Development of a fusion adaptive algorithm for marine debris detection within the post-Sandy restoration framework

Giuseppe Masetti and Brian Calder

Center for Coastal and Ocean Mapping & Joint Hydrographic Center – University of New Hampshire (USA)

Abstract

Recognition of marine debris represents a difficult task due to the extreme variability of the marine environment, the possible targets, and the variable skill levels of human operators. The range of potential targets is much wider than similar fields of research such as mine hunting, localization of unexploded ordnance or pipeline detection. In order to address this additional complexity, an adaptive algorithm is being developing that appropriately responds to changes in the environment, and context. The preliminary step is to properly geometrically and radiometrically correct the collected data. Then, the core engine manages the fusion of a set of statistically- and physically-based algorithms, working at different levels (swath, beam, snippet, and pixel) and using both predictive modeling (that is, a high-frequency acoustic backscatter model) and phenomenological (e.g., digital image processing techniques) approaches. The expected outcome is the reduction of inter-algorithmic cross-correlation and, thus, the probability of false alarm. At this early stage, we provide a proof of concept showing outcomes from algorithms that dynamically adapt themselves to the depth and average backscatter level met in the surveyed environment, targeting marine debris (modeled as objects of about 1-m size). The project is embodied in a modular software library, called MATADOR (Marine Target Detection and Object Recognition).

Introduction

This paper presents the status of development of a target detection and recognition library focused on marine debris. This library has been developing as part of a larger two-year research project that the Center for Ocean and Coastal Mapping is leading. The main aim of the overall project is to “develop, test, and evaluate new and alternative processing and analysis tools and procedures” for quickly and effectively process data in case of major disaster as Super Storm Sandy (NOAA, 2013).

In October 2012, Sandy deposited extensive debris along the East Cost (FEMA, 2013). Among the many negative consequences of her passage was the deposition along the coastline of an extensive amount of debris of different size, shape, and materials (Blake et al., 2013; Trembanis et al., 2013). Debris mainly ends up in shallow coastal water, which could threaten navigation, natural resources, or human safety. Almost any natural disaster such as Super Storm Sandy causes the deposition along the coastline of an extensive amount of debris due to the associated strong winds, heavy rainfall, and storm surge (Lin et al., 2014). Future climate warming may intensify the expected impacts of future events (Holland and Bruyère, 2014; Liu and Pang, 2012).

Effectively and quickly processing large amount of hydrographic data, collected using commercial systems, for detection and classification of marine debris would represent an effective contribution in case of similar events (e.g., tsunami, hurricane) to the necessary removal operations (Lebreton and Borrero, 2013). The Marine Target Detection and Object Recognition (MATADOR) project is focused on submerged marine debris, in contrast to most studies of marine debris, which have focused on floating or near surface objects.

Related works and other sources of information

Since the detection of underwater objects is an active topic of research, existing research done in similar fields was first examined. This showed that in most fields there is a more constrained range of target variability relative to the marine debris problem. For instance, in mine hunting there is often information about the target shape as well as the material, and mine detection algorithms often look for high backscatter objects of a given size over the natural acoustic background backscatter. An analogous concept also occurs in localization of unexploded ordnance, where the research criteria are often constrained to objects of specific shape. For pipeline detection, there is often additional information such as the pipelines being mostly linear, with a well-known maximum radius of curvature (Li et al., 2000; Stack, 2011; Telfer et al., 1994).

Unfortunately, the search for marine debris has fewer constraints. In fact, the definition of marine debris is often quite vague. As reported on the NOAA Marine Debris program website, marine debris can be “anything man-made” and made of “plastic, glass, metal, wood, […]” (NOAA, 2014). The direct consequence of this definition is that marine debris can be a substantial superset of possible types of objects, with different shapes, materials, roughness, etc. This, summed with the extreme variability of the marine environment, may represent a limitation in the creation of a model for the algorithms that are being implemented (particularly with respect to robustness). In personal communications, Marine Debris Program experts suggested that they are usually interested in debris bigger that one cubic meter. This value will be used, at this first stage, as a lower size bound.

Conventionally, submerged marine debris has been identified through the subjective evaluation of sidescan sonar records by a human operator. Understanding what criteria human operators use, therefore, is important for guidance of this research. Using the data being collected by NOAA contractor surveys, provided through NOAA/OCS, generic criteria are being evaluated so that they can be emulated (without the subjectivity) in software, if possible.

From the analysis of the targets selected so far, several common selection patterns emerged. For instance, a first group containing a rounded shape and/or a jump in seafloor reflectivity was common to many of the several hundred targets examined. A second group was based solely on bathymetry evaluation. A third group comes from an integrated analysis of the Digital Terrain Model (DTM) and the acoustic backscatter. Finally, although such data can now be readily collected on many systems, there are no examples of debris selection based on water column data, although the extent of availability of this data (and appropriate tools) to the observers is unknown. Although the probability of false alarm based on a combined analysis of multiple data sources is expected to be generally lower than when a single source is used, there are particular cases where a particular object might only be observable within a single data source. For example, a semi-buried target, or one with a flattened shape, might only be visible through acoustic backscatter. A careful analysis of the benefits of different algorithms and different data sources is therefore indicated.

