COMBINE MAGNETIC GRADIOMETER WITH ROV TO IMPROVE UXO SURVEY CAPABILITY

Qizheng Yang (Huawei Marine Networks Co., Ltd)
Email: yangqizheng1@huawei.com

Huawei Marine Networks Co., Ltd, 5/F, MSD-B2 Tower, 62 Second Avenue, TEDA, Tianjin, China ZIP: 300457.

Abstract: Unexploded Ordnance (UXO) survey is not usually compulsory for submarine cable system. However, it becomes extremely critical when the submarine cable has to cross the UXO risk zone. Magnetometer and gradiometer surveys are conducted using towed arrays as a traditional UXO investigation technology, which has poor flexibility, low timeliness and is more easily affected by seabed morphology as well as sea conditions.
This paper studies an alternate method that combines magnetic gradiometer with Remotely Operated Vehicle (ROV). This method provides improved manoeuvrability and accuracy compared with the traditional towed technology. Close-up examination of seabed can be achieved which benefits from the mobility and stability of ROV. The feasibility and practicalities of this approach are discussed to provide an alternative solution for UXO survey.

1. INTRODUTION

With the development of the global telecommunication, submarine fiber optic cables have been concerned by more and more counties due to the high relevant between submarine communication and the prosperity and development of the economy. When submarine fiber optic cable has to entry UXO risk zone, the UXO from a war including bombs, bullets, shells, grenades, land mines, naval mines, etc. would pose high risk to geotechnical survey, submarine cable installation (including divers, plough, vessel, crew, etc.) and submarine cable maintenance during whole lifecycle. Therefore, UXO survey for submarine fiber optic cable has been an important part in evaluating the security of marine operations in UXO risk region.
Both the location and size of the UXO in formerly used military test ranges, dump sites and historic battle sites precisely identified during survey will not only play a key role to minimize unnecessary diver inspections during subsequent operations for UXO removal, but also provide an effective basis for route design and cable installation. This article introduces the usage of the magnetic gradiometer for UXO survey in a recent project, analyzes the advantages of ROV and its development in marine engineering survey field, discusses an improved method that combines magnetic gradiometer with ROV and studies the feasibility and practicality of this approach to provide an alternative solution for UXO survey.

2. TOWED GRADIOMETER METHOD

According to the research of the terrestrial magnetic field, the terrestrial magnetic field could be regarded as a magnetic dipole which located in the center of the earth and skew with the Earth’s rotation axis. Therefore, the terrestrial magnetic field is distributed on the whole earth surface and the strength of the magnetic field will be different with the passage of time and space variation at the same time. However, in the engineering field, the study areas what we focus on would be regarded as a very narrow scope compared with the scale of the earth surface. Stable distribution of the terrestrial magnetic field in this area is assumed. In the space with non-disruptive of ferromagnetic materials, the strength of magnetic field in this area will be the same as the strength of the terrestrial magnetic field, which is seen as the background field. When ferromagnetic materials is present, the secondary magnetic field will be produced around them due to the influence of the terrestrial magnetic field magnetization, meanwhile, the magnetic anomaly will be detected. Based on this theory, the location and the size of UXO can be recognized by magnetometer through its magnetic anomaly data acquisition, processing and imaging. [2]

Towed gradiometer has been mainly applied to the UXO survey for submarine fiber cable in recent years. Usually it is consisted of two or more magnetometer to eliminate the influence of daily change, decrease the noise produced by the swells and improve the efficiency of magnetic objects detecting. Transverse gradiometer has the ability to reduce the towed water depth to minimize the security risk of the equipment and longitudinal gradiometer has the advantage to mitigate the influence of other geological body and highlight the location and size of the magnetic UXO. Due to these characters transverse and longitudinal gradiometer are widely used in UXO survey. [1]

A type of gradiometer are illustrated in figure 1.

