Tackling Cost Drivers of Maritime EXO Surveys

Torsten FREY, Mareike KAMPMEIER,
Patrick MICHAELIS, Daniel WEHNER,
Marc SEIDEL, Jens GREINERT,
GEOMAR Helmholtz Centre for Ocean Research, Germany

Torsten Frey is a researcher at GEOMAR Helmholtz Centre for Ocean Research Kiel. Following his studies, he became a researcher at Leipzig University, where he worked on the RoBEMM-project and wrote the Quality Guideline for Offshore Explosive Ordnance Disposal (EOD). At GEOMAR Torsten continues to research new opportunities to improve the quality and efficiency of the UXO detection process in the BASTA project. In the new ProBaNNt project, he and his colleagues investigate ways to improve decision making capabilities during EOD operations. He pursues a Ph.D. on risk-based decision making during UXO clearance operations.

During UXO survey and clearance campaigns, a large number of false positive target points drive costs and efforts. This paper presents three approaches for the improvement of maritime UXO surveys that allow for the immediate execution of target point investigations. (1) Data quality factors were generated to help determine, whether UXO can be detected in the acquired multibeam echosounder (MBES), side-scan sonar, subbottom profiler and magnetic data. (2) Artificial intelligence was developed to rapidly identify target points with potential UXO objects in MBES data. (3) Magnetometers and a high-resolution camera were integrated on an AUV to allow for autonomous target point investigation, that does not require permanent supervision of survey personnel.

INTRODUCTION AND BACKGROUND

Munitions in the sea present a global issue with effects on both maritime economy and marine environment. Due to military actions during wars, post-war dumping, and military test- and training activities, large amounts of unexploded ordnances (UXO) rest on seabeds worldwide (1). With increasing offshore development, such as windfarm installations, the topic gained increasing public and political attention over the past ten years. Offshore construction projects are not only delayed due to extensive munition detection surveys, but also face high costs for munitions clearance work.

The detection and identification of UXO is time-consuming and costly. The majority of objects that are detected during technical surveys and that are later on investigated turn out to be non-UXO objects (i.e. false positives), such as anthropogenic scrap and natural objects such as boulders (2). Hence the EU-funded project BASTA (Boost Applied munition detection through Smart data inTegration and AI workflows) aims at integrating the technical survey of larger areas and the investigation of target points.

In order to perform this integration, the following three requirements were identified:

1. *We need to be sure that data quality is high.*
2. *We need to be able to instantly generate a target list.*
3. *We need a means to conduct the technical survey of a larger area of interest and the investigation of target points simultaneously.*

The following chapters address one of these three requirements each in the order they are listed above.

DATA QUALITY FACTORS

Before the survey data can be analyzed, it is important to know, whether the acquired data are sufficient for the purpose of finding UXO altogether. Prior to the technical survey, a reference object needs to be defined and the survey needs to be designed in such a way, that this object and all larger objects will be found (3). During the survey, a continuous check on data quality can be implemented by using data quality factors.

Data quality factors for multibeam echosounder, side-scan sonar, sub-bottom profiler and magnetic sensors were developed (4). These are commonly used sensors during UXO surveys, when conducted by private companies, military and scientific institutions. Initially, a literature research was conducted to develop a preliminary list of data quality factors and assigned threshold values. These were presented to domain experts from survey companies, military and scientific institutions, who, over the course of four virtual and one on-site workshops, discussed the data quality factors and threshold values and voted on their relevance. The process was moderated by BASTA researchers, who ultimately decided on the set of quality factors that should be used for data quality checks during future UXO surveys. Threshold values for data quality factors are mostly based on properties of the reference object. Acquired data can then be compared to these threshold values to determine whether they can be used to detect the reference object.

Figure 1 provides an example of two data quality factors that were applied to two different reference objects. On the left, a subsection of an MBES bathymetry map of German munitions dump site Kolberger Heide is shown. The area is deepest in the northeast corner (blue) and the water depth is decreasing towards the west and southwest (red). On the right side, the four graphs show the same subsection, but with data quality factors applied to each beam (i.e. data point) represented by a colored point. Data quality is measured relative to the threshold values indicated in the figure caption. A value of 1 (yellow) shows that the data point meets exactly the threshold value of that data quality factor for the given reference object. The more the color changes towards green (value of 2), the more the data point outperforms the data quality requirements. The more the color changes towards red (value of 0), the less suffi¬cient the data quality of that point. Placing thousands of colored data points (i.e. beams) next to each other leads to the generation of the striped patterns visible in the figure, which follow the survey lanes taken during data acquisition.

