TEST OF A SUBMARINE TRANSIENT ELECTROMAGNETIC SENSOR FOR UXO CLASSIFICATION BY REMOTELY OPERATED VEHICLES (SUBTEM-ROV)

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Abstract: *A multi-component submarine transient electromagnetic sensor for the detection of unexploded ordnance with a remotely operated vehicle has been developed. This system (SubTEM-ROV) is the latest iteration of an ongoing line of development for the commercial application of advanced EM sensors in the marine realm. It allows to evaluate the geometry of targets and subsequently to classify them as potential UXO based on their characteristic electromagnetic polarizability. The system is presented here along with results of a test survey and comparison to conventional methods. Prior to conducting the survey, the capability of the SubTEM-ROV to distinguish objects of different sizes and geometry was demonstrated during a surrogate item trial (SIT). During the SIT, data were gathered over three items (dummy depth charge, steel tube, steel plate). Measured data were then inverted to determine the three-dimensional polarizabilities of the objects. Based on the inversion results, the items could be clearly distinguished in different orientations and standoffs. The test survey took place across a 50 m x 50 m area close to the island of Minsener Oog in the southern German Bight. This area is part of a region heavily polluted by UXO and other forms of debris. Anomalies indicating the presence of metallic objects have been picked and the data inverted to separate potential UXO from harmless debris. The results are compared to those of a previous single-component EM survey. This test highlights the strengths of the new system and demonstrates the value of a multi-component EM sensor for operations in a site polluted by both UXO and non-hazardous scrap.*

Keywords: *transient electromagnetic sensor, TEM, unexploded ordnance detection, UXO, marine unexploded ordnance, ROV sensor*

1. INTRODUCTION

Unexploded ordnance (UXO), originating primarily from World War II, pose a persistent challenge for offshore constructions in the North and Baltic Sea. The state of the art for UXO detection is multi-component transient electromagnetic (TEM) induction with subsequent inversion for the electromagnetic polarizability (Beran et al., 2011; Billings & Beran, 2017). This parameter relates the dipole vector components of a (secondary) magnetic field created in a target by induced eddy currents to the magnitude of the inducing uniform step-off (primary) field of the transmitter coil. As the induced eddy currents decay over time, the polarizability is given as three time-dependent curves along the principal axes of the target. Polarizability is an intrinsic property of a body which depends on its electromagnetic properties and geometry, but not on the orientation to the sensor. This method has been successfully used on land during the last decade for the identification of buried bodies (Prouty et al., 2011), but has only recently been transitioned to the marine environment (Shubitidze et al. 2008; Song et al., 2016).

In 2015, Boskalis Hirdes commissioned Gap Explosive Ordnance Detection (GapEOD) and Black Tusk Geophysics (BTG) with the development of a commercial multi-component TEM sensor with UXO specific inversion capabilities for marine environments. The first version of this instrument (SubTEM) was installed on a towed platform, while the second version that is the subject of this paper was developed for use by a remotely operated vehicle (SubTEM-ROV). The functionality of this instrument is demonstrated with two tests: First, the ability of the instrument to accurately identify objects of differing geometry is shown during a surrogate item trial (SIT) by comparing the inverted polarizability of three known, isolated objects. Then, results of two surveys in a UXO contaminated area in the southern German Bight, close to the island of Minsener Oog, are compared. Parts of this area were investigated in May 2018 using the Teledyne TSS-440, a single-component TEM pipe tracker that has seen wide-spread usage. In November 2018, a 50 m x 50 m box within the greater area, was re-surveyed with SubTEM-ROV.

2. INSTRUMENTS AND SURVEY

Both sensor arrays were attached to the same Schilling HD W-ROV, operated by pilots on board the Boskalis vessel *Smit Kamara*. Sensor positioning was provided by a Sonardyne USBL system, and altitude measured with a Tritech PA500 altimeter.

