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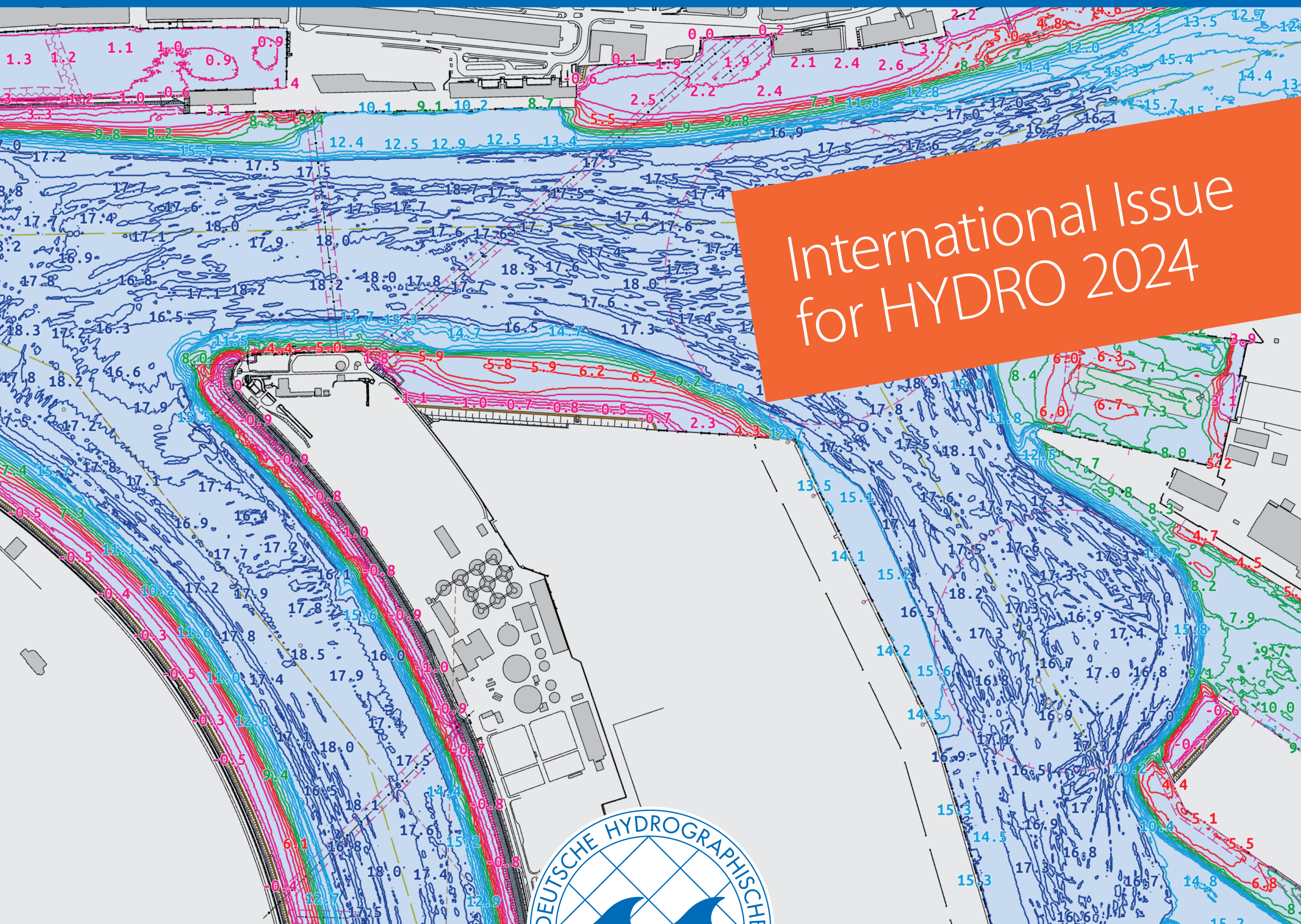

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Combined technologies for 3D cable tracking