An important source of inspiration for the MATADOR library is represented by the Automatic Contact Detection tool developed specifically for sidescan sonar data and based on such machine learning techniques as the multilayer perceptron network (Quintal et al., 2010). This work shows the feasibility of automated methods to reduce manual processing time required in detection of contacts of interest, maintaining high probability of detection and low false alarm rate.

Selected approach

From these observations, it appears that operator debris detection was mainly based on the bathymetry and the reflectivity of the seafloor, assuming any deviation from the ‘natural average background’ as hints of possible debris. From that consideration and given the intrinsic complexity of the targets, it is likely that a single algorithm will not be successful for robust marine debris detection. The proposed solution will therefore be based on multiple algorithms to process different sources (bathymetry, backscatter and water column data for acoustic systems, as well as lidar data), fused together so as to be adaptive to the environment, the context, and *a priori* knowledge (if available) of the possible targets. The goal is to use a collection of algorithms working at different levels (e.g., through per beam, single swath, snippet and pixel level operators), which are then fused by the core engine. One of the primary advantages of this approach is operating over different data with independent algorithms can reduce inter-algorithm cross-correlation and therefore the probability of false alarm.

Algorithms overview

The first of these algorithms has been developed based on a simple model of the detection of anomalies from the background acoustic backscatter, following the observation that operators regard anomalies against the generic background as potentially debris. This algorithm is based on an acoustic backscatter mosaic, and takes advantages of previous NOAA-sponsored work at the Joint Hydrographic Center to properly geometrically and radiometrically correct the collected data (Fonseca and Calder, 2005). The resulting mosaic is segmented into areas with similar reflectivity values through a clustering analysis, and a histogram of backscatter values as a function of angle of incidence is then computed for each clustered area (effectively forming a 3D histogram). A simple Bayesian classifier is subsequently used to identify areas in each segment where the statistics of a small window do not match that of the overall background distribution (as characterized by the appropriate marginalization of the histogram constructed previously). Areas of low probability of background membership are identified as potential marine debris. Subsequent edge detection and hierarchical filtering are applied to remove misdetections along the mosaic boundaries. The result (Figure 1) is quite promising, showing an appropriately limited number of detections that are similar to the results from a human evaluation of the mosaic.

