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Buisman, M.; Martuganova, E.; Kirichek, A.; Draganov, D.

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WATER-DEPTH ESTIMATION USING PROPELLER NOISE BY DISTRIBUTED ACOUSTIC SENSING

M. Buisman[1], E. Martuganova[2], A. Kirichek[1], D. Draganov[1]

[1] Delft University of Technology; [2] German Research Centre for Geosciences

Summary

This work shows the potential of using DAS for continuous water-depth monitoring by using the difference
in acoustic energy in water and mud. The advantage over conventional methods is that our method can be used continuously and remotely, given that there is traffic nearby. Due to the low cost of fibres and the far-reaching dynamic range of interrogators, DAS could be a very attractive alternative for water-depth monitoring using propeller noise in shallow marine environments, ports and waterways.

Water-depth estimation using propeller noise by Distributed Acoustic Sensing

Introduction

Ports and waterways' depths are regularly surveyed to ensure safe navigation. Current non-intrusive surveying methods have a low accuracy, and a low repeatability, due to their dependency on the availability of surveying vessels (Kirichek et al., 2018). The latter case especially poses problems after storm- or dredging-related bathymetrical changes. Nevertheless, due to the heavy traffic in ports and waterways, there is ample noise which can likely be used for continuous water-depth estimations with a (semi) permanent seismic installation. Distributed Acoustic Sensing (DAS) could potentially be used to measure the difference in attenuation, e.g. Q-factor, between the water and mud, and thus provides an estimate of the water-depth level given that the receiver location is known. DAS is a novel technique that measures strain or strain-rate in a (telecommunicational) optical fibre induced particle displacement from for instance a seismic wavefield. Due to the low cost, non-corrosive, non-conductive, and other properties of fibres, DAS allows monitoring surveys that have historically been cost prohibited (Lindsey et al., 2020). In addition, the dynamic ranges of DAS interrogators are reported up to 171 km (Waagaard et al., 2021), making DAS an attractive method for large monitoring campaigns.
Buisman et al. (under review) showed that one could estimate the depth due to the difference in Q-factor between water and mud using vertical seismic profile (VSP) laboratory setup and an active source. This VSP configuration was created by coiling an optical fibre around a PVC pipe, allowing for a much denser sampling in depth than a straight fibre. This work demonstrates that a similar setup can use ambient noise sources for water-depth assessments in the Port of Rotterdam. Depth measurements using DAS is particularly interesting for port authorities because DAS can be used remotely, allowing on-demand/continuous data acquisition.

Experiment Setup

The pilot is situated in the Botlek, located in the Port of Rotterdam. This location was chosen due to the high sedimentation rate and the abundant traffic. The setup consists of a 24-m long steel pole designed to hold a mantel containing the sensing fibre, as seen in Figure 1. The mantel is 2.4 m in length and

Figure 1 *Left: two mantels of which only the right one is used. Right: picture of a mantel being installed on a pole.*

is coiled with a standard communication fibre with a length of 750 m that covers 1 m of the mantle in height. This mantel is then submerged in mud for approximately 40 cm.
A Febus A1 interrogator is used for data acquisition by converting the fibre into seismic sensors. We use a gauge length, the averaged fibre length for a recording, of 2 m and 40 m. With the 2-m and 40-m gauge lengths, the channel spacing is about 2.7 mm and 53.3 mm in depth, respectively. A smaller gauge length