Integrated data acquisition of a 3D sub-bottom profiler and an array of magnetometers

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With an increasing number of offshore cables being installed, depth of burial (DOB) surveys are an important and regular task. DOB surveys determine the exact position and burial depth of the cable immediately after dredging and later at regular intervals throughout its lifetime. Innomar and Aquadyne have combined forces and technologies to use the positioning and real-time guidance information provided by Aquadyne's MagTrack magnetic cable tracking system to efficiently acquire acoustic data using Innomar's sixpack sub-bottom profiler (SBP) to produce a three-dimensional visualisation of the subsea environment around a cable in a single pass along the target. This paper summarises user requirements for DOB surveys, discusses the technologies used and presents encouraging field data from initial trials. The application of the methods presented is not limited to cable DOB surveys, they can also be used for pipeline surveys or other activities during construction and maintenance of offshore structures.

cable tracking | 3D sub-bottom visualisation | parametric acoustics | magnetometer | buried object localisation
Kabelverfolgung | 3D-Visualisierung des Meeresbodens | parametrische Akustik | Magnetometer | Lokalisierung vergrabener Objekte

Da immer mehr Offshore-Kabel verlegt werden, sind Vermessungen der Verlegetiefe (DOB) eine wichtige und regelmäßige Aufgabe. DOB-Vermessungen bestimmen die genaue Position und die Vergrabungstiefe des Kabels unmittelbar nach der Ausbaggerung und später in regelmäßigen Abständen während seiner gesamten Lebensdauer. Innomar und Aquadyne haben Kräfte und Technologien gebündelt, um die Positionierungs- und Echtzeit-Führungsinformationen des magnetischen Kabelverfolgungssystems MagTrack von Aquadyne zur effizienten Erfassung akustischer Daten mit dem Sub-Bottom-Profiler (SBP) sixpack von Innomar zu nutzen und eine dreidimensionale Visualisierung der Unterwasserumgebung um ein Kabel in einem einzigen Durchgang entlang des Ziels zu erstellen. Dieser Beitrag fasst die Anforderungen der Nutzer an DOB-Vermessungen zusammen, erörtert die eingesetzten Technologien und präsentiert ermutigende Felddaten aus ersten Versuchen. Die Anwendung der vorgestellten Methoden ist nicht auf Kabel-DOB-Vermessungen beschränkt, sondern kann auch für Pipeline-Vermessungen oder andere Aktivitäten während des Baus und der Wartung von Offshore-Strukturen verwendet werden.

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DOB survey requirements

Cables are often buried in the seabed to avoid damage from ships, waves, anchors or other impacts. The depth of burial depends on the location of the cable and is typically between one and three metres. In areas of heavy fishing or very dynamic seabed morphology, burials of up to ten metres or additional rock placement may be necessary.

The requirements for cable position density along the cable route depend on the type of survey. Immediate post-laying surveys need positions at least every metre, whereas maintenance surveys typically demand positions every 50 to 200 metres. For cable tracking systems, a position density of up to 25 cm may be required. Horizontal (XY) cable position accuracy requirements are mainly based on the accuracy of the positioning system used. Depth of burial (Z) accuracy requirements vary from 5 % of the sensor tilt range to 10 % of the depth of burial with limits of 5 to 10 cm r.m.s. For a sensor two metres above the seabed and a cable buried two metres below the seabed, these requirements give a vertical accuracy of 20 cm (Wunderlich et al. 2016).

Operating costs depend mainly on the cost of the vessel, so the survey time must be as short as possible. If a high position density is required, the cable detection system must run along the cable route and cover a wide swath across the route. It should also guide the vehicle steering along the cable to ensure that the cable does not fall out of the survey corridor. Cable positions are often required immediately after trenching, so good online data visualisation is essential for quality assurance and fast on-board post-processing with full positional accuracy.