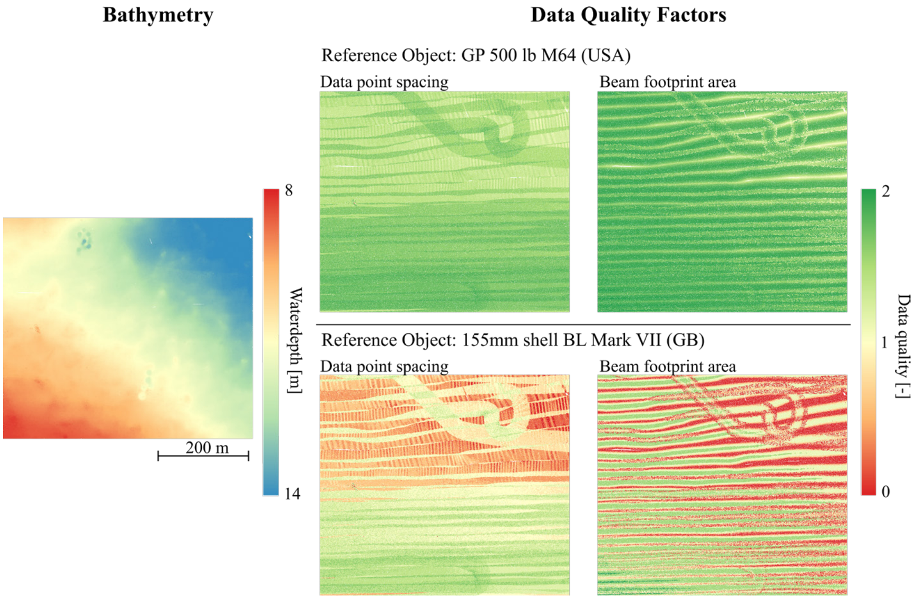

Figure 1: *Bathymetry measured with the MBES in the test area (left) and two exemplary data quality factors (Data point spacing, Beam footprint area – a combination of beam footprint along track and across track) for two different reference objects (right).*

AI-SUPPORTED TARGET LIST GENERATION

If the survey data pass the data quality check, they can be used to generate a preliminary target list. The target list acts as a register of all geographic locations at which, based on the interpretation of the survey data, UXO may be present (3). It is possible to develop and train an artificial neural network (ANN) to automatically identify possible target points. This has the potential to significantly reduce the time it takes to manually pick target points. During the BASTA project, such an ANN was developed to detect target points in MBES raster data. In order to make the use of the ANN easy to use, a plug-in for QGIS was developed (5).

An ANN can annotate the distinct shapes of UXO objects on the seabed in the MBES data. This is facilitated by using convolutional layers in the network. As ANNs rely on the principle of learning from data, a good training dataset is crucial for the performance of an ANN. The annotation of data has to be both complete and accurate to get good results. The task of the ANN is to assign a probability to each pixel of the input raster thereby classifying it as UXO or non-UXO. One advantage of this approach is the use of not only the pixel information itself, but also the information of its surrounding pixels. This leads to regularization and smoother results. An exemplified ANN application is shown in Figure 2.

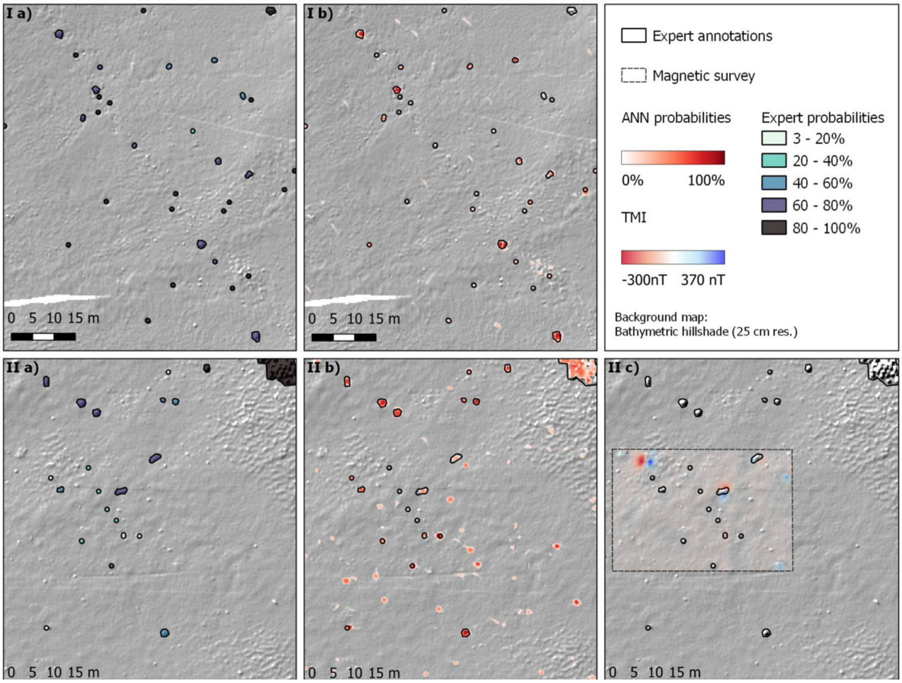

***Figure 2**: The maps show the bathymetric hillshade of the seabed of the munitions dumpsite Kolberger Heide in greyscale. Ia and IIa show how the objects were annotated with probabilities by experts. Ib and IIb show the probabilities generated by the ANN. A magnetic AUV survey revealed that several of the ANN-annotated objects are most likely no UXO (IIc), which means that additional training is required.*

