3D acoustic imaging in defining offshore UXO risk

Introduction

Historically when defining the risk of buried unexploded ordnances (UXOs) for any marine project the sources of information have been manly limited to desktop studies and magnetic surveys (Offshore & Marine Technology, 2024). Both sources will always be essential in understanding and assessing the risk, however, in some cases, they provide an incomplete picture with gaps in the information (Offshore & Marine Technology, 2024). These gaps in information include knowledge of the size, shape, and depth of burial of any detected target. Due to these gaps in the information, either magnetic targets that should not be investigated are, leading to increasing costs and project delays. Or magnetic targets are overlooked leading to potential UXOs being missed putting risk to the equipment, environment, and life during the future stages of a project. Likewise, with certain UXOs being non-ferrous they would go undetected in magnetic surveys meaning their detection relied solely on desktop studies or seafloor bathymetry imagery if they are situated on the seafloor.

Kraken Robotics Sub-Bottom Imager (SBI) technology has the capability to image sub-surface objects by producing three dimensional (3D) volumetric models based on acoustic impedance variations in the subsurface. Using 3D acoustic volumes, the SBI data can provide further clarity on the subsurface and identified magnetic targets by providing acoustic imagery of the anomalies and surrounding shallow soils. This allows information such as an object's dimensions, shape, depth of burial, and relative acoustic impedance to be established. The inclusion of this information along with desktop studies and magnetic surveys, UXO specialists can make a more informed decision on an object being a potential UXOs (pUXO), reducing potential risk.

Across five projects with a combined total of 1284 magnetic targets, which were surveyed using the SBI, 799 magnetic targets were found to be associated with buried acoustic anomalies and 289 acoustic anomalies were interpreted to be possible UXOs. That means that 995 magnetic targets that would normally require further investigations of unearthing the object, did not require any further investigations which reduced cost, time, risk, carbon footprint. Similarly, where a desktop study identified that non-ferrous UXOs are present in an area, the SBI was used due to the unreliability of magnetometer datasets in detecting these objects. Integrating interpreted non-ferrous UXOs from 3D acoustic data with magnetic datasets shows that interpreted acoustic anomalies that do not correlate with a magnetic anomaly are possibly representative of non-ferrous UXOs. Therefore, without the use of 3D acoustics, non-ferrous UXOs would likely remain undetected.

The Technology

The SBI survey equipment is comprised of 3 chirp sources operating between 4.5 to 12.5 kHz at a firing rate of 45 Hz, along with a 40-channel receiver array which is arranged in an across-track direction. The sources and receivers are mounted onto a frame along with an Internal Navigation System (INS) and Doppler Velocity Log (DVL) (Figure 1). The generated product of this system is acoustic data that are binned into a 0.1 m^3 gridded 3D volumetric acoustic models through the use of synthetic aperture technology. Acoustic impedance variations are imaged using the back scattered energy from discrete anomalies and lithological changes in the sub-surface (Dinn, 2012). This system can be mounted to either a remotely operated vehicle (ROV), towed platform, or a fixed platform where it requires to be continually moved forward, giving a data cross-sectional area of approximately 46.25 m^2 and infinitely long.

During data acquisition, buried objects create diffractions from the transmitted wavefronts, which are received by the multichannel hydrophone array (Figure 2). To discount potential false-positive anomalies, surveys are performed in a 'lawnmower' style pattern providing 200% coverage. The confidence in the interpretation of a discrete anomaly increases when resolved in multiple SBI datasets. Each anomaly is evaluated and assigned a score for shape, size, relative acoustic amplitude, and repeatability to assign it with a confidence score based on the combined score across all variables. These

confidence scores indicate the likelihood of the anomaly being a UXO based off the criteria supplied by a UXO specialist.

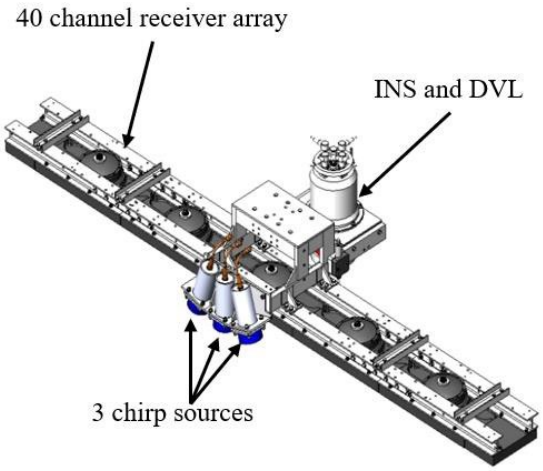

Figure 1 *3D image of the SBI system and its primary data acquisition components (Griffiths, 2024)*

