TARGET DETECTION IN CLUTTER FOR SONAR IMAGERY

1 PROPOSED RESEARCH AND ITS CONTEXT

This proposal is a direct response to Challenge 22: Target detection in clutter. The Oceans Systems laboratory have a large experience in Target Detection and Classification in high resolution sonar imagery using a variety of techniques based on target responses and highlight shadow pairs[1,2,3]. Experiments on real scenarios show that these techniques work well in benign environments (flat and small ripples seabed) but deteriorate dramatically in complex scenarios[4]. Our experience with seabed classification based on 2D textures [5,6] also highlights that targets, even in complex cases, can appear as local outliers in the texture field. Examples of such scenarios and associated detections are shown below:

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![Example of complex seabed textures](image1)

Seabed with multiple textures due to 3D bathymetry (a) Cluttered Seabed on a flat seabed (b) Example of classical detection (c) Equivalent Texture field perturbation in classified map (d)

Figure 1: Example of complex seabed textures

It is clear from those examples that the contextual information provided by the texture is a key element to the successful detection of targets in difficult scenarios. Targets appear as outliers in the texture field. However, this is a difficult problem to tackle using image processing techniques. First, different type of textures require different models (fractals, wavelets, stochastic geometry for clutter) as demonstrated by our work on sonar image simulation[8]. Second, the objects are normally occupying only a few pixels and therefore the estimation of their texture parameters is hard (only a few samples are available for estimation). Finally, in sonar and radar imagery, texture results from the natural texture of the seabed (2D texture) but also from the interaction between the illumination pattern of the imaging source and the 3D topography of the seabed. These 3D textures are in general non stationary and difficult to characterize using classical 2D texture descriptors and very few research has been done in this area[11].

Recent developments in our laboratory have demonstrated that it is possible to recover the high frequency components of 3D structure from images using a shape from shading approach[7]. An example of the output of the process is shown in figure 2. This new development, already used successfully to provide 3D simulation capability in sonar imagery[7], can also enable the use of 3D texture measures as well as 2D textures.
Furthermore, the recent development of swath bathymetric side scan sonars (SwathPlus, GeoSwath) gives access to joint 2D/3D information which has never been exploited before to target detection. They now provide the ability to extract jointly 3D information and side scan imagery therefore enabling to decouple the effect of the 2D and 3D textures in the imagery. An example of such images is shown in figure 3.

**Figure 3**: SwathPlus 3D data in the port of livorno (Italy). Image courtesy of SEA Ltd. Sunken boats and other harbour objects are clearly visible.

### 1.1 Programme and Methodology

In this project, we propose to study and model clutter and texture in sonar imagery to improve target detection performances in difficult environments. We do not believe that 2D texture models are rich enough to describe the complexity of the sonar (and radar) imaging problem. We also do not believe that a single statistical model will be able to encompass the large variety of potential textures and clutter models. Recent developments in realistic sonar simulations models [10,11] use a mixture of statistical models including K and Rayleigh distributions for noise and fractals and stochastic geometry for 3D structure modeling. It is clear that the texture seen in sonar and radar imagery is a combination of these two effects and needs to be analysed taking them both into account.
Simulation must and will play an important role to develop realistic models of sonar imagery. From simulation models (where the ground truth is known), it is possible to tackle the complex inversion problems (estimation of model parameters from imagery) and develop robust estimation techniques. We have already started developing fast realistic simulation engines for side scan sonar which includes the bathymetry, the type of sediment and the acoustic noises from classical sources such as surface and ambient noises. This was done under funding from the MOD Competition of Ideas programme in collaboration with Bae Systems who are supporting this project.

Once this problem has been tackled with simulated data, the results will be extended and evaluated for real data. Our laboratory is equipped with a REMUS 100 mounted with a Marine Sonics 900/1800 KHz. We also have 2 years of expertise in operating REMUS to gather sonar data (over 60 operational days). We are therefore ideally placed to perform real experiments to validate our approach. We also anticipate mounting a REMUS-100 SwathPlus module to gather joint SideScan/ 3D Data to ground truth our 3D recovery techniques[7] and validate the quality of our 3D texture models.

1.2 Objectives

The aims of this project are:

1. To develop new texture models for sonar imagery, which include both 3D bathymetric information and 2D albedo variations.
2. To develop simulation tools to synthesise realistic sonar textures.
3. To develop estimation techniques to analyse sonar textures (simulated and real)
4. To develop new pattern recognition techniques for high resolution 3D Sonar target classification.
5. To study the sonar resolution required (simulation) to detect targets in simple and complex 2D and 3D textured seabed scenarios.
6. To evaluate the estimation techniques developed in 3 for target detection.

1.3 Programme of work

**Work package 1: Literature Review**: This work package is the background reading and literature search required of a first year student in the area of texture modeling and analysis, target detection using anomaly detection in textures (from quality control arena) and machine learning based techniques such as PCA based target identification and Support Vector Machines.

