Superstructure scattering distribution based ship recognition in TerraSAR-X imagery

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Superstructure scattering distribution based ship recognition in TerraSAR-X imagery

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Abstract. Benefiting from the improved resolution and polarization information of SAR data, ship recognition has attracted much attention during the last decade. This paper considers the ship recognition in TerraSAR-X imagery. We propose a novel feature extraction algorithm, named Superstructure Scattering Distribution (SSD), by investigating the ship's superstructure and corresponding electromagnetic scattering mechanism. In SSD, we first segment the image areas that correspond to the scattering of ship's superstructure using segmentation and edge detection methods. Once the superstructure areas of ship in SAR imagery have been obtained, we then calculate a novel feature parameter to describe the distribution and shape complexity of the ship based on the fractal dimension and other shape complexity descriptors. Extensive experiments have been carried out on ship datasets collected from TerraSAR-X SAR imagery. The results validate that the SSD feature can achieve better performance together with other physical features.

1. Introduction
Ship recognition is an important research area, as it helps to improve surveillance and control activities. Due to the independence of meteorological conditions, synthetic aperture radar (SAR) provides wide coverage and high resolution for monitoring ships. In the last decade, there have been plenty of literatures that are interested in the ship recognition on SAR images [1].

As SAR presents the ship based on electromagnetic mechanism, the backscattering properties of ship is affected by various factors, such as the ship bearing, ship speed, sea state, and the radar elevation angle. In this sense, the description of ships in SAR images is important for recognition. Besides the recognition algorithms, encouraging results have been concentrated on the feature extraction to describe ships in SAR images. The features of merchant ships such as length, beam, and radar cross section (RCS) are discussed in [2]. Characteristics of ships in the TerraSAR-X and PicoSAR images are compared in [3,4] and the ship silhouette is recommended for recognition under the condition of high elevation angle. In particular, when the advanced SAR system is available, the characterization of ships can be more comprehensive and the recognition performance is expected to be improved. The polarimetric SAR provides the ability of characterizing ships with permanent symmetry scatters [5,6]. The type and distribution of these scatterers can be derived in the polarimetric interferometry SAR (PolIn SAR) images and therefore utilized for ship recognition [7].

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However, the Pol/PolIn SAR demands restrictive system requirements that are not operationally available in most satellite sensors [8]. As the resolution improves, single polarimetric SAR, such as TerraSAR-X, increases the potential for ship classification and detailed characterization. Different parts of the ship behave diversely due to their structures and the corresponding electromagnetic scattering mechanisms. The authors in [8] divide the ship into three parts and calculate the relative RCS of each part to recognize ships by applying a fuzzy logic scheme. The literatures [9-11] analyse the behaviours of more detailed superstructures on SAR images and achieve preliminary recognition results on high resolution TerraSAR-X images.

Motivated by the ideas in the literatures of [8-11], we propose a novel feature, namely the Superstructure Scattering Distribution (SSD), to characterize ships in high resolution SAR images. First, the behaviours of different ship superstructures are analysed from the viewpoint of scattering mechanisms. Then, the superstructure in the SAR image is derived with pre-processing and segmentation techniques. To describe the scattering distribution of the superstructure, the fractal dimension of each ship is calculated. Finally, the proposed feature is utilized to recognize the Container, Bulk, and Oil Tanker on TerraSAR-X images.

This paper is structured as follows. Section 2 analyses the superstructure and scattering characteristic for different type of ships. The ship's superstructure on SAR images is segmented out and the novel feature is calculated via the fractal dimension in Section 3. Experimental results are provided in Section 4, and conclusions are provided in Section 5.