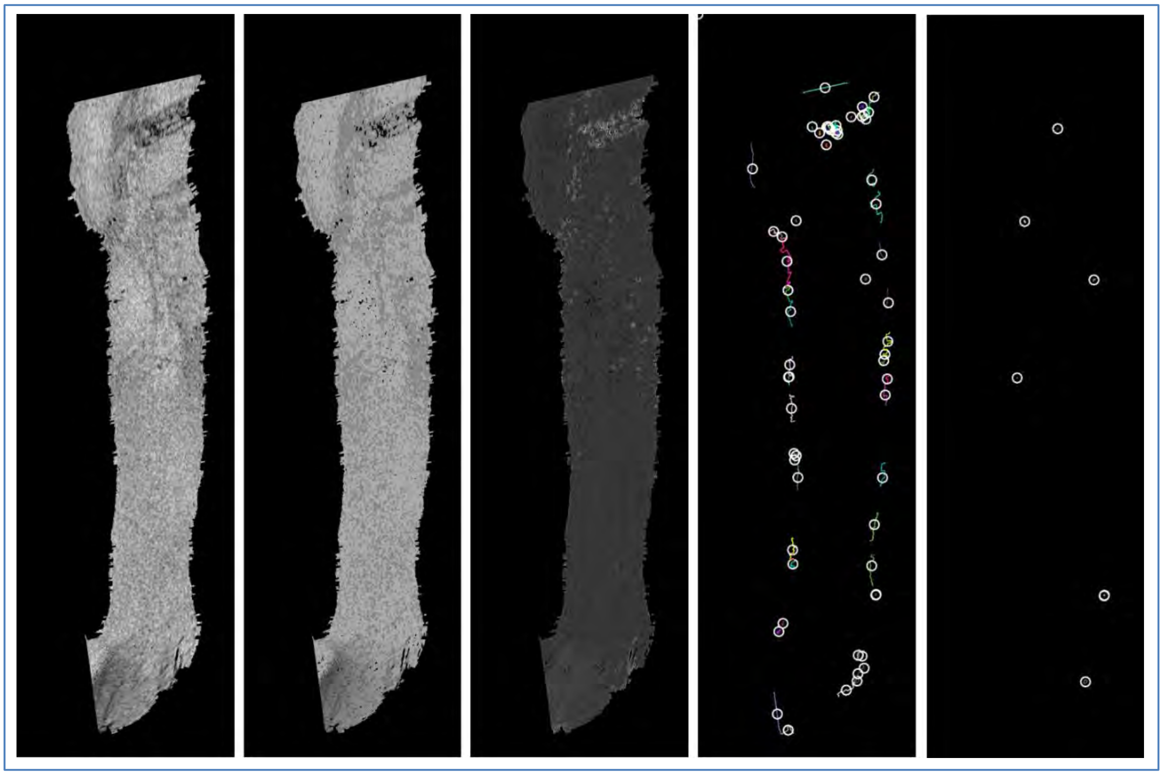
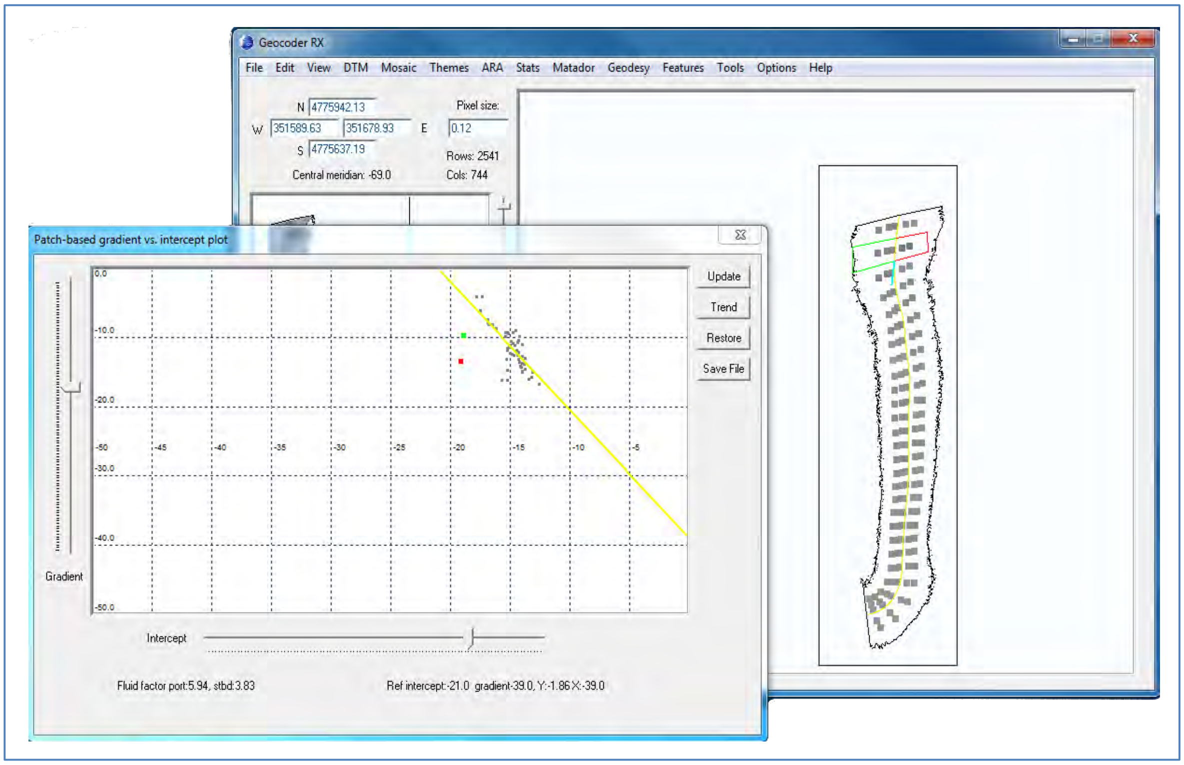


Figure 1 – Stages in the Bayesian analysis of backscatter anomalies. The sub-images show, left to right: the geometrically and radiometrically corrected backscatter mosaic; the clustered mosaic (clustering is based on simple backscatter values in the mosaic); the probability map for membership of each analysis window in its surrounding background (high values indicate lack of membership); edge detected segments indicating potential objects; and hierarchically filtered objects showing those likely not associated with edge effects in the mosaic. The limited number of detections is promising (from the point of view of limiting false alarms), and corresponds well to operator inspection of the mosaic.

This algorithm represents just one branch of the proposed workflow. Other areas being explored include the angular response for each acoustically clustered area (i.e., detecting anomalies from the average angular response, which is quite different from the mosaic response where angular differences are removed), and evaluation of the half-swath patch (i.e., stacking a certain number of successive pings to stabilize the statistics and reduce the noise), again looking for anomalies in the angular response of the immediate area. (In the past, the Center has developed an approach targeted to the identification of the sediment types based on the angular dependence of backscatter from a swath; here, the idea is inverted.) It seems likely that addition insights can come from the analysis of the spatial distribution of snippets (backscatter samples centered on the bottom detection) using, for example, a measure of texture (itself a well-studied field). In fact, simply increasing the bin size (that is, lower the resolution of the final product) generates more stable statistics, and then many additional features useful to describe the dataset (e.g., median, variance, kurtosis, GLCM energy, GLCM homogeneity) may be explored (Masetti and Calder, 2012).

Not all of the calculated features need necessarily be directly used by the detection algorithms. Several of them might be used, for example, to increase the overall confidence in the output coming from the fusion algorithm. A basic example of this approach is presented in Figure 2, where two features (gradient and intercept) calculated from the angular response of the acoustic patches are plotted against each other. In the resulting plot, two patches (showed in green and red and covering an area characterized by the presence of a marine debris) are located far from all the remaining patches. A quantitative measure of that distance can be used as indicator of areas with possible presence of marine debris.