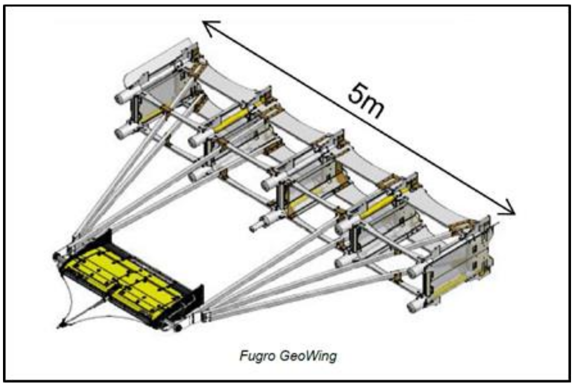

Figure 1: Gradiometer from Fugro [4].

Compared with other traditional magnetometer method, the gradiometer has the following advantages: 1) Not only suitable for magnetic anomaly detecting, but also can obtain the magnetic gradient anomaly to gain the higher precision UXO data. 2) The complicated and composite magnetic anomaly will be divided into several single consistent units of magnetic field through the magnetic gradient anomaly in the UXO survey. Under the condition of the same ambient field, eliminating the magnetic gradient of the large scale region can confirm the detail magnetic anomaly of the UXO location accurately. 3) Two or three dimensional data images can be generated to clearly find the UXO on or under the seabed by gradiometer during the survey stage. [3]

In a recent project of Huawei Marine, according to the UXO DTS, UXO survey were required at 9 of total 14 landing point and completed from a point 50m inland of the BMH to the 20m water depth contour incorporating elements of the landing site topographical survey, diver swim and marine geophysical surveys. Two of total 9 landing points that are required to conduct UXO survey are selected as the example and the survey line of the magnetic gradiometer from 3 to 20m water depth is showed in Table 1.

Landfall	3 – 20m Water Depth	
	Corridor Width (m)	No. Line
A point	50	11
B point	300	61

Table 1.UXO Detection Survey Summary

After UXO DTS, suitable width of survey corridor were pre-planned considering about the safe operation space and 5m space for the adjacent survey lines was recommended to obtain the high accuracy date. (300m corridor in B point is expanded due to the high density and risk of the UXO).

Fugro Geowing was selected as the main UXO survey equipment. The Geowing is a

5m wide, vertical and transverse gradiometer array which is operated using an EIVA ScanFish Katria III ROTV with 3D steering. The Geowing was deployed from the stern of the vessel using the vessels A-frame and controlled using a remotely operated winch.

The ScanFish and therefore the Geowing has the ability to maintain a constant height above the seabed, thus allowing the frame and mounted magnetometers to be towed at a constant altitude. The Geowing has 5 magnetometers set 1.5m apart. The frame had been equipped with multiple Geometrics G882 magnetometers. Sensors spacing was 1.25m horizontally and 0.5m vertically. The ability of the ScanFish to track the seabed and keep in-line could reduce to a minimum number of horizontal and vertical infills. Five industry-leading Geometrics G-882 marine magnetometers were mounted on the frame.

These sensors chosen for their proven reliability, offer precision of up to 0.004 nT and rapid sampling rates of up to 20 Hz. The Geowing is fitted with a 500 kHz altimeter to record accurate height above the seabed. Primary positioning used the HiPAP USBL system. No manual layback as a secondary back up method was used for the offshore operations with the Geowing. USBL transceivers were attached to the Geowing at a measured offset to the survey sensors; and this value was entered into MagLog. Accurate real time positioning of the survey sensors then was provided from the USBL via QINSy. The data was recorded in MagLog Interpolator (.INT) files. These files included the following fields: Date, Time, Line Number, Latitude, Longitude, Signal, Altitude, Magnetometer Total Field and Layback.