2. Superstructure and scattering behaviour for different type of ships

In this section, the superstructures of different type of ships are presented and their scattering behaviours are analysed. In the coastal area, there are three typical types of ships, i.e., the Container, Bulk, and Oil tanker. As a result, we focus our attention on these three types of ships.
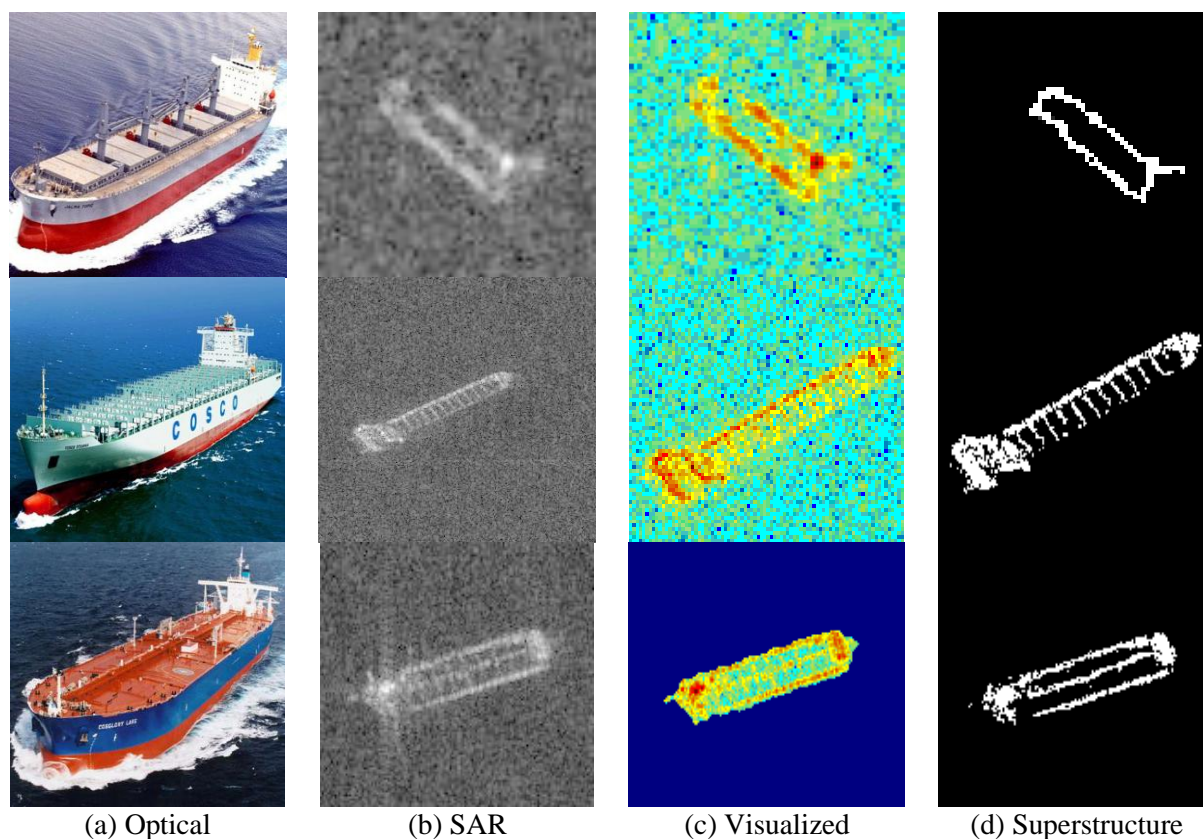

              (a) Optical   (b) SAR   (c) Visualized   (d) Superstructure

Figure 1. The images of the three type of ships. From top to bottom: Bulk, Container, and Oil tanker. (a) Optical images, (b) SAR images, (c) Visualized images, and (d) Superstructure images.

Due to their different functions, the aforementioned three kinds of ships possess diverse superstructures. The ship structure is composed of or can be considered as several elemental scatterers. The backscattering of the ship is determined by these elemental (or effective elemental) scatterers. If the elemental scatterers are different in terms of number, type, and position on the ships, the ships will behave diversely on the SAR images. It is thus possible to distinguish them from each other.

When imaged by the SAR, the dihedral, trihedral, and cylinder on the ships are the popular structures to give strong backscattering. For example, the shipboard and sea surface constructs a dihedral, while there is a trihedral in the hack area. As shown in figure 1, we present the three types of ships with their optical images, SAR images, visualized images, and the superstructure images.

3. The feature of superstructure scattering distribution

Based on the analysis of the scattering characteristics of the ships' superstructures in section 2, it is observed that the superstructure distribution on SAR image can be utilized to distinguish different types of ships. In this section, the fractal dimension is calculated to describe the distribution of the superstructure.

Suppose that the binary image of ship structure has been acquired by segment and edge detection techniques [12]. Then the fractal dimension of the binary image can be calculated as follows. First, a sliding window of size $d_1 \times d_1$ is moved across the whole image, and accordingly the number of bright pixels is recorded as N_1. Next, a similar procedure is realized by using a window of size $d_2 \times d_2$, from which the recorded number of bright pixels is N_2. Finally, the fractal dimension is defined in (1). In this paper, we define $d_1 = 1$, which means the first window counts all the bright pixels. The second window corresponds to $d_2 = 2$, which records the number of bright blocks with size of 2×2. Since there exist holes in the binary image, the number of connective area decreases as d_2 increases, resulting in a larger value for the fractal dimension.

