Ship Wake Detectability and Classification on TerraSAR-X high resolution data

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Abstract

This study elaborates on the detection of ship wake signatures on high resolution TerraSAR-X images. A new data-driven detectability model based on a binary logistic regression classifier is proposed. Additionally, to detect small and incompletely imaged wake signatures, a second machine learning approach is investigated. The second approach uses feature extraction and binary classification to classify the area around ships. By applying the detectability model before the classification, the sensibility of the resulting wake detection can be adjusted. The detectability model shows expected dependencies between wake visibility and the affecting parameters. Initial results reach above 70% accuracy for wake classification.

1 Introduction

SAR sensors represent a valuable data source for the monitoring of ship traffic. As non-metallic maritime objects can hardly be detected, in the recent years the detection of the signatures of ship wakes on the water surface has been studied. Approaches for automatic wake detection often apply Hough transform or image convolution by filter banks. However, these approaches only work, if either wake components with large extent or multiple wake components are visible and are not capable of identifying the wake vortex.

Figure 1: Visualization of the effect of different ship headings on the visibility of wakes, acquired during a campaign at German-Polish border on May 2014.

2 Method

In order to solve this problem we propose a new method for automatic wake detection based on the training of two machine learning models. The first model is a binary logistic regression classifier considering the different condition parameters, which have an effect on the visibility or non-visibility of wakes, e.g. local wind speed or ship heading as visualized in **Figure 1**. Based on these parameters the classifier provides probabilities under which wakes are detectable and thus guides the sensitivity of a subsequent automatic wake detection system. In this second system we apply a second classification model using as input, features extracted from the background of proven positions of ships (by colocation the SAR images in space and time with data from the Automatic Identification System (AIS)). The features extractor applied for the initial test is the Histogram of Oriented Gradients in the rectangular and circular form. The combination of feature extraction with the second classification model provides the possibility to detect wake signatures also when wakes are imaged with small or incomplete components, as the classifier provides probabilities of the wake's occurrence around a ship. This means the classifier differentiates between the classes "occurrence-of-wake" and "no-occurrence-of-wake".

The training dataset for initial testing contains around 1000 high resolution TerraSAR-X wake samples imaged under different conditions. It is planned to centre the samples on the wake vortex. Then by iteratively shifting the centres of the features extractors towards an increasing value for the probability of class affiliation to the class "occurrence-of-wake", the wake vortex can be found in the background of ship signatures.

We present two achievements on the field of automatic wake detection:

1. A data-driven detectability model describing the probability of visible wake components available in a SAR images based on multiple different environmental conditions, image acquisition parameters and vessel properties. Until now only simulated detectability model were available.
2. An automatic wake detection technique, capable of detecting also imperfectly imaged ship wakes and localizing the wake vortex around already detected ship signatures.

3 Preliminary Results

Results from a previous study show that a linear detectability model can represent expected dependencies of wake visibility on three different parameters [1]. **Figure 2** and **Figure 3** visualize the wake detectability from two 3D-models; the first model is based on the ship properties as well as environmental conditions:

- ship velocity (obtained from collocated AIS messages),
- local wind speed (estimated from sea surface roughness by XMOD2 geophysical model function [2]) and
- ship length (measured from the detected ship signature [3]);

the second model is based on the ship properties and image acquisition parameters:

- ship heading projected to 0° to 90° relative the radar beam looking direction (measured from the detected ship signature [3]),
- incidence angle (interpolated from product metadata) and
- ship length (measured from the detected ship signature [3]);

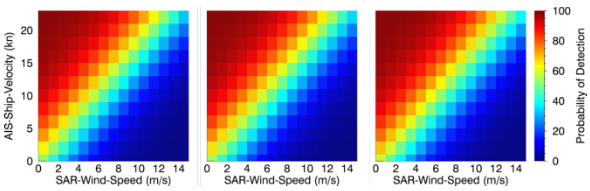

Figure 2: Wake detectability based on ship velocity (from AIS), wind speed (estimated by XMOD-2) and ship length (measured from SAR ship signatures, left: 25m, middle: 50, right: 100m)

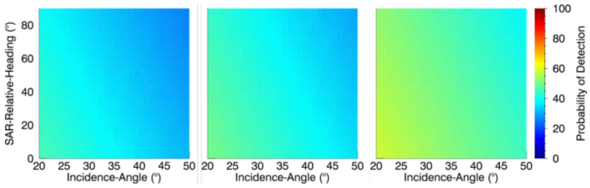

Figure 3: Wake detectability based on incidence angle (interpolated from product metadata), ship heading relative to the radar beam looking direction (measured from the detected ship signature) and ship length (measured from SAR ship signatures, left: 25m, middle: 50, right: 100m)

We will present a detectability model based on more than three parameters. Due to an increased training dataset the adopted model is based on a more complex non-linear, binary classifier.

Table 1 displays the classification accuracy of the initial tests for two gradient-based feature extractors (i.e. rectangular and circular Histogram of Oriented Gradients) combined with a complex (Multi-layer Perceptron) and a non-complex (Random Forest) classifier.

Feature Extractor + Classification model	Correctly Classified Instances	Kappa statistic	Weighted Average F-measure
Rectangular HOG + Random Forest	64.2%	0.25	0.63
Rectangular HOG + Multi-layer Perceptron	71.5	0.41	0.71
Circular HOG + Random Forest	74.6%	0.47	0.74
Circular HOG + Multi-layer Perceptron	77.6%	0.54	0.77

Table 1: Initial results on combinations of two gradient-based features extractors with a complex and a non-complex classification models some description for this table.

4 Discussion

Initial results on the wake detection model show that the new wake detection approach can reach an acceptable detection accuracy, although the wake samples in the underlying high resolution TerraSAR-X training dataset were not yet centred on the wake vortex. Pre-processing the training data by this means should increase the performance significantly. The rectangular HOG was expected to have worse performance as its geometry is no matching to the angular-based shape of wakes. Further, the settings of the feature extractors and the classification models were not optimized at all in this initial test. On EUSAR2018 an optimized wake detection approach will be presented.

5 References

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[3] Björn Tings, Carlos Bentes and Susanne Lehner: *Dynamically adapted ship parameter estimation using TerraSAR-X images*, International Journal of Remote Sensing, Vol. 37, pp.1990-2015, 2015, doi:10.1080/01431161.2015.1071898