Equipment

There are several types of equipment used for DOB surveys, mainly electromagnetic (EM) or acoustic sensors. EM cable locators either detect the magnetic field of an energised cable (passive mode) or emit an EM pulse and detect the presence of metal objects within the field generated (active mode). In either case the cable is located by triangulating two or more EM sensors. This gives the XYZ position of the cable, but the depth of burial also requires the position of the seabed, which is typically determined by multibeam echo sounders (MBES). The accuracy of the cable position depends on the distances between the sensors and to the cable, with typically less accuracy in Z (depth) than in XY. Acoustic sensors emit sound pulses and detect material changes within the sonified volume. They can therefore detect both, the cable and the seabed at the same time and determine the burial depth. Another advantage is that it does not matter whether the cable is energised or not. The resolution and therefore the accuracy of the cable position is limited, but typically better in Z than in XY. It therefore seems to be a good idea to combine the two technologies and obtain a common dataset.

In this study we used an Innomar sixpack SBP, an Aquadyne MagTrack cable tracker, a Kongsberg Seatex MRU-5 motion sensor (providing heave, roll and pitch data) and a Septentrio dual-antenna GNSS positioning and heading sensor. Further details of the acoustic and magnetic sensors are given below, and Table 1 summarises both sensors.

	Innomar sixpack SBP	Aquadyne MagTrack
Sensor type	acoustic projector / hydrophone	3-axis magnetometer, 2-axis inclinometer
Number of sensors	6	2 / 4 / 8
Sensor separation	adjustable, typ. 0.25 … 0.5 m	1 … 10 m
Range below sensor	0.5 … 20 m	0.5 … 20 m (*)
Range resolution	5 cm	4 cm at 4 m range
Frequencies	100 kHz / 4 … 15 kHz	10 … 1,000 Hz
Beam width	circa 5° × 5°	n/a
Depth rating	surface	500 m / 1,500 m / 4,500 m
Sensor bearing angle to cable	n/a	30° … 150°; ideal 90°

Table 1: Acoustic and magnetic sensors utilised in this study
(*) depending on sensor baseline and current in the cable

Sixpack sub-bottom profiler

The sixpack SBP uses a rigid linear array of six transducers (combined projector and hydrophone) with adjustable spacing to optimise the overlapping footprints of the individual sound beams depending on water depth and location. The acoustic data is recorded together with all the auxiliary sensor data (position, heading, motion) in the same data file. To minimise reverberation and ambiguity, short narrow-beam, low-frequency sound pulses are generated using the principle of non-linear (parametric) acoustics (Lurton 2002). The use of multiple narrow-beam projectors and hydrophones aligned across the cable route reduces ambiguity in the dataset (Wunderlich et al. 2016). The sixpack SBP model is mainly used for

- high-resolution 3D visualisation of buried objects in archaeological projects (Missiaen et al. 2018; Pydyn et al. 2021),
- for site surveys and route surveys, searching for boulders and UXO (Barradas et al. 2022; Ouglov 2022)
- and for the mapping of buried pipelines and cables.

The Innomar multi-transducer SBPs have been on the market for a number of years and are constantly being improved. The latest generation with a new multi-channel data acquisition and improved processing algorithms, provides significantly increased data resolution, which also improves cable detection capabilities.

MagTrack cable tracker

The newly developed MagTrack is a passive cable tracker system with four small sensors, each containing a three-axis magnetometer and an inclinometer. It can accurately locate cable positions, typically in front of and behind a ROV or trencher (Fig 1).

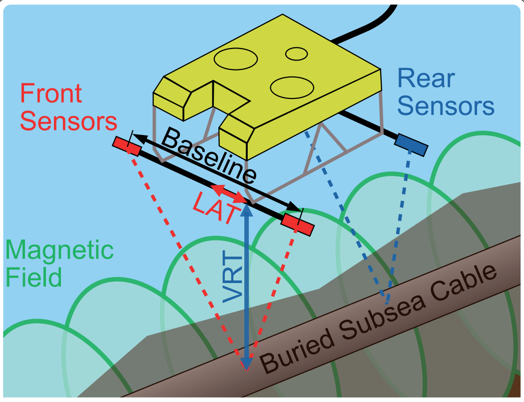

Fig. 1: MagTrack principle mode of operation in a typical four-sensor setup, building two independent cable trackers. Important distances are highlighted: sensor spacing (baseline), lateral cable offset (LAT) and vertical cable offset (VRT)