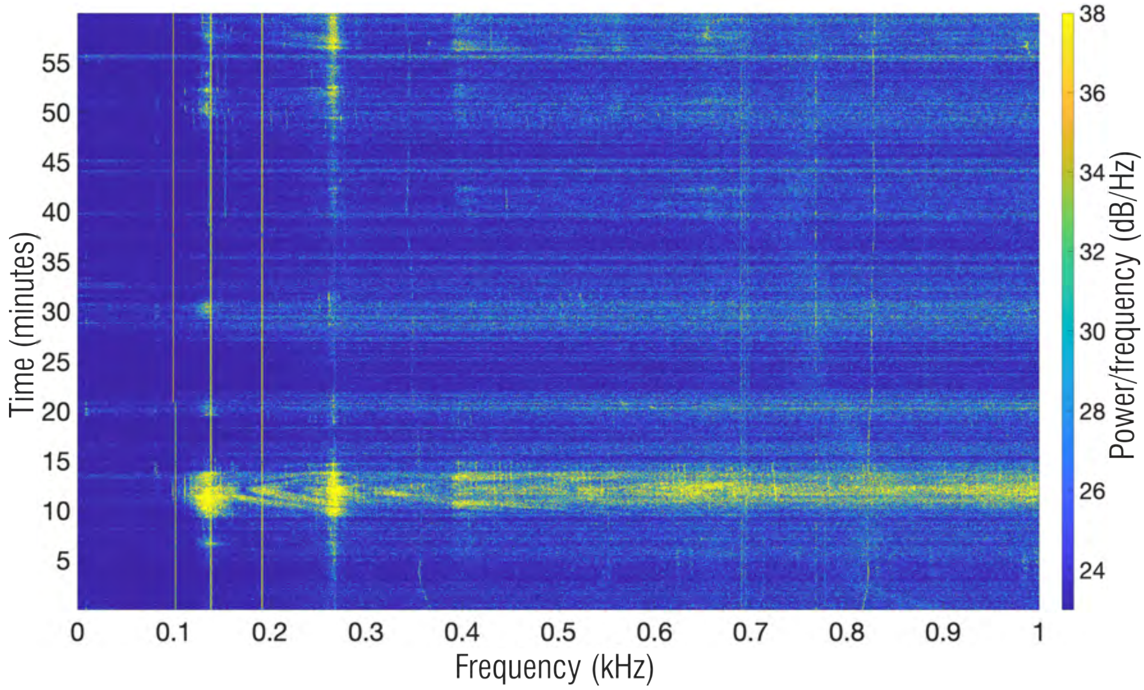

Figure 2 *Spectrogram of channel 16 which is located in water, with a gauge length of 40 m and a time sampling frequency of 2 kHz. During this hour-long recording, a boat passed between minute 8 and 14. Another boat passed at the end of the recording, which is why it is partly recorded after minute 50. In addition, one can observe various machine-noise frequencies, such as at 0.1 kHz, 1.3 kHz and 0.2 kHz.*

is used for a high spatial resolution, but at the expense of a lower signal-to-noise ratio. The larger gauge length is used for achieving a higher signal-to-noise ratio and can thus be more beneficial to measure the broad frequency content of our noise sources.
We record for four consecutive hours in a single day with a 40-m gauge length and 2 kHz time sampling. With a 2-meter gauge length, we record for 1 hour during various days with various time sampling frequencies, ranging from 800 Hz to 2 kHz, to limit the data size.

Water-depth estimations based on frequency content

Our results in Figure 2 result show that DAS can measure noise from passing vessels. During the recording in Figure 2, one ship passed between minutes 8 and 14, and one approached the sensing mantel at the end of the recording. Unfortunately, the measurements contain machine noise, likely from the interrogator itself. In a power spectral density plot, we observe a fundamental mode at 130 Hz and at least two overtones. These resonances are probably originating from the pole.
After one month, the mantel is raised for visual inspection to ensure that the mantle is partly submerged in mud. Barnacles that grew on our mantel, together with an unsightly brown coating, confirmed that our setup is indeed partly submerged in mud. Because of this, we expect the water/mud interface between 5.60 m and 5.8 m depth. The water/mud interface depth varies due to sedimentation and dredging in the vicinity. Due to gas pockets in mud and due to drag forces, a sharp transition can be expected.
When we zoom in on the frequency range of the fundamental mode and the first overtone and select the time window 8 to 14 minutes, we notice a distinct difference in the frequency content beyond a depth of 5.7 m, as shown Figure 4. This contrast in frequency content becomes even more apparent with a gauge length of 2 m, as shown in Figure 5, where we observe a sharp boundary in acoustic energy at a depth of 5.66 m. The difference in transition is likely related to the smaller gauge length, implying more measuring points in depth and thus less averaging at the transition zone. Our measurements show a sharp boundary at 5.66 m depth, which is well within our expectations. Therefore, we believe that the difference after 5.66 m is our water/mud boundary.