N 4775942.13
W 351589.63
E 351678.93
S 4775637.19
Pixel size: 0.12
Rows: 2541
Cols: 744
Central meridian: -69.0

Fluid factor port:5.94, stbd:3.83

Ref intercept:-21.0 gradient-39.0, Y:-1.86 X:-39.0

Figure 2 – Bivariate plot of acoustic backscatter-derived features computed from a half-swath patch of MBES data. The red/green indicated half-swaths have distinctly different behavior (as measured by the slope and intercept of a line fitted to the acoustic backscatter angular response in the patches) from the other patches, an indication of anomalous behavior. Use of multivariate combinations of features can help to clarify detections and reduce false alarm rates.

Data collection requirements

Analysis of the requirements for the techniques adopted by MATADOR algorithms to be successful has led to some caveats on the data being used, and the processing being applied. In particular, the acoustic system used should be fully understood, with particular attention to the internal backscatter processing, otherwise the appropriate corrections cannot readily be made. In addition, the system used to collect the data should be calibrated, and the resulting calibration parameters correctly applied (in real time or post processing), or the results may be misleading. Finally, the environment should be properly characterized (e.g., absence of issues with the sound speed profiles, correct absorption coefficients, etc.) for the corrections being done to be effective. Missing one or more of the above requirements may affect the developed algorithms, at least with respect to performance, emphasizing the need for careful survey planning and management.

System calibration is mainly required by the fact that elements in the receive array do not usually have absolutely identical characteristics or mounting position (Meurling and Volberg, 2007). The resulting differences in magnitude and phase must be taken into account to relate the received data to absolute values of backscattering strength with the level of accuracy required by those MATADOR algorithms based on a physical model. Similarly, any signal distortion on the backscatter time series collected around the seafloor detection point should be reduced / avoided.

At the same time, in case of availability of pre- and post-disaster datasets, relevant insights may come from a comparative approach. However, proof that the seabed changes (e.g., presence of marine debris) are not related to instrumental and integration artifacts requires confidence in the absolute accuracy of both the bathymetric and backscatter output of the integrated sonar system (Hughes Clarke, 2012; Mayer et al., 2007). The relevance of the accuracy tends to increase with the reduction of marine debris size (e.g., spatial scale of decimeters), and it often lies at the limit of many acoustic systems used to collect disaster-driven datasets. A possible consequence of the described situation is the appearance of features in a dataset not present in the pre-disaster products due to a better ‘focusing’ of the used instrument (e.g., higher operational frequency), in case different systems are in use, or to different settings (e.g., operational modes) where the same system is in use.

More generally, important information that should be properly evaluated both in the selection of the system for data collection and in the assessment of the MATADOR results is the achievable resolution of a specific system, and its variability as a function of the settings selected in the field. In fact, even if specific performance is theoretically achievable based on the manufacturer product specifications, all systems have fundamental constraints and trade-offs that are a function of operational frequency, resolution, and range of transmission (Mayer et al., 2007).

The resolution directly influences the size of detectable marine debris. In case of a MBES, the resolution is strongly related to the beam footprint which is characterized by the transmit (along-track resolution) and receive beamwidth (across-track resolution), and the equivalent length of the transmitted pulse, properly projected on the seabed (Lurton, 2010). In case of detection based on phase measurement, features can be discerned at lower grazing angles at a scale significantly finer than the beam footprint dimension (Hughes Clarke, 2012). Another factor that influences the minimum size of detectable marine debris is represented by the beam forming approach. The approaches most commonly in use are equiangular, equidistance, and high definition modes. The last of these, although not implemented by all sonar manufacturers, usually represents the best trade-off among the beam spacing in the nadir region and the required additional detection solutions at lower grazing angles (where multiple soundings are defined within a single beam) (Kongsberg, 2013c; Masetti and Calder, 2012). Alternatively, a similar result can be obtained by increasing the number of beams in equidistance mode (Meurling et al., n.d.). Another common solution to the same issue is having multiple pings in water at the same time (with slightly different frequencies) (Hughes Clarke, 2012).

In general, it is highly desirable that the data density within all the acquired dataset is uniform, both in the along- and in the across-track direction. Irregular sounding density coming, for instance, from not properly compensated pitch and yaw may result in undetected features. A ‘full sea floor search’ of the survey area should be not simply based on the assumption that everything within the bounds of the edge of the swath is ‘covered’ (IHO, 2008). In fact, a lack of local data density can drastically reduce the reliable detection of small targets that is based on the assumption that the seafloor is sampled at a scale significantly finer than the target dimension to be resolved (Kongsberg, 2013a).