The EIVA ScanFish Katria III and frame were towed from a single Cormac 2 winch with armoured tow cable, the bespoke flight control software could then control the height of the ROTV and associated magnetic sensors in a terrain following mode. Add to this higher tow speeds compared to conventionally towed magnetometers, a more accurate and comprehensive data set as the magnetometers were in the fixed frame of the Geowing. For this survey an altitude above the seabed in the range of 2 to 5 m to minimize infill and maximize overall survey efficiency, overlap the outer sensors on adjacent lines were conducted.

After survey data was imported into the Oasis Montaj software package whereupon basic filters and navigation checks were carried out. As all sensors were towed at the same altitude, biases in the data would not be introduced due to varying distances from the seabed. In addition, the triangular configuration allows the direct computation of the three vector gradients of the total magnetic field.

Diurnal effects and changes in the Earth's magnetic field had a limited influence on the data as magnetic field values from each sensor were subtracted from one another to create the component vector gradients. Long wavelength anomalies, often indicative of background noise and geological interference were removed from the dx, dy and dz gradient grids with short-wavelength high-amplitude anomalies, often indicative of ferrous debris, left remaining.

The analytic signal grid could then be produced from the vector components using the following equation:

$$\text{analytic signal grid} = \sqrt{(\frac{dt}{dx})^2 + (\frac{dt}{dy})^2 + (\frac{dt}{dz})^2} \qquad (1)$$

Finally, a Blakely test was carried out to model any identified targets and calculate sizes, apparent weights and depth of burial. [4]

In comparison, towed gradiometer has limited capability to detect UXO and reject clutter. It cannot keep a stable distance between the equipment and the seabed and it can also be affected by the severe weather because of the lack of the control. When survey is conducted in the steep slope area, due to the bad controllability it is a high probability for the equipment to collide with slope, seamount, and rock… to damage the device. And then it would affect the accuracy of the data, the expense of the survey work and the delivery date of the whole project.

3. REMOTELY OPERATED VEHICLE (ROV)

ROV has been developed since 1950s. The first tethered ROV of the world called POODLE was invented in 1953 by Dimitri Rebikoff a French engineer. The United States Navy advanced the technology and conducted some at-sea tests about the underwater ordnance recovering in the following years. In 1966 "Cable-Controlled Underwater Recovery Vehicle" (CURV) that was funded by the US Navy recover a nuclear bomb lost in the Mediterranean Sea after the Palomares B-52 crash cooperated with the manned submersibles ALVIN. And then saved the pilots of a sunken submersible off Cork, Ireland, the Pisces in 1973, with only minutes of air remaining. ROV technology has been paid close attention and developed gradually to be widely used in many different fields.

Survey vessel is usually used as the mother ship for ROV operation and different kinds of equipment and sensors can be loaded and installed in the platform of ROV. Meanwhile, with the flexible great water depth submarine moving ability and advanced underwater dynamical, control and mechanical system, ROV can reach very deep water and unsafe area that diver cannot arrive in to conduct submarine monitoring and other kinds of survey works. At the same time, it has become one of the most advanced survey equipment in the modern marine geology survey due to its economy, safety, high working efficiency, severe environment working ability and unprecedented range and endurance. [5]

ROV has been used in many marine geological and environmental survey works gradually in recent years. Such as sediment site sampling, seawater sampling, in-situ test for temperature, salinity, heat flow and any other parameters, through high resolution real time monitoring and video or photo capture function to obtain the information of the topographical feature of the seabed, detect the biological activities and gain the photo, video data of the deep area. In addition, real time monitoring, installing, checking and repairing for other regional submarine survey equipment like submarine observation network can also be achieved by ROV.

4. GRADIOMETER FRAMED ON ROV

Based on the above-mentioned theories and method about gradiometer and ROV, gradiometer mounted on a ROV can be applied to the UXO survey field of submarine fiber optic cable in order to take the best of both approaches. This method can efficiently resolve the UXO survey operation under the condition of varied topography, lack of controllability for towed gradiometer and so on to obtain high accuracy survey data. Cameras on the ROV also ensure visual coverage of the seabed. It has been applied to the gas and oil pipeline UXO survey gradually in the recent years.