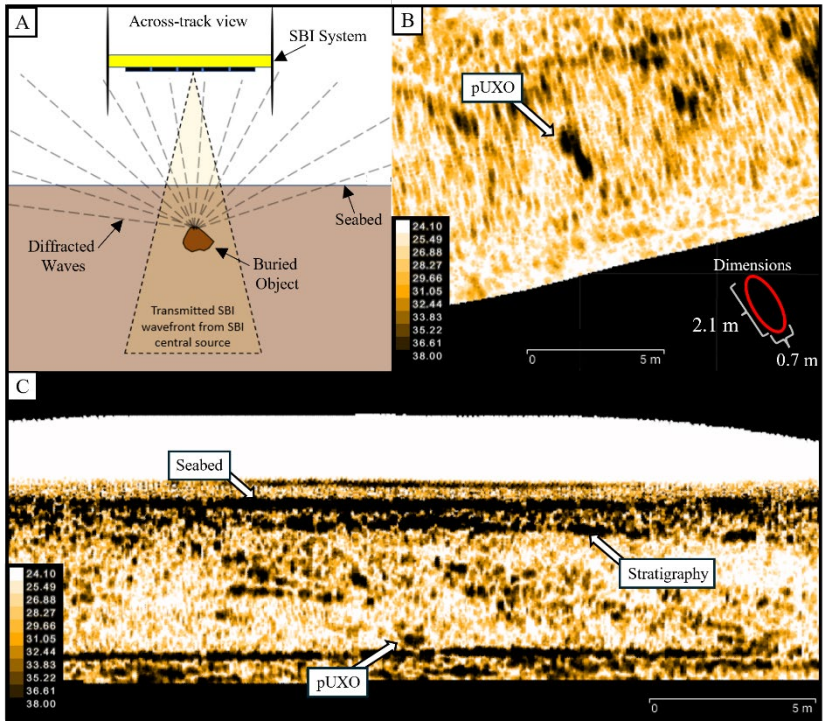

Figure 2 *A) Image of the SBI system mounted on a SeaKite travelling in the along-track direction with the chirp signal from the central source producing a resultant diffraction. B) SBI data plan view of an imaged pUXO that is buried 4.1 m below the seafloor C) SBI along-track view of an imaged pUXO that is buried 4.1 m below the seafloor.*

Magnetic Anomaly Surveys

A total of 1284 magnetic targets were surveyed across 5 different campaigns using the SBI to provide further information such as size, shape, depth of burial (DoB), relative acoustic impedance and acoustic images over the magnetic anomalies that were deemed as pUXO. From interpreting the SBI data, it was found that 799 of these magnetic anomalies had an associated acoustic anomaly present, meaning 485 magnetic anomalies were false-positives where nothing would likely be found during the ROV investigation stage. Of these 799 magnetic anomalies, 286 acoustic anomalies met the predetermined minimum requirements for a pUXO. Magnetic and acoustic anomalies deemed a pUXO by the UXO

specialist were considered for further investigation with an ROV unearthing the anomaly or adapting the future construction plans to avoid the flagged pUXOs (Table 1). Finding the average reduction rate for each target provides an overall magnetic target/pUXO reduction of 84%. This shows the benefits of integrating acoustic imagery with magnetic data, as presented in Figure 3. In Figure 3, three similar magnetic anomalies were all deemed as pUXO. Following an SBI survey, a further assessment of the magnetic anomalies was possible for the UXO specialist.

Table 1 *The overall results of target detection with integrated magnetic and 3D acoustic volumetric data.*

Survey ID	Magnetic Anomalies	Associated Acoustic Anomalies	Interpreted pUXO	Magnetic Anomaly Reduction	Reduction Percentage
1	242	125	76	166	69%
2	39	5	5	34	87%
3	670	454	188	482	72%
4	50	15	2	48	96%
5	283	200	15	268	95%
Total	1284	799	286	998	78%