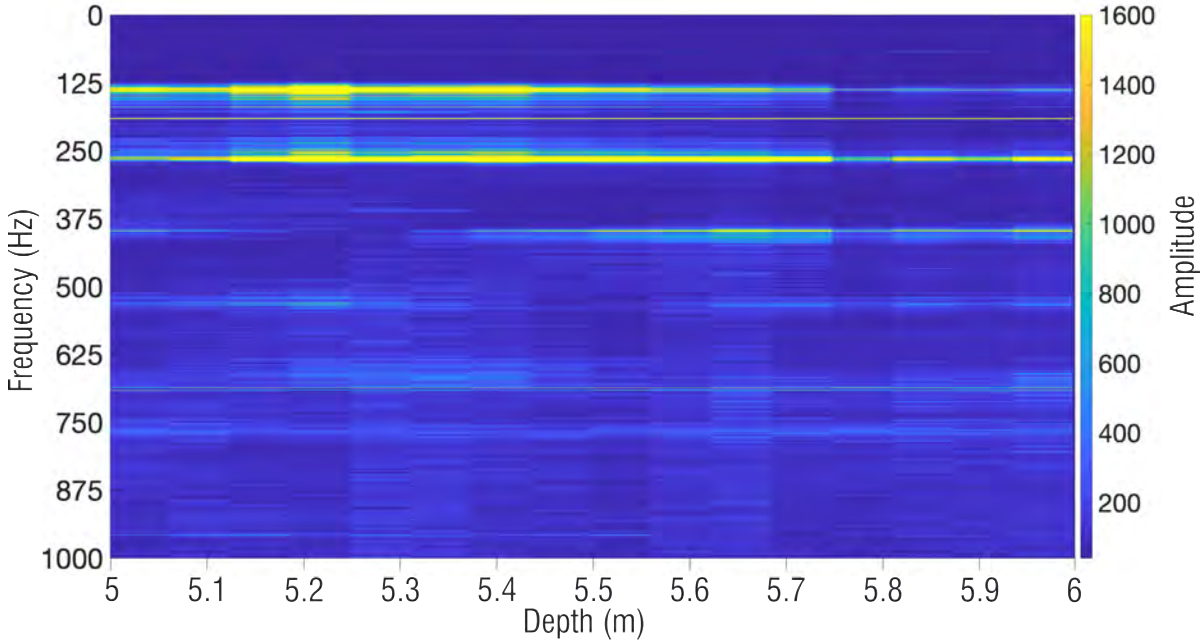

Figure 3 *A power spectral density plot of a 10 s recording with a 2 kHz time sampling and a 40-m gauge length. At a depth level of around 5.7 m, there appears to be a transition zone. This can either be a very liquid mud or this is due to the averaging effect of the 40-m gauge length.*