AUV-BASED CAMERA AND MAGNETICS

Once a target list has been prepared, individual target points can be investigated. An AUV-based investigation allows acquiring additional detailed data, while continuing surveying the larger area with a vessel. Accordingly, the technical survey and the investigation of target points can take place simultaneously. In the BASTA project, AUV-based magnetometers and cameras were used to investigate target points. Figure 3 shows one of the GIRONA 500 AUVs that were used during the project.

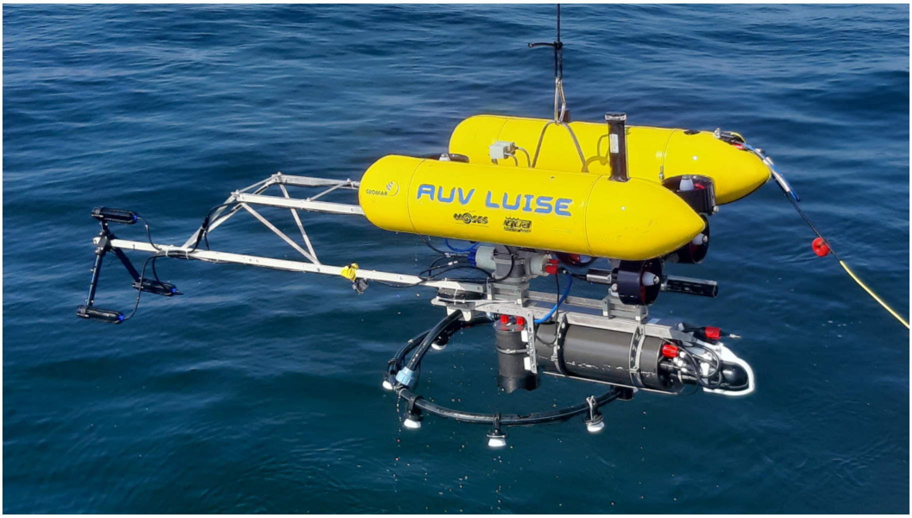

Figure 3: *GEOMAR's GIRONA 500 AUV "Luise" with the integrated magnetic sensors and camera.*

For the visual investigation of target points, a CoraMo mk II Camera was mounted on two AUVs. This downward or forward-oriented camera system for photographic surveys can take up to two images per second with a resolution of 12.34 MP. This allows the generation of high-resolution photo mosaics of the seabed (6). In cases of good underwater visibility, these photomosaics allow identifying, whether objects on the seabed are UXO, other anthropogenic objects or natural objects, such as boulders.

To be able to investigate target points with buried objects, BASTA scientists and technicians installed magnetometers on the AUVs. The magnetic sensors, three SENSYS 3-axis fluxgate magnetometers of the type "FGM3D UW II", were attached to the AUV via an aluminum arm, which allows for a maximum distance of up to 2 m between the sensors and the nose of the AUV. Since the main thrusters of the AUV, which are considered to be the primary source of electromagnetic noise, are located in the back of the AUV, the distance of the sensors to the main thrusters is up to 3 m. Different construction configurations were tested to identify the optimal solution for attaching the magnetometers to the AUV's arm. Arranging the sensors in the shape of a vertical triangle perpendicular to the direction of travel turned out to be the ideal solution. This layout allows for the measurements of all three spatial magnetic gradients. In the triangle, the two lower sensors act as a horizontal gradiometer (first gradient) while the third magnetometer is located above, to act as the upper sensor of a vertical gradiometer (second gradient). The third gradient, is obtained by comparing acquired values while moving forward. The magnetometers are sampling at frequencies of up to 200 Hz. Operational flight altitudes of the system vary between 1 and 1.5 m. During BASTA, surveys were usually conducted at velocities around 0.4 m/s. With the solution, noise floors as low as 2 to 3 nT can be achieved. The setup can therefore be used to reliably detect medium sized target objects such as 81 mm mortar shells. Under favorable conditions, even smaller munition objects like hand grenades may be detectable.

CONCLUSION

During the BASTA project, researchers were able to address requirements that must be met to allow for the seamless integration of technical surveys of larger areas and detailed target point investigations. Data quality factors allow determining, whether the acquired survey data are sufficient for the detection of specific types of UXO. Next, using a well-trained ANN enables surveyors to instantly generate a target list, with points that require further investigation. Finally, AUV-based camera and magnetics make it possible to perform target point investigation, while the survey vessel simultaneously continues with the area survey. Applying these results to commercial maritime UXO surveys has the potential to decrease the costs of future offshore construction projects.

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