In Nord Stream gas pipeline project linking Russia and Germany the state-of-the-art equipment multi-channel surveys have been used to identify a small number of targets as conventional munitions in geophysical survey. And UXO survey was conducted by a ROV with a 12-sensors gradiometer which is 6.7m width in 25m survey corridor and the locations of these objects were recorded. It detects ferrous materials on the seabed in order to minimize the risks associated with munitions dump sites and mines. Meanwhile, due to its high-range capability the gradiometer array can detect buried objects that may have penetrated the soft sediments. Cameras on the ROV also ensure visual coverage of the seabed. The gradiometer data is processed within a digital terrain model to record objects for further visual inspection. [6]

Gradiometer array with 12-sensors framed on a ROV is illustrated in figure 2.

Figure 2. Gradiometer framed ROV for Nord Stream Project [6]

Figure 2. Gradiometer framed ROV for Nord Stream Project [6]

The figure 3 shows the munition density distribution in Gulf of Finland that came from Nord Stream based on the DTS, geophysical survey and UXO survey. The red, green and blue represent the high, middle and low risk UXO area respectively. Through the high quality gradiometer data processing, the most suitable cable route in Gulf of Finland was selected for Nord Stream gas pipeline.

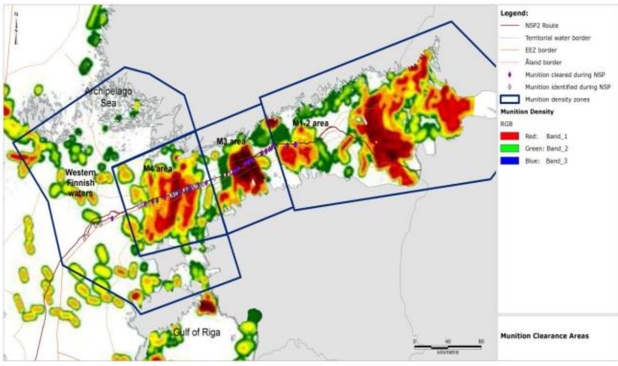

Figure 3. UXO sensitivity assessment zones in Finnish part of the Nord Stream Project route [7]

5. CONCLUSION

As the world continues to develop, there will always be the potential for submarine fiber optic cables to have to cross potential UXO area. In this paper, based on a recent project, the application of gradiometer and the data processing procedure have been reported. Meanwhile, we also described the development of ROV and the advantages for ROV using in the marine engineering area. In this study, the method that combines magnetic gradiometer with ROV was attractive and effective to apply to the pipeline UXO survey. The feasibility and practicality of this approach are studied to provide an alternative solution for submarine fiber optic cable UXO survey especially in complex seabed area.

6. REFERENCES

[1] Liang P Y, Cai L R, Guang L C, et al. Principle of marine magnetometer and specification comparative analysis[J]. Marine Sciences, 2005.
[2] Wang S Q, Huang Y J, Feng-Sheng L I, et al. Research of Magnetic Gradient in Detecting Trenchless Metal Pipe [J]. Chinese Journal of Engineering Geophysics, 2005.
[3] Xing X U, Gong Y H, Wang G X, et al. Application of the Marine Magnetic Gradient Measurements to the Exploration of Gas Hydrate [J]. Marine Geology & Quaternary Geology, 2005.

[4] Fugro Proposal for Provision of Cable Route Survey Services [R]. 2017.
[5] Sheng Y, Tan Y, Chen Z, et al. The Application of Haishi ROV to Regional Geological Survey in China [J]. Marine Geology Frontiers, 2013.
[6]https://www.nord-stream.com/press-info/images/rov-remotely-operated-vehicle-with-12-sensor-gradiometer-array-being-launched-2712/.
[7] Marine mammals in Finnish, Russian and Estonian waters in relation to the Nord Stream 2 project. [R]. 2017.