The system has been used on a variety of cable types including:

- fibre-optic cables, with a tone injected to the fibre protection tube inside the cable, Baltic Offshore used the MagTrack system for positioning;
- high voltage direct current (HVDC) and high voltage alternating current (HVAC) cables with either a separate or integrated return path, Reach Subsea has used several MagTrack systems on various cables for several clients including Nexans and NKT;
- 3-phase cables.

The MagTrack sensors detect a magnetic field generated by an energised cable and measure the XYZ components of the field. These measurements are then converted in the Subsea Electronics Module (SEM) to a direction towards the source of the field, i.e. the cable. The position of the cable is then calculated and displayed on the operator's graphical user interface (GUI) as the depth below the sensors (VRT) and the distance off track (LAT). This allows to steer the vehicle along the cable. Cable position and raw magnetic data can be recorded for quality assurance and post-processing.

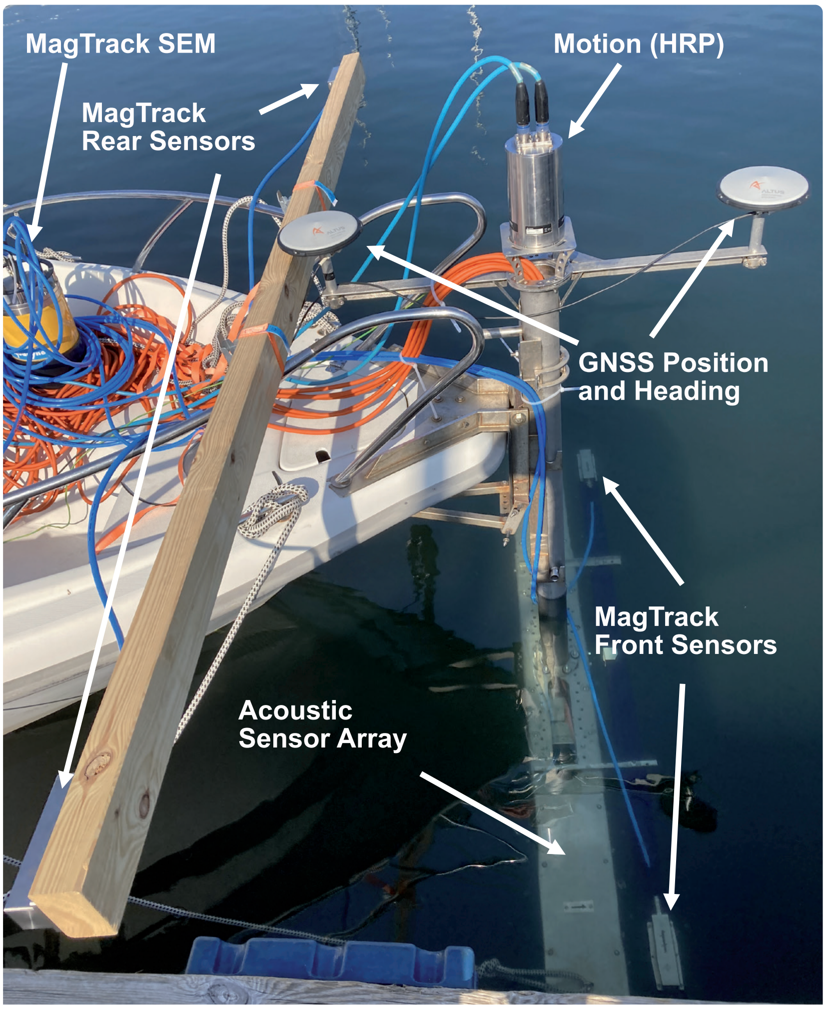

Fig. 2: Experimental sensor setup

The MagTrack system works well with currents of a few amps either from a single phase (one conductor) or from an unbalance between the phases in a three-phase cable. For high-voltage DC cables, the system is set to ignore the DC current and look for ripple frequencies from the rectifiers at 300 Hz. In fibre optic cables, the fibres are often protected by stainless steel tubes, which can be used to inject a low-frequency tone to make the cable detectable. Often this armour has a relatively high impedance, 150 to 250 ohms/km. For long cables it can be a challenge to drive a suitable current of more than 1 amp through this resistance. Tone generators with high voltage output (several thousand volts) may therefore be required for good detection of existing cables. For new cable designs the electrical impedance of the tubes should be minimised. Copper foil or tape wrapped around the fibre protection tube is commonly used for this purpose.

Sea trials

As both systems, the sixpack SBP and the MagTrack, are proven sensors for DOB surveys, the aim of this case study was to evaluate whether both sensors could be used simultaneously on a small surface vehicle. The sea trials for this study took place on three separate days in August 2024 off the coast of Rostock-Markgrafenheide on two near-shore power export cables connecting the Baltic 1 and Baltic 2 wind farms to the grid. The three-phase cables, which are operated by 50Hertz, are 25 cm in diameter (50Hertz 2012).