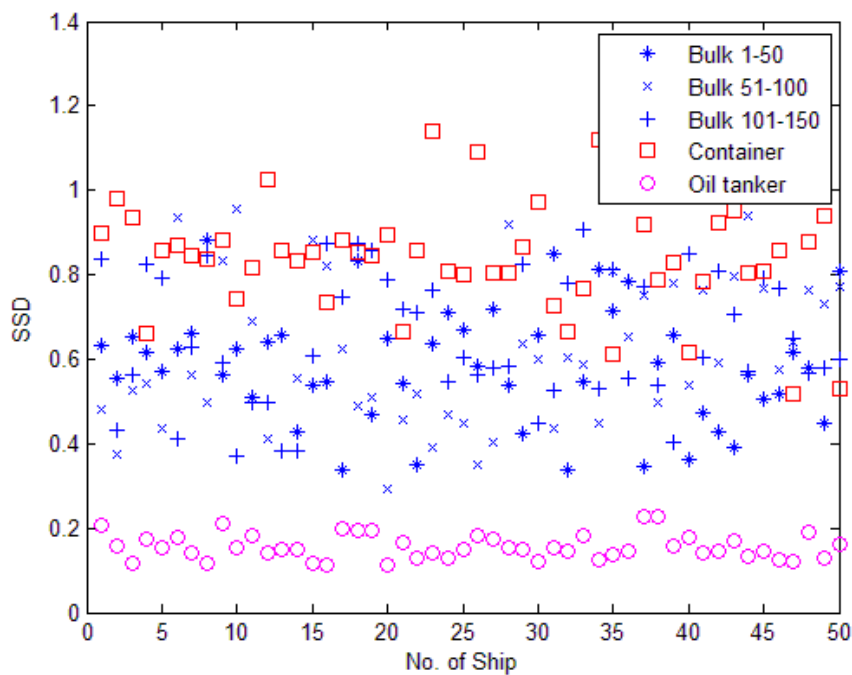$$F = \frac{\log_{10} N_1 - \log_{10} N_2}{\log_{10} d_1 - \log_{10} d_2} \tag{1}$$

Figure 2. Superstructure scattering distribution of each ship in the dataset

4. Experimental results

In this section, extensive experiment results are presented based on the high resolution TerraSAR-X SAR images. First, the superstructure scattering distribution of each ship is calculated. Then, the novel feature is combined with the ship length to recognize ships based on the support vector machine classifier. The radial basis function (RBF) is adopted as a kernel function of SVM, and the RBF parameters are selected empirically to achieve optimal performances.

In the experiment, the ship dataset is collected from TerraSAR-X stripmap mode SAR imagery with $2.0m \times 1.5m$ resolution in azimuth and range direction. With the aid of ground truth information supplied by AIS, there are three kinds of ships in the dataset: Container (C), Oil Tanker (OT), and Bulk (B). The numbers of these three kinds of ships are 50, 50 and 150 respectively. All the experiments are carried out using MATLAB implementations on a 3.0GHz machine with 4 GB RAM.

Figure 2 illustrates the SSD of each ship in the dataset and Figure 3 represents the scatter diagram of the SSD and ship length. In Figures 2 and 3, the proposed feature is capable of distinguishing the three types of ships, especially when it is combined with the ship length. In fact, the Container and Oil tanker are similar to each other in terms of length. If we only use the ship length to recognize ships, then the performance is not satisfactory. Together with ship length, the SSD improves the recognition performance.
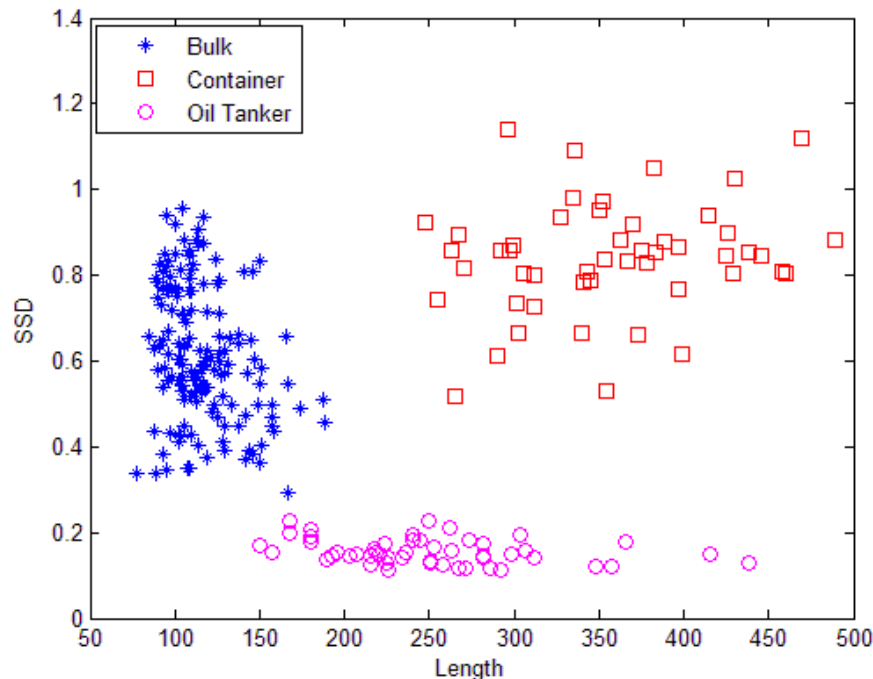