The common target of maintaining three swaths on any given target is a useful rule of thumb, and more swaths per target should be maintained where possible. Assuming roll and pitch stabilization (offered by almost all manufacturers) a yaw-stabilized MBES system may be advantageous where available. In fact, given a 1-meter cube as the assumed lowest bound for debris size, the along track spacing among swaths in shallow waters can require particularly low speed for small boats, usually characterized by higher yaw rates than larger vessels at low engine regime (Kongsberg, 2013a). Simply increasing the data density does not necessary imply better data quality, but it often provides a wider margin for data filtering and statistic tools application.

The data density along-track for single-ping MBES system is mainly controlled by the two way travel time required by the outermost area of each swath to be received. The main implication is that any attempt to improve the swath coverage reduces the ping rate (and then the along-track distance between each ping increases).

MBES along-track beamwidth is usually much wider than that used by conventional sidescan sonars (SSS), so that SSS imagery tends to be better quality (Pohner et al., 2007). However, unless the SSS is hull-mounted (which has its own difficulties) variable distortions are usually introduced due to the uncertainty in the towing fish position and weakness of the flat-seafloor assumption. A better solution, when feasible, is to integrate accurate MBES bathymetry and high resolution SSS imagery. In such a case, the SSS-based mosaic can also take advantage of being properly geometrically corrected by using the MBES-based DTM.

Together with the resolution, it is also important to reduce all the possible sources of Total Propagated Uncertainty (TPU) and absolute accuracy. Since a large part of the MATADOR algorithms are based on products that combine different survey lines (e.g., mosaic, DTM), the areas of overlap (that is, each node whose final value is based on the integration of data coming from more than a single survey line) will be variously affected by any introduced 'corruption' (e.g., ray tracing with incorrect sound speed profiles, inaccurate tide reduction, loss of GPS differential corrections, time delays between the different sensors in use) with the double risk to mask the presence of marine debris (defocusing) and to create false detections driven by artifacts. The adoption of commonly used patch test procedures before and after the survey (as well as after any variation in the vessel configuration) usually helps to reduce and track many of the possible issues (Eisenberg et al.; Wheaton, 1988). However, there could be residual misalignment or mistiming of sensors relative to each other that may produce both static biases and dynamic residuals, called wobbles (Hughes Clarke, 2003). This latter can be confused with or mask the presence of marine debris.

Similar issues arise comparing products built with the same identical parameters (e.g., grid spacing for DTM), but with different uncertainties and accuracies. In such a case, only scales of seabed change larger than the combination of the accuracies characterizing the compared surveys will become detectable (Hughes Clarke, 2012).

The characteristics of the water column are continuously changing both in time and in space (Burdic, 1991). As a consequence, there is not a simple direct relationship between the time since, and the distance from, the sound speed measurement in use. The measurements of sound speed must be taken often enough to capture both the actual spatial and temporal variability (Beaudoin et al., 2009). If an underway profiler is available, an adequate sampling interval should be adopted (Wilson et al., 2013).

As an additional consideration, it is of overall importance to know and/or have experience with the adopted system so that the best settings will be adopted for target detection. In fact, many manufacturers have specific bottom detection algorithms and operation modes for this type of survey where the requirements are different than a standard bathymetric survey (Kongsberg, 2013b).

The MATADOR library has been developing to take advantage, when available, of well-collected and calibrated hydrographic data. Nonetheless, thanks to a variable system of weights for the available algorithms (in fact, some of them are less affected than others by improper data acquisition), marine debris detection will still be possible, with expected increased false alarm rates, even in the event of lack of some of the above described best practices.

Library development and products

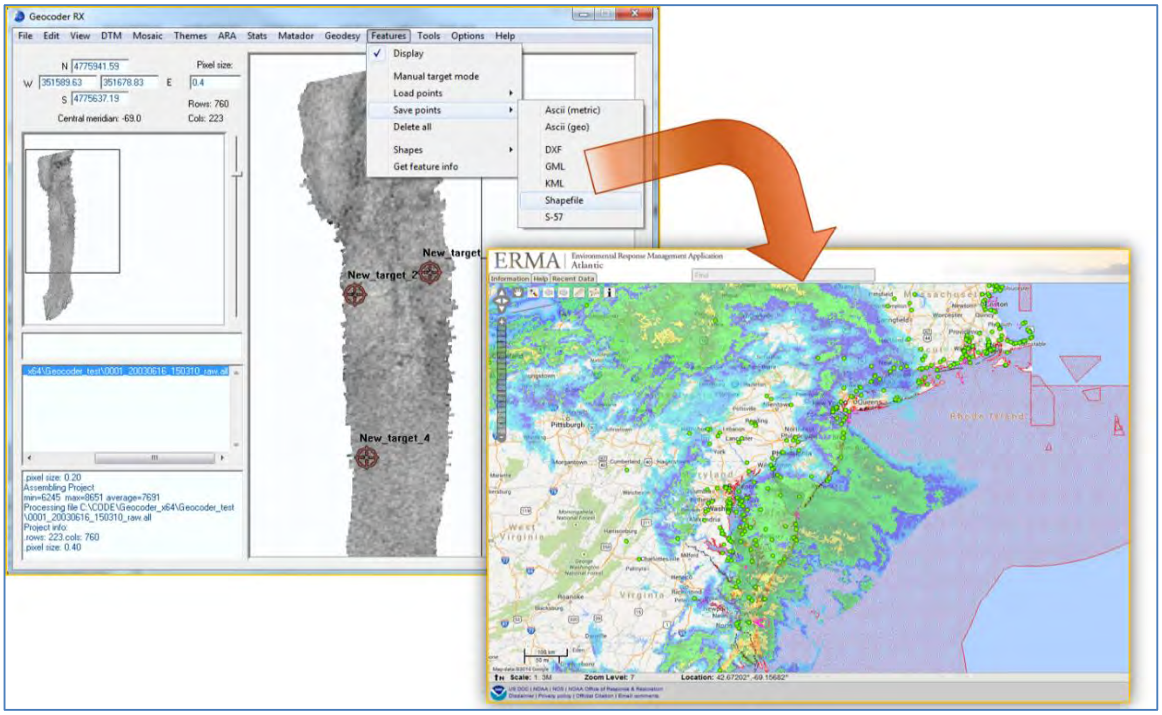
The MATADOR library consists of a primary library, and a number of auxiliary libraries and other software. In order to provide for consistent development, the code is being developed in a cross-platform, portable manner, primarily in modern C++11. The code uses HUDDL (Hydrographic Universal Data Description Language) to manage input data, a project that is in parallel development to this effort at CCOM (Masetti and Calder, 2014).