The sixpack acoustic sensor array and the front pair of the MagTrack sensors were mounted at the bow of a small survey boat. The motion, heading and position sensors were installed on the same pole, aligned with the centre of the acoustic array. The rear pair of the MagTrack sensors was mounted above water level on the deck or on the roof of the boat to reduce the potential noise from the SBP array. The sensor setup is shown in Fig. 2. Both systems were monitored in real-time to ensure quality and efficiency of data acquisition. All data was time-stamped and recorded on the same computer for post-processing.

The probability of cable detection and the accuracy of the MagTrack cable location depend on the signal-to-noise ratio (SNR) of the cable's magnetic field at the sensor positions and the distance between the sensors (baseline) used for triangulation. The SNR depends on the magnetic field strength of the cable (signal) and the strength of other magnetic fields (noise), e.g. from electrical equipment, such as motors and transformers, at the sensor positions. The field strength of the cable at the sensor position decreases with increasing distance and increases with increasing electrical current in the cable.

To ensure optimum boat operation, days with minimal wind have been selected. However, low wind speeds result in less power from the wind farm and therefore less current in the cable, making detection more difficult. In a perfectly balanced three-phase cable the field from each phase is 120° apart from the other two phases, resulting in a magnetic field that cancels each other out. However, the load is rarely 100 % balanced and the cables are not perfectly symmetrical. Therefore, a detectable field will still be present even from three-phase cables, but at a low field strength.

The distance between two grouped MagTrack sensors, the baseline, determines the angle between the sensors and the cable, which is ideally 90°. In the survey area of this case study the water depth ranges from 5 to 6 metres and the cable's burial depth was expected to be around 1 metre. The front MagTrack sensors had a baseline of 1.9 m (angle approximately 20°), while the rear sensors were spaced 2.9 m apart (angle approximately 30°). At the given distance from the cable the baseline should be increased, but with a stable survey platform and a strong magnetic field, even a 20° angle may be sufficient.

Electromagnetic noise can be reduced by avoiding using equipment that operates at the same frequency as the electrical current in the cable. The MagTrack is DC powered and can be battery operated. During the sea trials, the equipment used had to be mains powered and the generator was set to operate slightly below 50 Hz. The generator frequency and another strong component at 16.7 Hz from a railway were removed by notch filters set in the MagTrack GUI.

