BIO-INSPIRED CABLE TRACKING USING AUTONOMOUS UNDERWATER VEHICLES

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1 INTRODUCTION

The Ocean Systems Laboratory (OSL) is developing a bio-inspired wideband sonar system for autonomous underwater vehicles (AUVs) for improved detection and recognition of subsea objects [1]. One application for the new system is the autonomous tracking of underwater cables. The bioinspired approach offers potential for cable recognition as well as improved detection, making tracking more robust in cluttered environments. This paper covers proof-of-concept research in which the bio-inspired system has been tested against a number of different cables under various test conditions. These experiments aim to demonstrate the validity of the wideband approach in cable recognition and to explore the impact of reverberation and consistency of cable responses measured against different background sediments.

1.1 CABLES

Four different cables, designated A–D, have been studied during the experimental programme, with differences in construction for types A–C illustrated in Figure 1. The external diameters of the cables are between 16.5mm and 32mm. The type D cable is similar to type A but with a fibre optic core. All of the cables have a number of steel strands for strength with configurations varying between types.

1.2 EXPERIMENTAL SETUP

Responses have been measured midwater and against two different sediment backgrounds, very fine sand and coarse sand/grit. Cable aspect was varied in the horizontal plane using a Bowtech PT-25 pan-and-tilt unit. Wideband high and low frequency projectors were tested with a matched pair of receivers. This sensor configuration is suitable for vehicle mounting in conjunction with a sidescan sonar and can be readily adapted to run alongside video or other sensors.

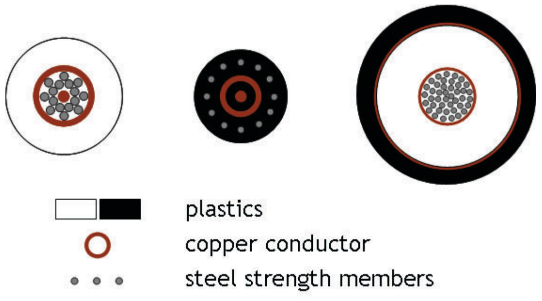

Figure 1: Cross sections of cable types under test

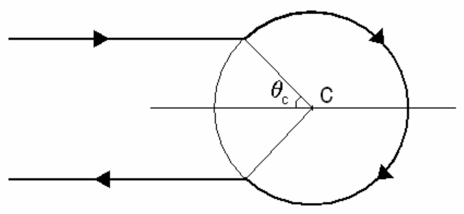

Figure 2: Lamb wave propagation path in cylindrical cross-section

1.3 SENSORS AND SIGNALS

The OSL wideband sensors are based on bottlenose dolphin (Tursiops truncatus) sonar, covering a frequencies 30-130kHz with a relatively wide beam, varying from 40° at the highest frequency to 80° at the lower end. Two projectors, each covering around two octaves, used in conjunction are capable of emitting significant energy in a band ranging from 30-200kHz. The higher frequency unit has both peak response and -3dB band centre at around 100kHz and has proved most effective in cable discrimination. A set of six short duration bio-inspired wideband pulses comprising pairs of downchirps is used. Labelled DC1–DC6, only the rates of change of frequency of the constituent chirps differ between signals. As previously reported these allow us to mimic much of the spectral variation seen in recordings from live dolphins performing target recognition tasks [2].

2 CABLE RESPONSES

Measured multiaspect cable responses are consistent to $> \pm 15°$. Beyond $\pm 10°$ the higher frequencies are lost progressively due to the frequency-dependent nature of the transducer beamwidths. The wideband responses are characterised by spectral notches derived from interferences between overlapping target echoes. For the simpler cable structures, notch positions can be predicted using a thin cylindrical shell model. Since the outer plastic sheath has relatively low impedance (close to water) some sound is re ected at this layer, but much of the energy is transmitted through to the higher impedance copper layer. Sound enters this layer at the critical angle θ_c, propagates around the metallic shell and is back-diffracted at the same angle θ_c, see Figure 2. These phenomena are the S_0, symmetric, and A_0, anti-symmetric, Lamb waves. At biosonar frequencies the A_0 wave is subsonic and only the S_0 need be considered The delay between specular and secondary echoes can be calculated given sound speeds in the water and the copper layer, eqn. (1),