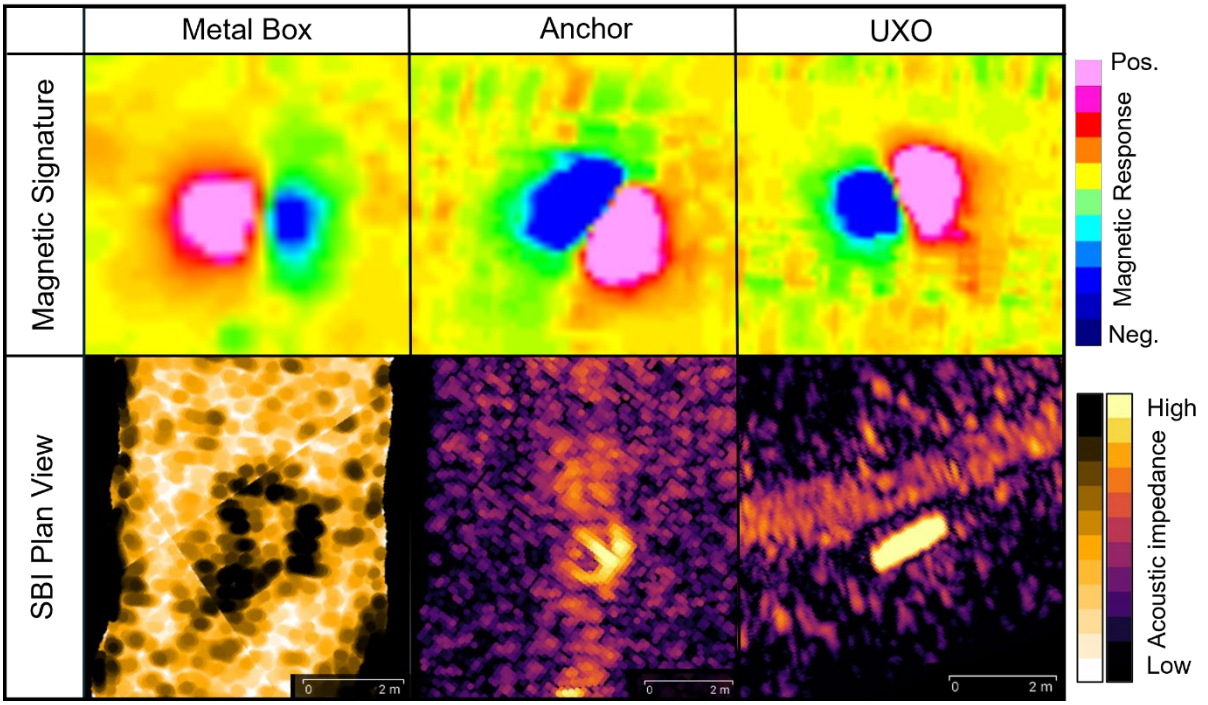

Figure 3 *A series of three magnetic targets flagged as pUXOs with their responses presented in the SBI data.*

Non-Ferrous Anomaly Surveys

Another advantage of using 3D acoustic imagery as part of the UXO detection and risk assessment is the ability to detect non-ferrous UXOs such as Luftmine A and B (LMA/LMB, respectively). With 3D acoustic imagery being one of the only ways to detect these types of UXOs, the SBI was implemented across 8 different campaigns covering approximately 2,900 km^2. A total of 14,868 acoustic anomalies were identified where 1,297 acoustic anomalies met the minimum UXO size and shape requirements (Table 2**)**. From these acoustic anomalies, a total of 212 were marked as pUXOs by a UXO specialist. None of these acoustic anomalies were observed to be associated with any magnetic anomaly and would go undetected without acoustic imagery prior to encountering them during the following construction campaigns.

Table 2 *The overall results of target detection within non-ferrous surveys using 3D acoustic data.*

Survey ID	1	2	3	4	5	6	7	8	Total
Survey Area (km^2)	1945.2	6.3	0.3	0.3	9.2	928.5	10.0	0.1	~2900
Acoustic Targets	437	103	10	23	16	14157	35	87	14868
Acoustic Targets Meeting pUXO Criteria	44	57	2	4	9	927	26	16	1297
pUXO	18	20	1	1	1	166	1	4	212

Conclusions

Prior to engaging the SBI to be used to assess magnetic anomalies in a UXO survey, a survey campaign had interpreted a total of 20,534 magnetic anomalies where 6,002 of those were deemed to be pUXOs. With the nature of the project 1,204 required to be excavated with an ROV for further assessment and removal. It was found that 88 of the magnetic anomalies were false-positives, 854 of the recovered objects didn't meet the size criteria of a UXO and 117 of the objects didn't meet the shape criteria of a UXO. This means a total of 1,059 ROV investigations (~88%) could have been potentially avoided. Integrating interpreted magnetic and acoustic anomalies could have provided the object's size and shape, which may have discounted certain magnetic anomalies being interpreted to represent UXOs. If 3D acoustic data were used for the entirety of the survey campaign, then the overall project cost, time, risk, and carbon footprint may have been reduced.

It is important to note that 3D acoustics should not replace magnetic based surveys, however the 3D acoustic data should be used in conjunction to provide the most information possible and to provide the industry with the best chance of derisking the offshore environment (Morrow, et al., 2014).

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