Data processing and results

Post-processing of the acoustic data includes transducer offset correction, individual trace motion compensation, bandpass filtering and amplitude normalisation to the echo signals. Correction and conversion of the irregularly distributed point cloud to a regular grid with adjustable cell sizes is a prerequisite for the visualisation in 3D software packages. The gridding process can also include multiple survey lines along the cable, which may result in a higher point density and increased coverage across the cable. 3D visualisation within a volume renderer allows for adjustable amplitude and opacity transfer functions to enhance the visibility of specific reflectors and clip planes are used to remove noise and unnecessary parts of the volume. Fig. 3 illustrates the visualisation of the acoustic data in a 3D renderer and how the cable position and the burial depth are determined in the 3D volume. Fig 4 compares the traditional cable position picking from 2D seismic sections with the cable position extraction from the 3D volume.

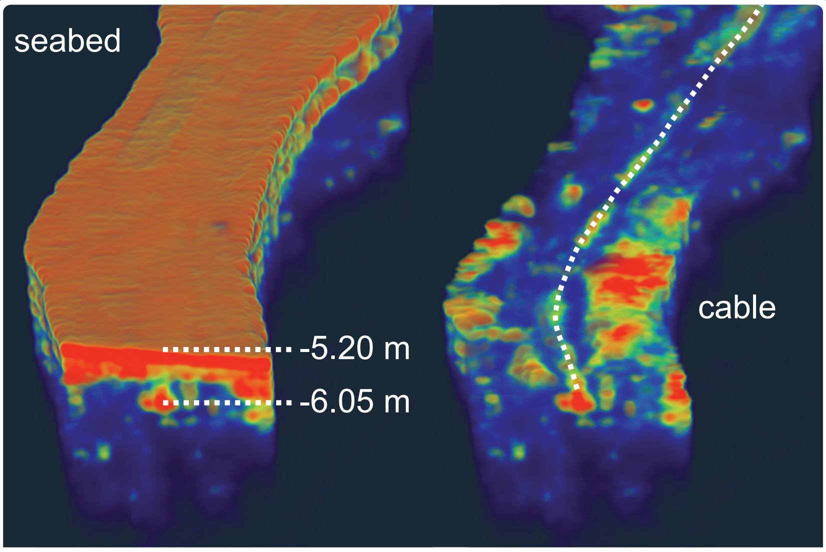

Fig. 3: 3D volume rendered from the acoustic data showing the cable buried approximately 0.85 m below seafloor