The library is being designed to be flexible in data requirements. That is, the best results are expected to be obtained with properly calibrated and collected data; however, in case this type of data are not available, different weights will be used for the algorithms (in particular, the ones that are model-based) so that outputs are still robust in marine debris detection at the expenses of the probability of false alarm.

In order to make the developing library as useful as possible, the data format to store MATADOR products was carefully evaluated. The selected approach is to support the most commonly used formats rather than to attempt the definition of some specialty format. For this reason, the library has been extended to export raster data in many different and commonly used formats (from plain ASCII to Geotiff). This also represents an important outlet to continue the processing for any given dataset with existing commercial and open source software (e.g., Caris BDB, ESRI ArcMap, GRASS, QGIS, QPS Fledermaus Suite).

In addition, the library can also export a ‘hyper mosaic’, this data container is simply a multilayer GeoTiff where the mosaic represents one of the available layers, and the other layers are used to capture more information about the survey dataset. Easily loadable by existing commercial software, the hyper mosaic was developed with the intent to provide means for quickly comparing new data with existing surveys. At the same time, this type of output is suitable for applying many of the techniques commonly used in signal processing for hyper-spectral image exploitation (e.g., Karhunen-Loeve transform, Reed-Xiaoli anomaly detector) from spatial, spectral, radiometric, and temporal perspectives (Lo and Ingram, 2008; Masetti and Calder, 2012; Shaw and Manolakis, 2002).

At the same time, vector outputs are being supported (e.g., ESRI shape file, S-57, GML, DWG, KML) so that the data are ready to be imported in decision support systems, environmental databases (e.g., the PPMS GeoDB) (Masetti and Calder, 2013) and other external GIS tools (Figure 3). Among the existing systems, particular attention is provided to support the interaction with the Environmental Response Management Application (ERMA), a web-based GIS platform capable of interfacing both static and real-time data sets accessible simultaneously to a command post and assets in the field with an open source internet mapping server (NOAA, 2012). This platform is well suited for integration with MATADOR products (that can be directly loaded by ERMA technical users) both for specific planning and for general understanding in case of natural disasters (Jacobi et al., 2008).



N 4775941.59
W 351589.63 351678.83 E
S 4775637.19
Central meridian: -69.0
Pixel size: 0.4
Rows: 760
Cols: 223

```
x64\Geocoder_test\0001_20030616_150310_raw.all
```

```
pixel size: 0.20
Assembling Project
min=6245  max=8651 average=7691
Processing file C:\CODE\Geocoder_x64\Geocoder_test
\0001_20030616_150310_raw.all
Project info:
rows: 223 cols: 760
pixel size: 0.40
```

Figure 3 – Interface from M*ATADOR to ERMA. The* M*ATADOR library, embedded inside a research version of the extended and refactored GeoCoder application (used for backscatter corrections, mosaic construction, and analysis), is designed to output results of the marine debris analysis process in a variety of formats, including well-known vector formats such as KML, GML, ESRI Shapefile, and S-57, and a number of raster formats (where appropriate). These are readily adoptable into applications such as ERMA, as well as other GIS-style tools.*

High-resolution multibeam sonar and state-of-the-art data processing and visualization techniques have been used to quantify the degree of burial of instrumented mines and mine-shapes (Mayer et al., 2007). It has been largely documented that the presence of mine-like objects produce scour pits with its long axis nearly perpendicular to the predominant incoming wave direction (Traykovski et al., 1999; Trembanis et al., 2007). Some techniques used to characterize the bedform morphology (e.g., Skarke and Trembanis, 2011) could be adapted to obtain relevant insights for marine debris detection.