$$\Delta t_n = 2r\left(\frac{n\pi - \theta_c}{v_g} - \frac{1-\cos\theta_c}{c}\right) \tag{1}$$

where, n represents the number of turns around the cylinder, r is the radius of the copper layer and v_g is the group velocity in the copper. For the type C cable: $\Delta t_1 = 21\mu s$ and $\Delta t_2 = 43\mu s$. The empirically measured notch spacing is around 23kHz, equivalent to a time delay of $43.8\mu s$, corresponding well with the predicted Δt_2 value.

2.1 CABLE DISCRIMINATION AND PULSE TYPE

Figure 3 gives midwater spectral responses for each of the cable types to three different bio-inspired pulses. Variations are due partly to the spectral shape of the pulse and partly to the echo responses themselves. For the type B cable, the ring of strengthening cables typically produces more oscillatory spectral responses. For cable type C, pulse DC5 provides a good candidate for discrimination from strong oscillations in the 50-80kHz band. For cable type D, consistency between pings is good, but this cable does have the lowest SNR, indicated by the higher noise levels towards 200kHz.

3 REVERBERATION IMPACT

To assess reverberation impact, cable responses were measured against two sediments, very fine sand and coarse sand (particle sizes: 0.4mm to >4mm). The coarse sediment presents more difficulty due to increased reverberation, related to the bottom scattering strength through the equation [3],

$$RL = SL - 2TL + S_v + 10\log\frac{c\tau}{2}\psi r^2 \tag{2}$$

Figure 5 shows APL-UW scattering strength models for three seabed types [4], illustrating two important points for cable detection. Firstly, a rougher seabed gives a higher reverberation level. Secondly,

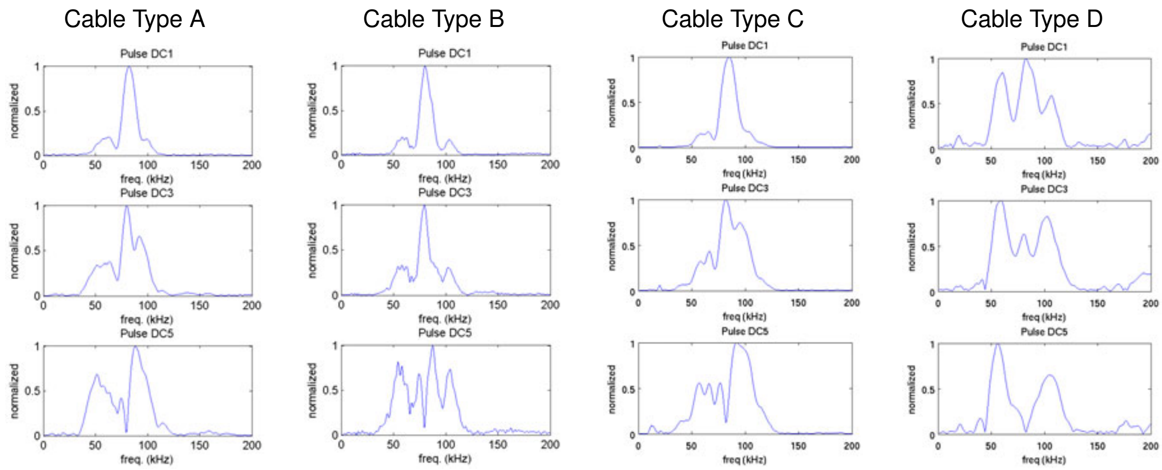

Figure 3: Echo spectra for each of the four cable types insonified with pulses DC1, DC3 and DC5

