Multiresolution Markov Random Field Wavelet Shrinkage for Ripple Suppression in Sonar Imagery

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1 Introduction

As autonomous underwater vehicles become more sophisticated there is growing interest in computer aided approaches to object detection using sonar imagery. Example application areas include the oil and gas industry, oceanography, and defence. The complexity and variability of the seabed floor gives rise to the classical image processing problem of detection in the presence of clutter. We here focus on a defence application where the objects of interest are underwater mines and the clutter are sand ripples.

Sand ripples exhibit highlight and shadow features that can cause detectors to give many false positives. They can also form quite complicated pseudo sinusoidal, bifurcated, and braided patterns at various frequencies and orientations.

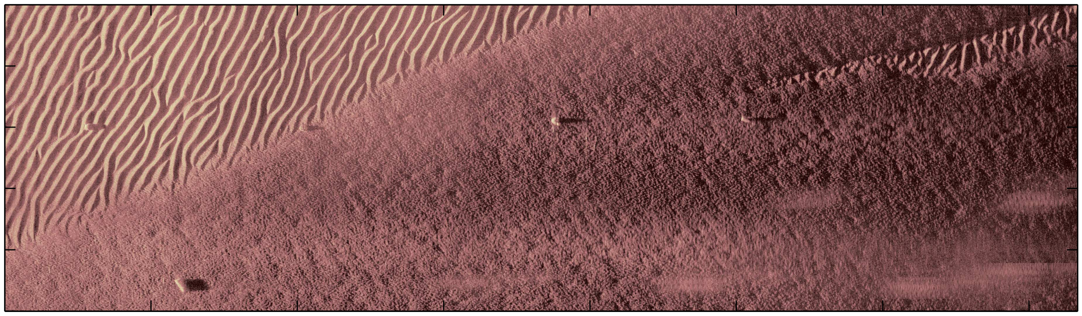
2 Methodology

Unlike previous approaches, we consider a scale and rotation invariant, multiresolution Markov random field (dual-tree) wavelet shrinkage approach to suppress ripples. We note that the wavelet energy of the non-rippled regions broadly follow a power law decay with respect to finer scales. This contrasts with the oscillatory nature of the rippled regions which cause a spike in the directional wavelet spectra. To this end, the non-rippled seabed is described by a (weak) statistically self-similar model. For non-ripples it is shown that the Hurst index in the corresponding power law relationship provides scale invariant bounds on the interscale wavelet energy ratio. On the other hand, the spike in the spectra of typical rippled regions produces energy ratios outside these bounds.

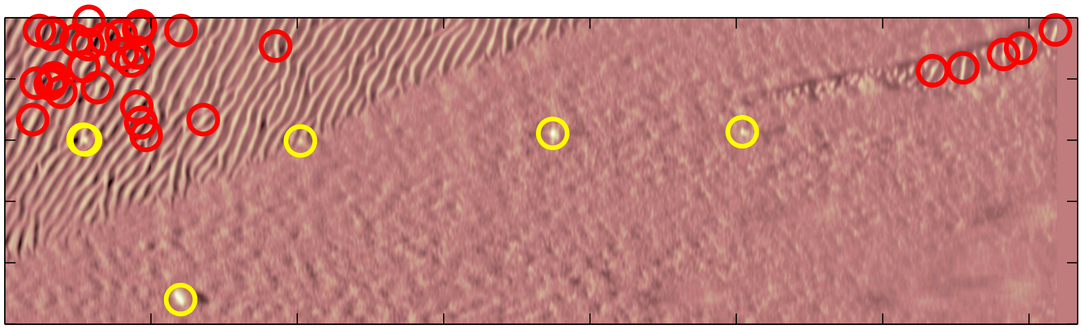
The ratios are used to construct feature-based adaptive shrinkage functions with respect to location, orientation, and scale. Coefficients which contribute to the rippled regions are proportionately shrunk and the inverse dual-tree wavelet transform is applied to recover a ripple suppressed image. This is extended by incorporating a Markov random field (MRF) model to exploit the observation that rippled and non-rippled locations are unlikely to appear at isolated points. The likelihood function is designed to 'soft-shrink' coefficients according to the energy ratio value; the prior (Ising model) encodes spatial constraints into the shrinkage functions. Markov Chain Monte Carlo provides an efficient, tractable way to estimate the conditional distribution of the posterior marginal ripple/non-ripple state in the dual-tree wavelet domain. Ripple suppression is then realised by multiplying the dual-tree wavelet coefficients by the marginal probabilities of the non-ripple states.

3 Results

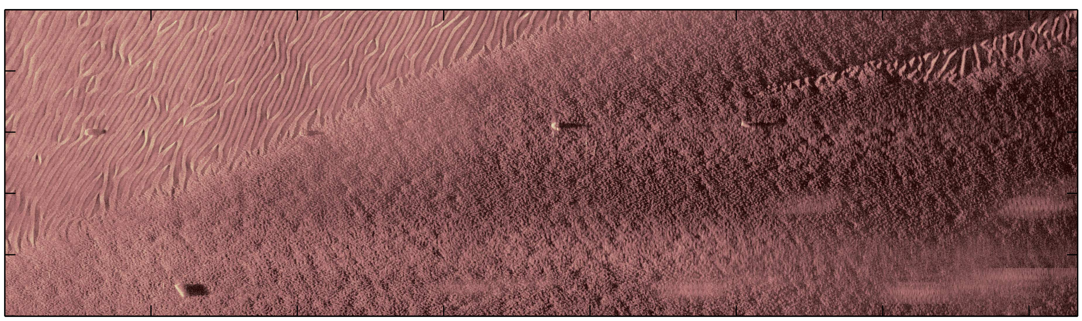
For validation, a matched filter is applied to 201 suppressed and unsuppressed images from a NATO Undersea Research Centre 'MUSCLE' data set. It is found that the MRF ripple suppression method delivers a significant reduction, of around 76%, in the number of false positives compared to no ripple suppression; and a reduction of 34% compared to a non-MRF, dual-tree wavelet shrinkage approach. See Figure 1 below for an example.



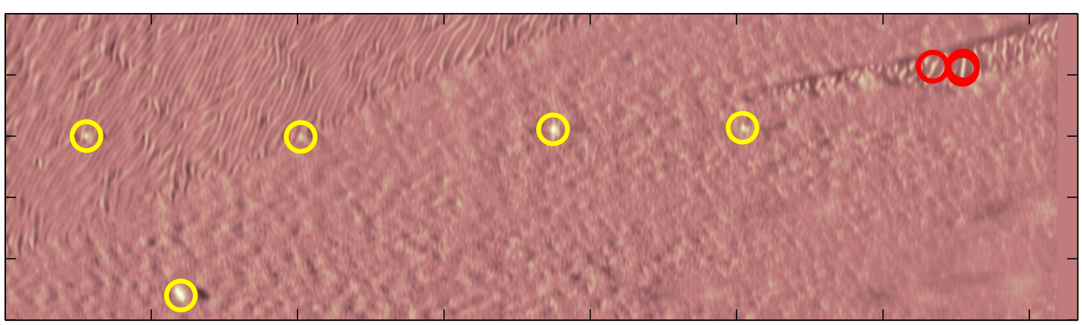
(a) Original Sonar image



(b) Unsuppressed correlation surface



(c) MRF suppression



(d) MRF suppressed correlation surface

Figure 1: Left: original and ripple suppressed images; right: correlation surfaces; yellow (resp. red) rings show location of true (resp. false) positives after choosing the optimal threshold in each example for illustrative purposes only.