Conclusions

A modular software library, called MATADOR, has been developing with the main aim to provide a fusion adaptive algorithm able to quickly and effectively detect and recognize the possible presence of marine debris from large datasets collected with commercial systems after a major disaster like a tsunami or a hurricane.

One of the main issues of this project is about the consistent nature and definition of marine debris together with the extreme variability of the marine environment, and the variable skill levels of human operators. This condition requires efforts for the correct adoption and implementation of different techniques developed in similar fields of research such as mine hunting, localization of unexploded ordnance or pipeline detection.

During the first phase of library development, many of the radiometric and geometric corrections developed in recent years at the Center for Coastal and Ocean Mapping have been evaluated and integrated in a common framework. These corrections represent the preliminary step for properly linking the physical aspects related to the collected data with some of the mostly used statistical techniques for pattern recognition and anomaly detection.

The MATADOR core engine ensures the proper fusion of the increasing number of algorithms. Each algorithm works at different levels (swath, beam, snippet, and pixel), using both predictive modeling (that is, a high-frequency acoustic backscatter model) and phenomenological (e.g., digital image processing techniques) approaches. The expected outcome of this fusion approach is the reduction of inter-algorithmic cross-correlation and, thus, the probability of false alarm. Future developments will investigate the addition of techniques based on DTM analysis, water column backscatter, and lidar data.

The integration of the MATADOR products with existing commercial and open source software and decision support systems is one of the development milestones. Support of the most common raster and vector formats is provided. An additional data container, a multilayer Geotiff called a hyper mosaic, has been identified as an output to capture more information about a survey dataset than a simple mosaic or DTM.

References

Beaudoin, J., Calder, B., Hiebert, J., Imahori, G., 2009. Estimation of sounding uncertainty from measurements of water mass variability. International Hydrographic Review 20-38.

Blake, E.S., Kimberlain, T.B., Berg, R.J., Cangialosi, J., Beven II, J.L., 2013. Tropical Cyclone Report: Hurricane Sandy. National Hurricane Center 12.

Burdic, W.S., 1991. Underwater acoustic system analysis. Prentice Hall New Jersey.

Eisenberg, J., Davidson, M., Beaudoin, J., Brodet, S., Rethinking the Patch Test for Phase Measuring Bathymetric Sonars.

FEMA, 2013. Hurrican Sandy Recovery Efforts One Year Later. Federal Emergency Management Agency, p. 3, http://www.fema.gov/media-library/assets/documents/85068.

Fonseca, L., Calder, B., 2005. Geocoder: An Efficient Backscatter Map Constructor, U.S. Hydrographic Conference: San Diego (USA).

Holland, G., Bruyère, C., 2014. Recent intense hurricane response to global climate change. Climate Dynamics 42(3-4) 617-627.

Hughes Clarke, J.E., 2003. Dynamic Motion Residuals in Swatch Sonar Data: Ironing out the Creases. International Hydrographic Review 4(1) 6-23.

Hughes Clarke, J.E., 2012. Optimal use of multibeam technology in the study of shelf morphodynamics. Sediments, Morphology and Sedimentary Processes on Continental Shelves: Advances in technologies, research and applications (Special Publication 44 of the IAS) 108 3.

IHO, 2008. IHO S-44 - Standards for Hydrographic Surveys, 5th Edition ed. IHB, Monaco.

Jacobi, M., Kinner, N.E., Braswell, B.H., Schwehr, K.D., Newman, K.S., Merten, A.A., 2008. Environmental Response Management Application. International Oil Spill Conference Proceedings 2008(1) 881-885.

Kongsberg, 2013a. The advantages of yaw stabilization in multibeam surveying, EM Technical Note. Kongsberg Maritime, p. 2.

Kongsberg, 2013b. Detector modes in SIS for EM 2040, EM 2040C and EM 3002, EM Technical Note. Kongsberg Maritime, p. 2.

Kongsberg, 2013c. Sector coverage and beam spacing modes for multibeam echosounders, EM Technical Note. Kongsberg Maritime, p. 1.

Lebreton, L.C.M., Borrero, J.C., 2013. Modeling the transport and accumulation floating debris generated by the 11 March 2011 Tohoku tsunami. Marine Pollution Bulletin 66(1–2) 53-58.

Li, D., Azimi-Sadjadi, M.R., Dobeck, G.J., 2000. Comparison of different neural network classification paradigms for underwater target discrimination, pp. 334-345, http://dx.doi.org/10.1117/12.396261.

Lin, N., Emanuel, K., Vanmarcke, E., 2014. Physically-based hurricane risk analysis. Extreme Natural Hazards, Disaster Risks and Societal Implications 1 88.

Liu, F., Pang, W., 2012. Influence of Climate Change on Future Hurricane Wind Hazards along the US Eastern Coast and the Gulf of Mexico, Advances in Hurricane Engineering, pp. 573-584.

Lo, E., Ingram, J., 2008. Hyperspectral anomaly detection based on minimum generalized variance method, pp. 696603-696603-696607, http://dx.doi.org/10.1117/12.778929.

Lurton, X., 2010. An introduction to underwater acoustics : principles and applications, 2nd ed. Springer, published in association with Praxis Publishing, Chichester, UK, Heidelberg ; New York.