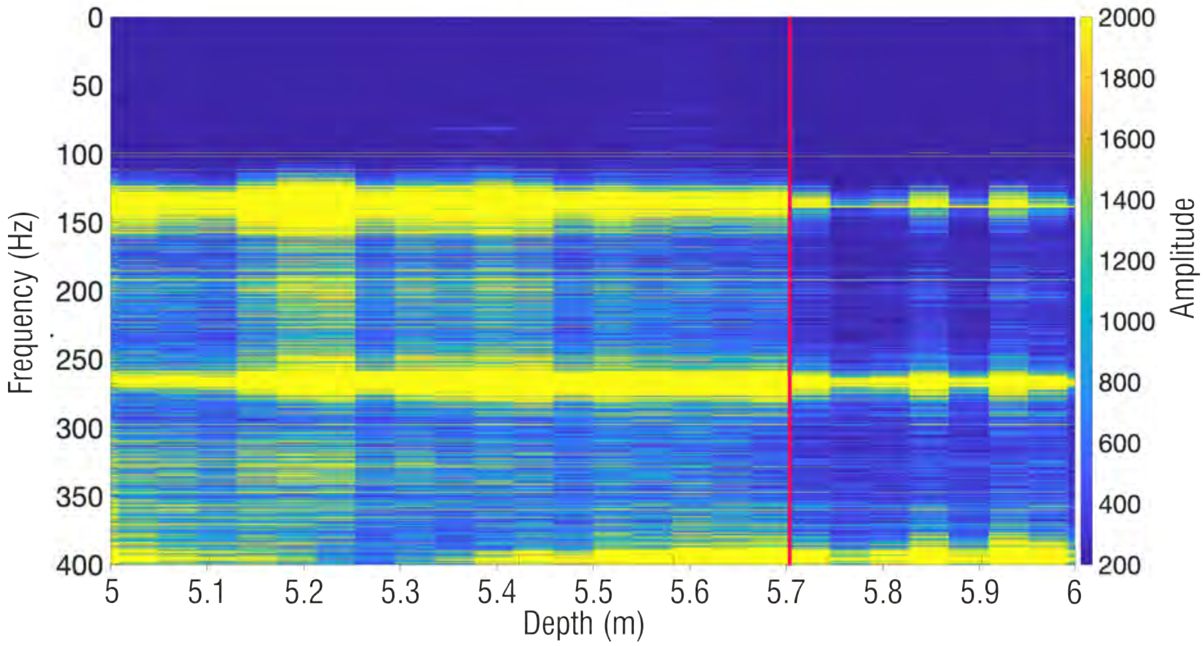

Figure 4 *Time slice of minutes 8 to 14 during which a boat passes, as shown in Figure 2. A change in frequency content can be observed around 5.7 m depth.*

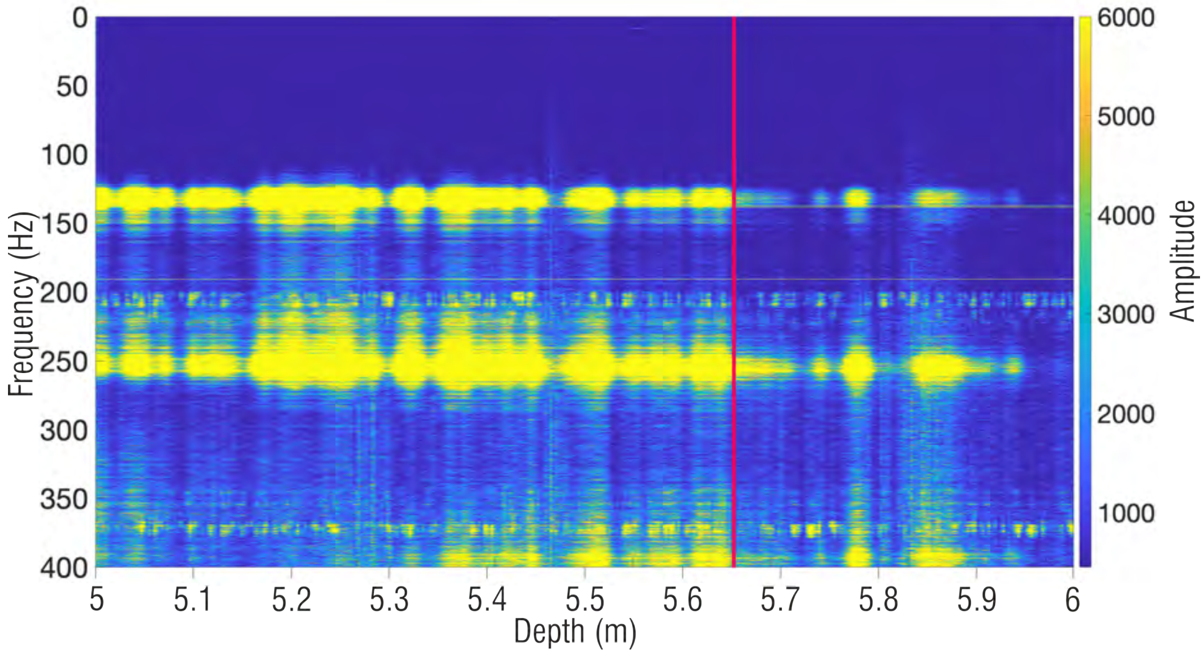

Figure 5 *A power spectral density plot of a 120 s recording with a 800 Hz tune sampling and a 2-m gauge length. At a depth of 5.66 m, there appears to be a sharp boundary which is likely the water/mud interface.*

Conclusions

Our VSP results showed the potential of using DAS for continuous water-depth monitoring by using the difference in frequency content in water and mud. Both the 2-m gauge length and 40-m gauge length could use ambient noise sources for depth estimations. The 2-m gauge provided a more accurate estimation due to the denser spatial sampling, even with a lower signal-to-noise ratio. The advantage of our DAS method over conventional methods is that our method can be used continuously and remotely, given that there is traffic nearby. In addition, due to the low cost of fibres and the far-reaching dynamic range of interrogators, DAS could be a very attractive alternative for water-depth monitoring using propeller noise in shallow marine environments, ports and waterways. Monitoring the water/mud interface with DAS could potentially resolve temporal resolution problems at a relatively low expense.

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