<u>SubTEM-ROV</u>

The sensor array consists of five horizontal 1.8 m x 1.8 m transmitter (Tx) coils in two rows of three, resp. two, coils, and 19 three-component (x, y, z) receiver (Rx) cubes arranged in a regular pattern across the array (Figure 1). Tx currents are set to achieve 300 Amp turns. Rx voltages are normalized by the coil area and the Tx current and given in values of nT/s/A.

Before surveying the area of interest, the responses of three test items (steel tube, dummy depth charge and steel plate) were evaluated. For this test, the items were placed in a line on the seafloor with 5 m distance between them; if applicable, the long axis of the item was oriented parallel to this line. The sensor was first moved along the line four times with variable altitude of 1 m, 1.5 m, 2 m and 2.5 m. After that, the test was repeated across the steel tube and the dummy depth charge on lines perpendicular to the first (as the steel plate is horizontally isometric, it was not measured again).

The subsequent field survey with SubTEM consists of 12 profiles oriented roughly east to west with a nominal height above ground of 1 m at 0.3 kn. The raw data were leveled, and the background response subtracted by applying a running mean filter. The inversion algorithm makes use of responses recorded between ca. 100 and 10,000 µs after Tx shutdown.

Figure 1: SubTEM-ROV deployment

Teledyne TSS-440

The Teledyne TSS-440 consists of three 1 m x 0.94 m coils which function both as transmitter and receiver. Tx currents are limited to 20 A. Rx voltages are given directly in values of µV. The TSS-440 survey consists of 25 parallel profiles with a nominal height above ground of 0.5 m at a speed of 0.4 kn. Raw data were processed by applying positional filters to de-spike recorded USBL coordinates of each coil and reject all data measured higher than 0.65 m altitude above ground. EM data were likewise de-spiked, and the average background response subtracted. The TSS-440 provides two values for each measurement, one for the early time and one for the "standard" response (300 µs to 400 µs after Tx shutdown). The latter one was used for evaluation.

3. RESULTS AND DISCUSSION

Results of the SIT are shown in Figure 2. The steel tube exhibits a polarizability pattern typical of a ferromagnetic cylindrical object, with one relatively high value along its long axis and two lower values associated with the short axes. The dummy depth charge has a more compact build and more complex internal structure, which results in approximately equal polarizabilities along all three axes. Finally, the signature of the steel plate consists of two relatively high polarizabilities along the horizontal and a smaller one along the vertical axis. These results are consistent regardless of the orientation of the target.
Reference curves like these, taken from actual UXO, can also be stored in a library and used for an automatic matching and classification routine.