Masetti, G., Calder, B., 2012. Remote identification of a shipwreck site from MBES backscatter. Journal of Environmental Management 111(0) 44-52.

Masetti, G., Calder, B., 2013. Design of a standardized geo-database for risk monitoring of potentially polluting marine sites. Environment Systems and Decisions 1-12.

Masetti, G., Calder, B., 2014. HUDDL for description and archive of hydrographic binary data, Canadian Hydrographic Conference: St. John's, NL (Canada), p. 24.

Mayer, L.A., Raymond, R., Glang, G., Richardson, M.D., Traykovski, P., Trembanis, A.C., 2007. High-Resolution Mapping of Mines and Ripples at the Martha's Vineyard Coastal Observatory. Oceanic Engineering, IEEE Journal of 32(1) 133-149.

Meurling, T., Baldwin, M., Lockhart, D., Malzone, C., NA. The Ultra-High Resolution Future of Hydrography p. 9, http://www.fugro-pelagos.com/papers/High-Res_Future.pdf.

Meurling, T., Volberg, B., 2007. The Evolution and Future of Multibeam Echo Sounder Technology, Underwater Technology and Workshop on Scientific Use of Submarine Cables and Related Technologies: Tokyo (Japan).

NOAA, 2012. Environmental Response Management Application (ERMA) - User's Guide, 1.2 ed, p. 32.

NOAA, 2013. FY 13 Disaster Relief Appropriations Act IOCM Processing Center Research. National Ocean Service (NOS), National Oceanic and Atmospheric Administration (NOAA), Department of Commerce, p. 20.

NOAA, 2014. Disaster Debris. Marine Debris Program, Office of Response and Restoration, http://marinedebris.noaa.gov/disaster-debris.

Pohner, F., Bakke, J., Nilsen, O., Kjaer, T., L., F., 2007. Integrating Imagery from Hull Mounted Sidescan Sonars with Multibeam Bathymetry, U.S. Hydrographic Conference: Norfolk, VA (USA), p. 16.

Quintal, R.T., Kiernan, J.E., Shannon, J., Dysart, P.S., 2010. Automatic contact detection in side-scan sonar data, Technologies for Homeland Security (HST), 2010 IEEE International Conference on. IEEE, pp. 270-275.

Shaw, G., Manolakis, D., 2002. Signal processing for hyperspectral image exploitation. Signal Processing Magazine, IEEE 19(1) 12-16.

Skarke, A., Trembanis, A.C., 2011. Parameterization of bedform morphology and defect density with fingerprint analysis techniques. Continental Shelf Research 31(16) 1688-1700.

Stack, J., 2011. Automation for underwater mine recognition: current trends and future strategy, SPIE Defense, Security, and Sensing. International Society for Optics and Photonics, pp. 80170K-80170K-80121.

Telfer, B.A., Szu, H.H., Dobeck, G.J., Garcia, J.P., Ko, H., Dubey, A.C., Witherspoon, N.H., 1994. Adaptive wavelet classification of acoustic backscatter and imagery. Optical Engineering 33(7) 2192-2203.

Traykovski, P., Hay, A.E., Irish, J.D., Lynch, J.F., 1999. Geometry, migration, and evolution of wave orbital ripples at LEO-15. Journal of Geophysical Research: Oceans 104(C1) 1505-1524.

Trembanis, A., DuVal, C., Beaudoin, J., Schmidt, V., Miller, D., Mayer, L., 2013. A detailed seabed signature from Hurricane Sandy revealed in bedforms and scour. Geochemistry, Geophysics, Geosystems 14(10) 4334-4340.

Trembanis, A.C., Friedrichs, C.T., Richardson, M.D., Traykovski, P., Howd, P.A., Elmore, P.A., Wever, T.F., 2007. Predicting Seabed Burial of Cylinders by Wave-Induced Scour: Application to the Sandy Inner Shelf Off Florida and Massachusetts. Oceanic Engineering, IEEE Journal of 32(1) 167-183.

Wheaton, G., 1988. PATCH TEST, A system check for multibeam survey systems, Proc. Hydrographic Conf, pp. 12-15.

Wilson, M.J., Beaudoin, J., Smyth, S., 2013. Water-column variability assessment for underway profilers to improve efficiency and accuracy of multibeam surveys, U.S. Hydrographic Conference: New Orleans, LA (USA), p. 24.

Author biographies

Giuseppe Masetti received a MS degree in Ocean Engineering (UNH, USA) in 2012, and a Master in Marine Geomatics (2008) and a Ph.D. degree (2013) in System Monitoring and Environmental Risk Management (University of Genoa, Italy). At CCOM/JHC he works mainly on signal processing for marine target detection.

Brian Calder is an Associate Research Professor and Associate Director at CCOM (UNH, USA). He has a Ph.D. in Electrical and Electronic Engineering, completing his thesis on Bayesian methods in SSS processing (1997). He is currently focusing on statistically robust automated data processing approaches and tracing uncertainty in hydrographic data.