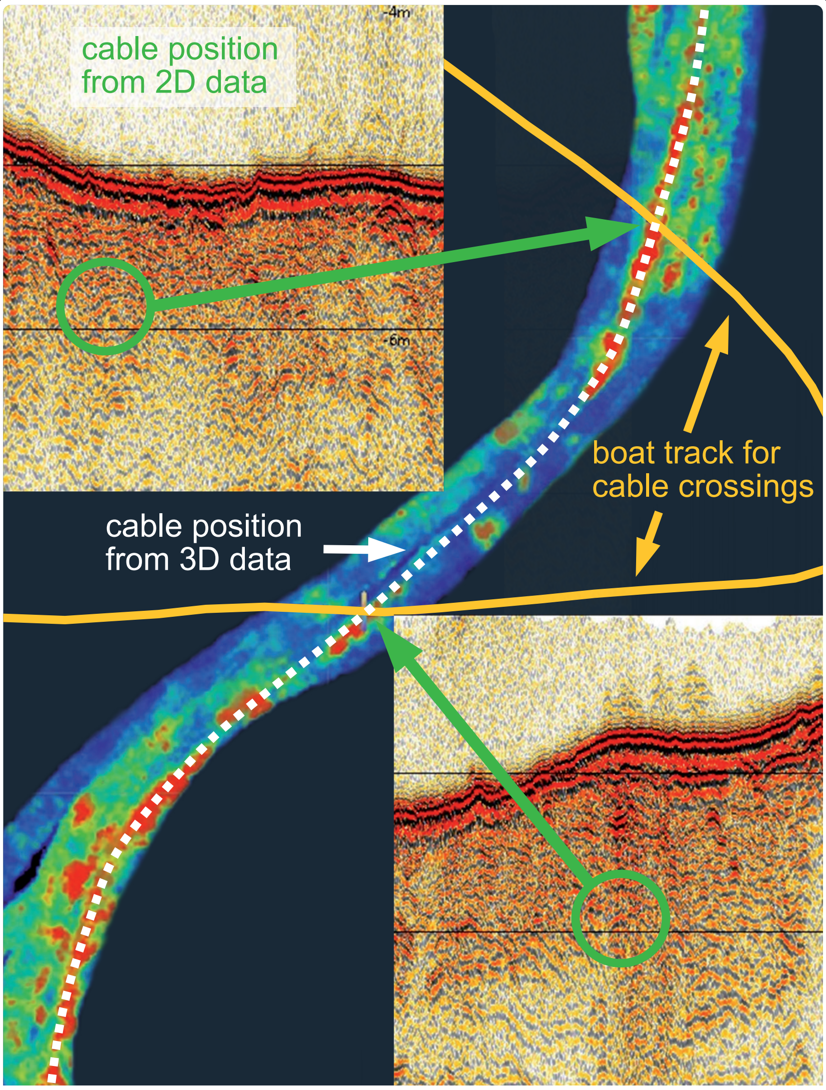

Fig. 4: Top view of the 3D volume rendered from the acoustic data and cable detection in the 3D volume vs. in the 2D sections of cable crossings

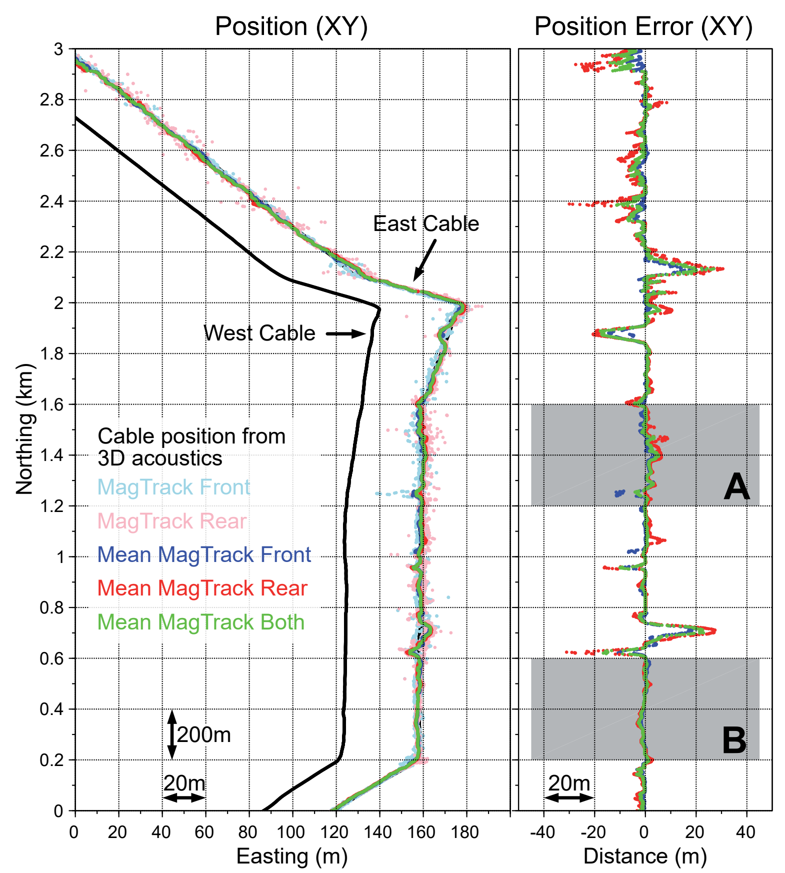

Fig. 5: Cable positions from the acoustic data (black; both cables) and from the MagTrack (three runs, front blue, rear red; east cable only) and difference between the acoustic and averaged MagTrack XY cable position; two sections A and B are highlighted, see text