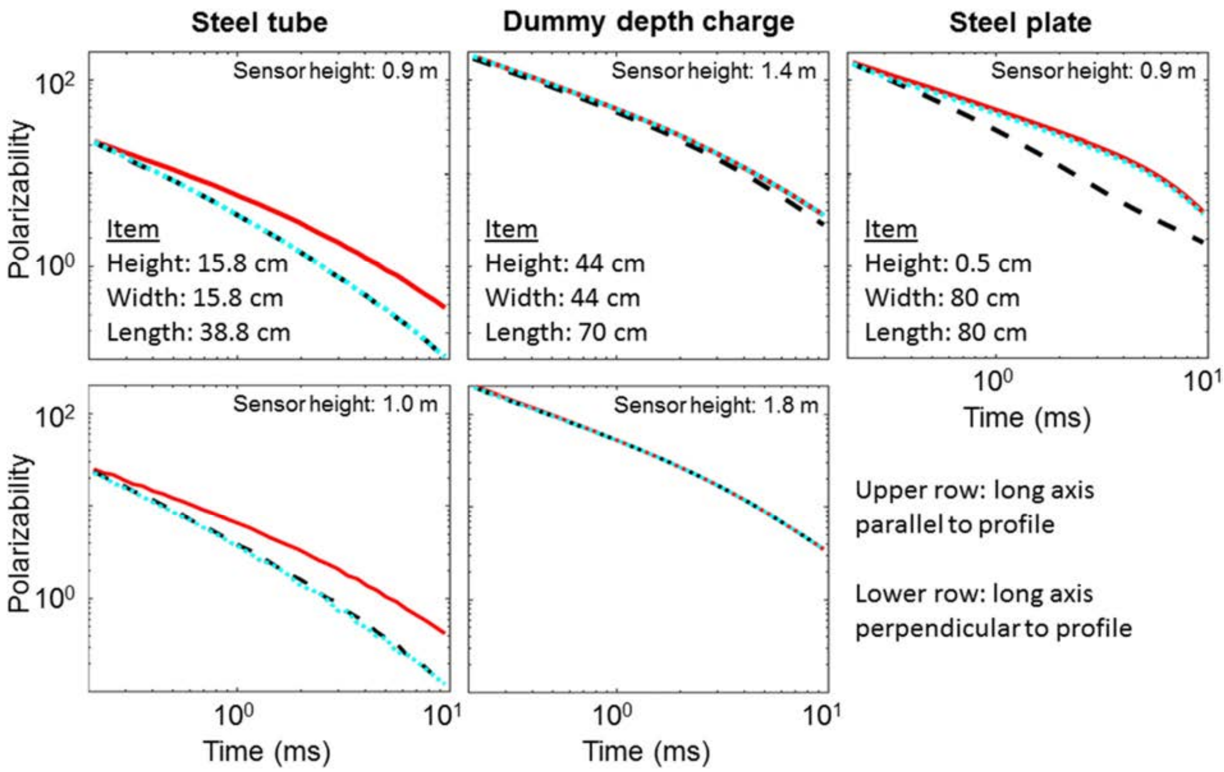

Figure 2: Examples of the inverted polarizabilities along the primary axes of the three test items.

The results of the test survey are shown in Figure 3. The processed TSS-440 data have a base noise level of about +/- 20 µV; it is usual practice to consider positive anomalies larger than twice the noise level as valid targets. In total, 16 suspicious anomalies were identified. One of these was cleared as part of sampling campaign to assess the regional UXO contamination in June 2018. The excavation revealed metal debris, which was identified as remnants of a ground mine.

During the SubTEM-ROV survey, 14 relevant anomalies were detected. The direct comparison shows that while most of the larger anomalies are stationary – as would be expected for a deeply buried object – some of the smaller anomalies detected in May did not appear again in November. Likewise, a number of new small-scale anomalies were detected with SubTEM-ROV, that did not appear during the TSS-440 survey. A part of these could be explained by the performance of the two systems, e.g. differences in the data acquisition, the higher detection range provided by the larger SubTEM-ROV transmitters and the greater spatial resolution achieved by the higher number of receivers. However, the area also has a highly dynamic tide-induced seafloor morphology, and small surficial debris can easily be transported with the currents.

Upon closer analysis, only one of the 14 anomalies detected with SubTEM-ROV displays a polarizability that can be associated with an intact, cylindrical UXO. All other objects appear to be either plate-like or random in their geometry; examples with best matches from the currently implemented UXO library are shown in Figure 4. In an actual UXO disposal campaign, this kind of information would drastically reduce time and cost requirements. In addition, remote classification by matching measured responses to an extensive library of known ordnances would allow for a better risk assessment before an excavation. The adaption of this technology to an ROV provides a high degree of flexibility in the operations, as the survey of a small area and excavation of potential UXO can be done in a single dive. A drawback of using an ROV would be the relatively small sensor footprint and the requirement of a suitable support vessel, trading high data quality and discrimination capability for the ability to survey large areas in short times and at low operational costs. Overall, the performance of SubTEM-ROV is excellent.