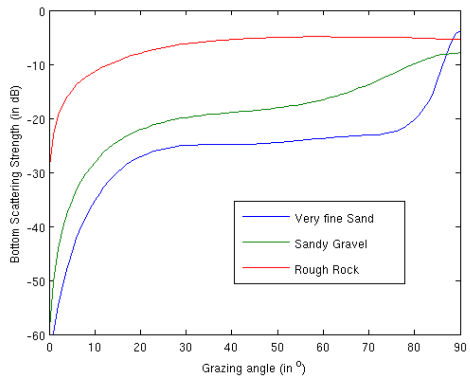

Figure 4: Bottom scattering strength v. grazing angle – APL-UW models

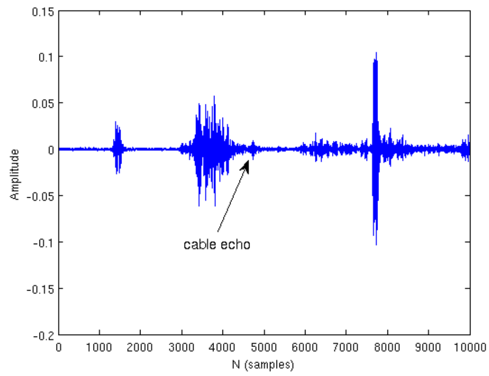

Figure 5: DC4 record at 45° grazing angle, coarse sand – cable echo is arrowed

grazing angle plays an important role and for rough sediments, a lower grazing angle will provide better results. Here we consider our worst case with low SNR type D cable lying on coarse sediment. At 45° grazing angle the cable response is buried in reverberation noise at the beam centre and detection is not possible. Better results are obtained from the periphery of the beam, in effect using a shallower grazing angle. Figure 4 shows such a response with the cable echo arrowed. At the 27° grazing angle we can use the main lobe returns without losing the cable echo in reverberation noise. At the shallower grazing angle the match with the midwater measurements is better and there is better consistency between pings. The variability in response over the coarse sediment has been assessed using a sequence of 43 DC3 echoes recorded at 5cm intervals along a 2m cable segment, Figure 6 . In addition to the sediment reverberation, these data are compromised by cable curvature, tank wall returns, disturbances in the sediment surface and ambient noise sources.

4 CABLE TRACKING

Robust recognition is unlikely to be achieved from individual echoes, but we can improve performance by integrating over series of pings to determine the most likely matches. For open water trials on board a REMUS-100 AUV, the wideband system will be interfaced to Autotracker [5,6], an embedded control system which uses detections from the wideband sensor data to feed tracking modules based on Kalman filter and particle filter architectures to maintain vehicle track on the cable of interest.

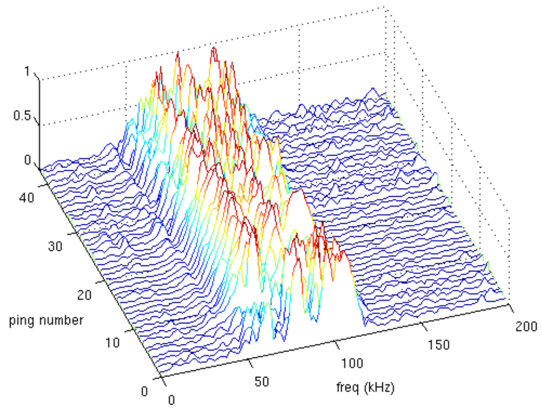

Figure 6: Waterfall plot of successive echo spectra at 5cm intervals tracking along cable on coarse sand – characteristic three-lobed DC3 echo for this cable is strongly evident

5 CONCLUSIONS

This study has demonstrated the capability of the wideband bio-inspired sonar system to distinguish between different cable types, laying down the groundwork for the automated tracking of small communications cables underwater. In summary, we have demonstrated that cables give a consistent, measurable and discriminatory response to the wideband pulses. We have noted that over more reverberant surfaces a shallower grazing angle is required to maintain good SNR. The wide beamwidth of the sensors ensures good detection over a wide range of aspects ($\pm 20°$).

ACKNOWLEDGEMENTS

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