contrast is low, some of the target regions might be erased with the background. Consequently, the iterative method may not acquire the complete target from the low-contrast infrared images. Recently, an improved fuzzy *c*-means method grounded on the spatial information has been proposed [23,24], which utilized the non-local space information and refined the local spatial constraint through Markov Random Field with spatial shape information from the contour of target. Also, the intact ship target may not be extracted from the infrared ship image when the target is large or the contrast is low. In a word, these methods may not produce satisfying results for the segmentation of low-contrast infrared ship image or images with noises.

Since there are lots of defects in the infrared ship image, a feature based infrared ship image segmentation method utilizing fuzzy inference system is proposed for ship target segmentation. The fuzzy inference system plays an important part in lots of theories and application fields, such as pattern recognition, data compression, system identification, control, decision making, supervision and some other fields [25–29]. There are several advantages for fuzzy inference system [30–35]: first, fuzzy inference system could represent expert knowledge; second, it is convenient to understand and apply fuzzy rules to many fields since these rules are transparent and interpretable; third, fuzzy inference system could export a target degree to address general complex problems. In infrared ship image, the priori knowledge could be extracted to represent the ship target. In addition, the fuzzy rules could be designed based on the priori knowledge and the ship target could be extracted from the target degree map. Therefore, the fuzzy inference system could handle the segmentation of low-contrast infrared ship image.

This paper is a substantial extension of our conference paper, which has been presented in an international conference [36]. The mainly extensions are as follows. Firstly, a new global spatial feature has been added as the third input of the fuzzy inference system. Secondly, 27 rules have been designed to express the expert knowledge. Thirdly, the experiments have been conducted on a completer dataset, which contains 80 infrared ship images with low contrast. Fourthly, more analyses about the method and the experimental results have been displayed. Fifthly, more image segmentation methods have been employed for comparisons, including 2D maximum entropy based method (2D Entropy) [12], minimum error thresholding (MinError) [13], spatial fuzzy *c*-means method (SFCM) [16], level set method (Level Set) [18], marker based watershed method (Watershed) [19–22] and Markov Random Filed constraint SFCM method (MRF-SFCM) [23,24].

To make the best of information in infrared ship images, the intensity feature, local spatial feature and global spatial feature are constructed. Besides, fuzzy inference system is capable of effectively dealing with the uncertainty in an image and easily expressing the expert knowledge with fuzzy rules. So we utilize the fuzzy inference system to integrate the features and segment the target. Firstly, the intensity feature is selected as one input of the fuzzy inference system, which is a fundamental feature of target in the infrared images. Secondly, two spatial features are extracted to signify the spatial information of infrared ship image. The local spatial feature is extracted to determine the contour of the infrared ship, while the global spatial feature could be used to suppress the background. Three steps are taken to construct the local spatial feature: saliency detection, region growing and morphology processing. And a weighted distance transformation map is used to construct the global spatial feature. Thirdly, these features are accommodatively fuzzified with statistical information of infrared ship image and prior knowledge. Then, according to expert knowledge, the fuzzy rules are defined to integrate with the three fuzzified features. Finally, the ship target is extracted from the target degree map from the fuzzy inference system, which achieves the segmentation of the ship target. Experimental results indicate that the proposed method is effective to extract the intact targets from the infrared ship images with low contrast and outperforms some existed segmentation methods.

The pre-processing and post-processing procedures have contributed to the segmentation of infrared ship images. However, as far as we known, the pre-processing and post-processing steps are challenging tasks for the infrared ship images due to the existence of low contrast and noises. Actually, to obtain better segmentation results, we directly considered the low contrast and noises of the infrared images when designing the feature based fuzzy inference system for segmentation of the infrared images. Thus, there is no other pre-processing or post-processing steps in our algorithm.

The novelty of the paper is the constructions of the three features. Firstly, the intensity feature is constructed using the unimodal threshold, which is consistent with the intensity distribution in the infrared images. Thus, the intensity feature segments the target from the sea background and helps to preserve the low-gray pixel in the low-contrast infrared images. Secondly, the local spatial feature is designed by employing saliency detection, region growing and morphology processing. The local spatial feature could signify the shape information of the target due to the application of