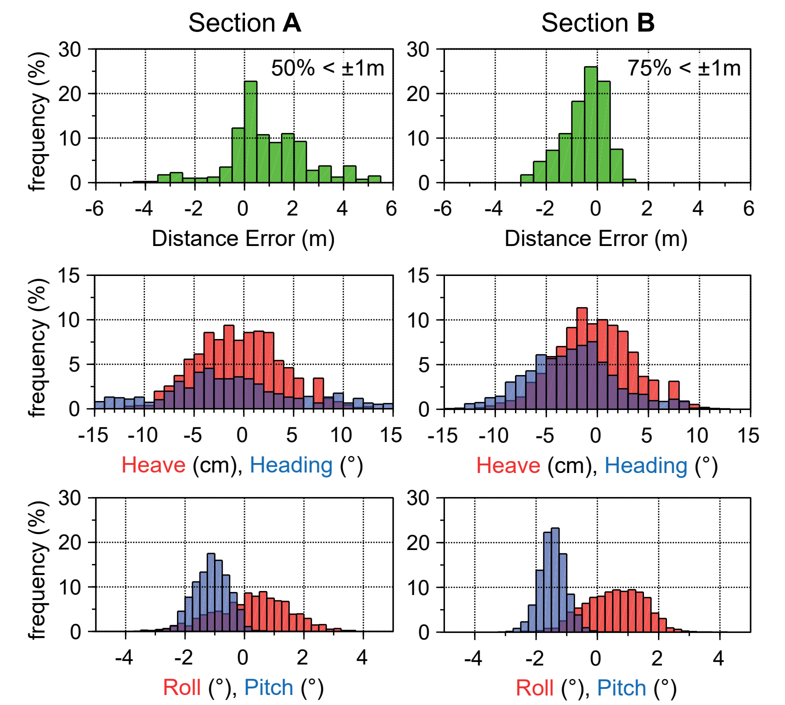

Fig. 6: Histogram plots of the position difference and motion data of the two sections higlighted in the position plots in Fig. 5

The latter gives a much higher position density along the cable without any additional effort and the cable is much easier to locate than in the 2D sections.

Post-processing of the MagTrack data includes position correction, motion compensation and outlier removal based on the Modified Z-Score method. The XY position of the cable shows significant variance, but improves when averaging three runs along the cable (see Fig. 5). This variance is probably due to the relatively large distance between the sensors and the cable, the low magnetic field strength of the three-phase cable and the short sensor baseline. However, there are sections with less variation, particularly in the south. The position obtained from the front pair of sensors, mounted directly on the acoustic array, mostly just follows the boat track rather than the cable. This can be attributed to the lower SNR due to the large amount of metal, the electromagnetic fields from the acoustic array and the associated cables, and the shorter baseline. Despite being even further away from the cable, the rear pair of sensors performed better, especially for the cable depth. This is probably due to the longer baseline and the greater distance from the acoustic array.

Further analysis of two sections of the cable route, each 400 metres long, showed differences in the XY position error and the heading variations (see Fig. 6). The other motion data (heave, roll, pitch) show almost the same distribution and with their small range of values they cannot cause larger position errors. Also, the water depth was almost the same in both areas, so the larger position errors seen in section A compared to section B are probably related to the larger heading variance. However, to guide the vehicle to ensure that the acoustic data will cover the cable, an XY positional accuracy of the MagTrack of ±1 m is sufficient. This was the case for more than 50 % of the averaged values in both sections.

Conclusions

Both sensor systems proved to provide good data for DOB surveys. The positional accuracy of the MagTrack was not as good as hoped, suffering from the much too short sensor baseline for the given cable distance and the unstable survey platform, especially the rapid changes in heading. However, the averaged cable position was good enough to ensure that the acoustic array was positioned over the cable. The on-line data output and visualisation of the MagTrack will need to be improved to guide the vehicle steering in these conditions.

The 3D volume rendered from the acoustic data proved to be a good tool for extracting the XYZ positions of the cable with high positional accuracy and density. However, this requires some post-processing and is not yet possible in real-time. The workflow needs to be improved.

The combination of both sensors improves survey speed and data quality. This in turn reduces the cost of data acquisition and post-processing. //

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