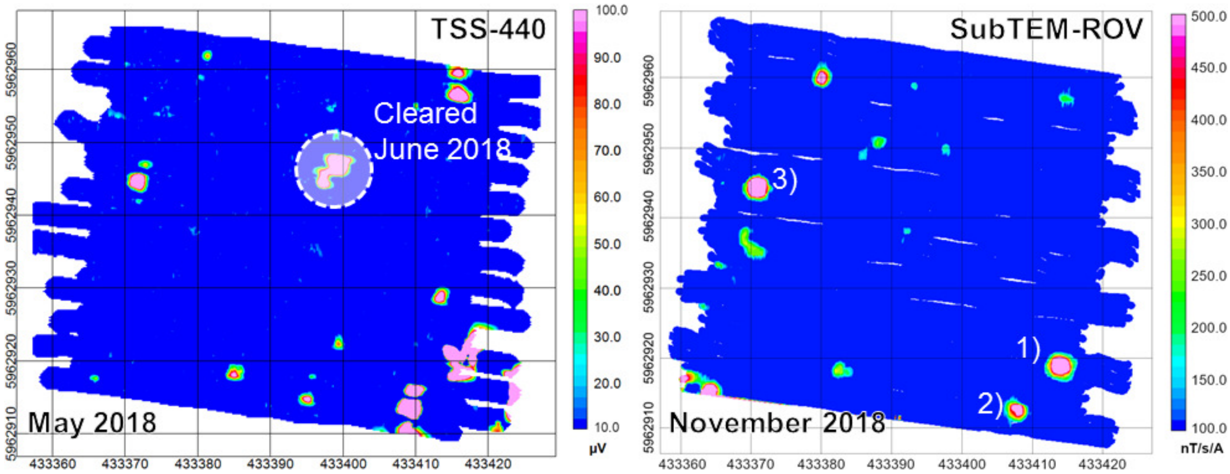

Figure 3: Comparison of the TSS-440 and SubTEM-ROV surveys. TSS data are recorded within the 300 µs to 400 µs time gate, SubTEM data show the 100 µs to 1000 µs time gate of the vertical field components in a monostatic Tx/Rx selection. One anomaly was cleared before the SubTEM survey took place; all other TSS anomalies would be considered valid targets. Closer analysis of SubTEM data reveals only one potential UXO (No. 2, see Figure 4).

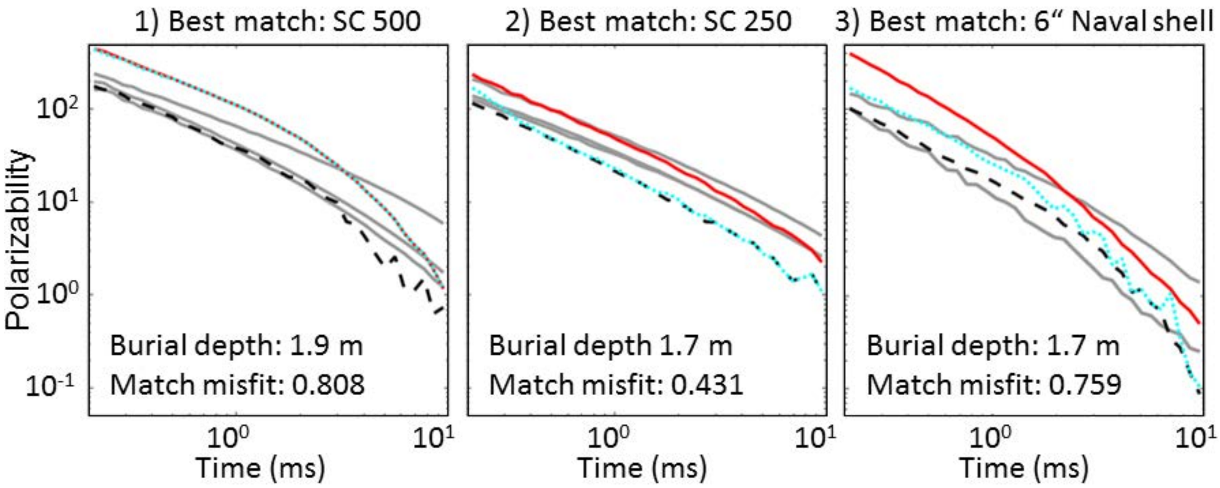

Figure 4: Examples of inverted polarizabilities and best matching library item for 3 anomalies. None of the items are a close match to the currently available UXO library. No. 1 appears to be plate-like, No. 2 cylindrical (UXO-like), No. 3 irregularly shaped.

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