**Work package 2: 2D/3D texture and clutter simulation tool**: In this work-package, we propose to develop 2D/3D texture and clutter models based on a series of statistical models. Recent developments in modeling from learning will be studied as well as recent 3D texture synthesis models. In parallel, models coming from stochastic geometry will be used to tackle clutter which cannot be easily represented by classical texture models such as fractals (see figure 1b). The outcome of the process will be a set of techniques, identified from the literature that can be used for realistic sonar modeling. The models developed will include realistic physical parameters and take into account the sonar equation into the image formation process. We have already started developing such a simulator over the last year (publication pending) and have demonstrated very encouraging results for a variety of seabeds. Examples of results and a schematic of the principle are shown in Figure 4.
Work package 3: Robust parameter estimation: The estimation of the texture models parameters from the imagery will be attempted in this work-package. They will be used to support the detection of texture disturbances in work package 4. It is likely that nonlinear estimation techniques will be required due to the image formation process. Robust techniques, capable of estimation from limited sample sets will also be needed. Early data gathering experiments using SWATH PLUS will enable to create a data set of ground-truthed 3D textures.

Work package 4: Target detection and classification
This is a key work package in the study and will consist of three strands:

(a) First, we will evaluate the ability of our texture modeling to perform target detection. In that context, target detection can be treated as the detection of anomalies (or outliers) in the local estimation of clutter and texture models. One way to perform such detection will be to test the ability of the clutter or texture model (estimated from a local surrounding of coherent background) to correctly model the current sample. We will also evaluate approaches from early vision such as saliency detection. In this framework, the target would appear as salient feature in the texture field as defined by Itti & al [13].

(b) In a second step, we will perform a study to find the limits of high resolution imaging for target recognition in clutter based on the ability of an ATR system to distinguish targets. For instance, PCA or eigen-models have been used for face-recognition and recently for 3D target recognition in lidar and sonar imagery. They provide an effective way to learn the target’s appearance whilst not taking into account the background (clutter) but generally require large training sets. These images will be provided by our simulator and real targets acquired from REMUS missions using standard Side-Scan Sonar or SwathPlus Data. Early experiments in our group have shown the ability of this approach to achieve good
recognition performances and to test the limits of the imaging system. We will extend these results to 3D models and other ATR. Early experiments showing the dependence of the system to imaging resolution and SNR are shown in Figure 5.

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<tr>
<th>Examples of Simulated targets with increasing levels of SNRs</th>
<th>Influence of SNR on PCA based target classification</th>
<th>Influence of pixel resolution on PCA based target classification</th>
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(c) Finally techniques coming from machine learning will be tested to integrate clutter models in the decision process. In particular, ada-boost and cascade classifiers, which lead to fast and accurate recognition in video imagery will be tested, informed by the results of (b). Other classifiers adapted to recognizing targets whose appearance varies such as bag of words will also be studied.

**Work package 5: Experimental validation.** The Oceans Systems laboratory owns a REMUS 100 vehicle. This fully operational vehicle is equipped with 2 side-scan sonar at two different frequencies, 900 and 1800 kHz. The vehicle will be used to validate the approaches developed in the first three work packages in a variety of terrains in UK waters. We have the ability to deploy targets and have access to fresh water and sea lochs with a variety of seabed types within 2 hours of the laboratory. These sites have already been surveyed with REMUS in the past and offer good potential for validation.

1.4 **Leverage**

This proposal will leverage existing work in the area of sonar simulation and MIMO sonar models currently supported in Heriot-Watt University by EPSRC (EP-F068956). We have also secured the support of BAE Systems and SEA for this project. The former will provide requirements and act as a system evaluator. The latter will provide a in-kind contribution by lending us their swath+ 3D sonar free of charge and helping us with its integration on our platforms for data gathering and system evaluation. We are also currently collaborating with the NATO Undersea Research Centre where one of our staff has been invited as a research scientist in 2009 to work on target detection using their Synthetic Aperture Sonar (MUSCLE).

1.5 **Relevance to Beneficiaries**

This research will benefit all the stakeholders interested in seabed analysis: the offshore industry, the marine science community and the military. They all require accurate detection and classification techniques for the most prevalent sensing modality underwater: Sonar. Applications are varied and critical for the sustainability of these industries and our planet. Interests in pipeline and cable detection and inspection for the offshore and telecommunications industry is demonstrated by recent and currently funded projects in our laboratory by BP (AutoTracker) and the Office of Naval Research (Cable Tracking). Seabed survey and classification for environmental assessment is critical for climate change studies and coastal management. Change detection and trend analysis is important for security and marine science applications whilst target detection is of interest to all of these sectors.
1.6 Dissemination and exploitation

The results will be submitted for publication to international journals such as IEEE Transactions. It is also intended to target international conferences such as ICASSP, Oceans, ICCV, ICPR and ECUA. Within the UK there will be participation in workshops and IET colloquia. Lists of all published material will be available on the Internet via the World Wide Web. Any specific results which might be exploited will be given the necessary protection and appropriate MOD authorization before any details are published. Advice will be sought from the commercial arms of the University. BAe, SEA and SeeByte Ltd, the spin out of the Oceans Systems Laboratory have all expressed interest in taking forward the technology developed in this project commercially.

References