Figure 3. Scatter diagram of the SSD and ship length

Table 1. Classification results with different features (B: Bulk, C: Container, OT: Oil Tanker)

Feature	SSD			Ship Length			(SSD, Ship Length)		
	B(%)	C(%)	OT(%)	B(%)	C(%)	OT(%)	B(%)	C(%)	OT(%)
B	70.67	29.33	0	100	0	0	100	0	0
C	28.00	72.00	0	0	80	20	0	100	0
OT	0	0	100	24	12	64	0	0	100
Avg.	76.8%			88.8%			100%		

To validate the discrimination ability of the proposed SSD feature, classification experiment is carried out on the collected TerraSAR-X dataset. Taking half of the ship images as training samples and the rest half as test set, the classification results are illustrated in table 1. The results indicate that the SSD feature distinguishes all the Oil Tanker from the other two types of ships, while the ship

length distinguishes the Bulk clearly. The combination of the SSD and ship length achieves very good performance on this TerraSAR-X dataset.

5. Conclusions

In this paper, a novel ship feature is proposed to recognize ships on high resolution TerraSAR-X images. Based on the analysis of ships' superstructures and scattering behaviours, the superstructure of ships on SAR images is extracted. The novel feature named Superstructure Scattering Distribution (SSD) is defined as the fractal dimension of the binary superstructure image. The experiment results validate that the proposed feature is effective and credible in SAR image ship recognition. Nevertheless, the feature needs to be calculated more accurately through advanced segment techniques and edge detection methods. More extensive experiments will be carried out on a larger dataset to confirm the conclusions.

6. Reference

[1]   W. Chen, K. Ji, X. Xing, H. Zou 2012 Ship Recognition in High Resolution SAR Imagery Based on Feature Selection *International Conference on Computer Vision in Remote Sensing* pp 301-305

[2]   P. Chen, W. Huang, J. Yang, and B. Fu 2006 Features of Merchant Ship in High-Resolution Spaceborne SAR Imagery *Geoinformatics 2006: Remotely Sensed Data and Information* pp 64190V-1-9

[3]   A. O. Knapskog, S. Brovoll and B. Torvik 2010 Characteristics of Ships in Harbour Investigated in Simultaneous Images from TerraSAR-X and PicoSAR *IEEE Radar Conference* pp 422-427

[4]   A. O. Knapskog 2010 Classification of Ships in TerraSAR-X Images Based on 3D Models and Silhouette Matching *EUSAR 2010 - 8th European Conference on Synthetic Aperture Radar* pp 234-237

[5]   R. Touzi, R. K. Raney and F. Charbonneau 2004 On the Use of Permanent Symmetric Scatterers for Ship Characterization *IEEE Trans. Geosci. and Remote Sens.* **42** 2039-2045

[6]   G. Margarit, P. Blanco, J. Sanz, J. J. Mallorquí, *et al*. 2004 Simulation of fishing vessel polarimetric signatures as first step to vessel classification *SAR Image Analysis, Modeling, and Techniques VI Proceedings of SPIE*

[7]   G. Margarit, J. M. Jordi and X. Fabregas 2007 Single-Pass Polarimetric SAR Interferometry for Vessel Classification *IEEE Trans. Geosci. and Remote Sens.* **45** 3494-3502

[8]   G. Margarit and A. Tabasco 2011 Ship Classification in Single-Pol SAR Images Based on Fuzzy Logic *IEEE Trans. on Geosci. and Remote Sens.* **49** 3129-3138

[9]   D. Pastina and C. Spina 2009 Multi-feature based automatic recognition of ship targets in ISAR *IET Radar, Sonar and Navi.* **3** 406-423

[10]   X. Zhang, J. Zhang, Y. Ji, and J. Meng 2010 The Capability Analysis of Ship Classification by Structure Feature using SAR Images *Acta Oceanologica Sinica (in Chinese)* **32** 146-152

[11]   X. Yin, C. Wang, H. Zhang, and F. Wu 2012 Vessel Recognition With High Resolution TerraSAR-X Image Based on Structure Feature *J. of Image and Graphics (in Chinese)* **17** 106-113

[12]   Choi H, Richard G, Baraniuk 2001 Multiscale Image Segmentation Using Wavelet Domain Hidden Markov Models *IEEE Trans. on Image Proc.* **10** 1309 – 1321