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Monitoring tidal water-column changes in ports using distributed acoustic sensing

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

[1] TU Delft; [2] Port of Rotterdam

Summary

We show results of of using distributed acoustic sensing (DAS) for continuous relative water-column changes monitoring by relating the oscillating frequencies to measurements of a nearby tidal-station. The oscillations have a great qualitative agreement with the tidal-station, having a period of 12 hours and 25 minutes. No calibration is required to measure the tides and the relative difference in water height,

though calibration would allow measuring the absolute water height at any location. Because we used two poles with different exposure lengths to air, at different depths and only 38 m apart, we can interpret he spectral oscillations are a result of constructive interference in our poles, likely generated by the wind. DAS could be a very attractive alternative for tidal monitoring in shallow marine environments, ports and waterways. DAS could potentially resolve spatial resolution problems with tidal monitoring, which is currently cost-prohibited, at a relatively low expense by wrapping a fibre around a pre-existing structure such as a docking pole. Furthermore, DAS can be used remotely and continuously, allowing for better model calibrations or local tidal fluctuation monitoring. This monitoring system could help determine if ships have enough water clearance to dock and, in turn, increase the occupation rate.

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Introduction

Low-cost tide measurement stations are needed for research applications and naval operations. Conventional pressure gauges, are expensive, require electric power, calibration, and occasional personal intervention. Furthermore, corrosion, data transfer, and the limited operational life span of batteries hampers the ability to have many tidal-stations across ports and waterways. Because of this, tidal-stations are usually deployed near locations of interest, such as harbour entrances or harbour estuaries (Giardina et al., 2000).
Becker and Coleman (2019) showed in a laboratory setup that the difference in water pressure can be measured using distributed acoustic sensing (DAS). DAS converts an optical fibre into a seismic array by measuring the phase change of the back-scattered light. This phase change is then converted to strain or strain-rate (Lindsey et al., 2020; Waagaard et al., 2021). Optical fibres have many advantages over conventional electric sensors. These fibres are non-corrosive, non-conductive, very cheap, and do not require an electric power source (besides power for an interrogator) (Shao et al., 2016; Xu et al., 2017; Yang et al., 2001). Furthermore, DAS measurements using conventional telecom fibres have been reported over 125 km (Waagaard et al., 2021), making them most suitable to monitor over long distances and at many locations.
In this work, we show that DAS can detect the relative water column change connected to the tides in waterways without the need for calibration using constructive interference, or resonance frequency, generated by the wind on a solid metal pole. Unlike Becker and Coleman (2019), we do not measure a difference in pressure but a difference in exposure length of a metal pole. This approach is efficient and hardly influenced by other environmental vibrations, which might be the case for a setup similar to the one described in Becker and Coleman (2019).

Experiment setup

The experimental setup is installed in the Botlek, located in the Port of Rotterdam, and consists of two 24-m-long steel poles designed to hold a mantel containing the sensing fibre, as seen in Figure 1. Due to a difference in the subsurface and water depth, the steel poles were driven in at different depths and had different exposure lengths to the air of approximately 3 m and 2.4 m. The poles are driven at a location with a water depth of 5.7 m and 3.2, and are spaced 38 m from each other. The mantels are 2.4 m in length and 0.37 m in diameter. Both mantels are coiled with a standard single-mode direct burial communication fibre with a length of 317 m that covers 1.6 m of the mantle in height. The mantels are then carefully lowered to prevent the connecting fibre from breaking during installation and put on the water-mud interface.
An ASN OptoDAS interrogator is used for data acquisition that converts the fibre into seismic sensors. We use a gauge length, the averaged fibre length for a recording, of 3 m and a channel spacing of 1 m. The 3 m gauge length was chosen because our initial objective was to record surface waves with a short wavelength. The OptoDAS interrogator is housed 70 m away in a container. We record for five consecutive days using a time sampling of 62.5 kHz, which afterwards is temporally decimated 62 times to 1008 Hz to increase the signal-to-noise ratio (SNR).

Tidal water depth estimations based on frequency content

When we select a single channel at each pole and plot a spectrogram for a length of 400 000 s, or 4.6 days, we obtain Figures 2 and 3. These figures show oscillating frequency patterns. These frequency oscillations have a most exciting period of 12 hours and 25 minutes and are likely caused by the tides and wind, which cause resonances in our poles. In the port of Rotterdam, the duration of the tides is 12 hours and 25 minutes, which exactly coincides with the tidal period we observe. When we compare the nearest tidal-station recordings for the same time period we recorded the data, we also see a great qualitative agreement. Especially the sharp peaks and troughs are visible in both the tidal-station and our frequency spectra. For example, a trough can be observed around 250 000 s on the tidal-station measurement in Figure 4. This same trough is also clearly visible in Figures 2 and 3. The SNR in Figure

Figure 1 *Left: two mantels with the direct burial single mode fibre being lowered onto the steel poles. Top and bottom right: sketch of the setup and a picture of a mantel with the fibre.*

2 is higher than compared to Figure 3. The difference in the location of the poles can likely explain this difference. The pole from Figure 3 is closer to the shore and more sheltered from the wind. Additionally, a difference in wind direction and velocity also plays a role in generating a difference in pole-vibration amplitudes, explaining the differences throughout the recording. Another striking difference between these two poles, besides the SNR, is the difference in frequency content. Figure 2 shows oscillations between 1.75 and 2 Hz. The oscillations in Figure 3 are almost twice as large, between 2.6 Hz and 3 Hz. This difference in frequency bandwidth is likely related to the difference in exposure length of the pole to air with the pole closer to the shore, having a relatively larger difference in exposure to the air with the tidal fluctuation due to the shorter initial exposure length, though absolutely, this difference in tidal length exposure is the same. Because the oscillation period for both poles is the same but with a different frequency content and bandwidth, we believe that the wind generates these low frequencies. It is unlikely that these frequencies are related to ocean gravity waves. Even though our setup is located close to the sea, both poles are only 38 m away from each other, implying that a similar frequency content is expected in both poles if the source is a propagating wave field instead of constructive interference in the setup itself.
A potential implication of this research could be continuously measuring the water height at quay walls or docks. Pre-existing structures such as docking poles could be turned into a tidal-station by wrapping a few tens of meters of fibre around it. Because over 100 km of fibre can be used with a single interrogator, an elaborate continuous water height or tidal monitoring system could be developed with DAS to cover (most) of a port at a relatively low price.

Conclusions

We showed results of of using distributed acoustic sensing (DAS) for continuous relative water-column changes monitoring by relating the oscillating frequencies to measurements of a nearby tidal-station. The oscillations have a great qualitative agreement with the tidal-station, having a period of 12 hours and 25 minutes. No calibration is required to measure the tides and the relative difference in water height, though calibration would allow measuring the absolute water height at any location. Because we used two poles with different exposure lengths to air, at different depths and only 38 m apart, we can interpret

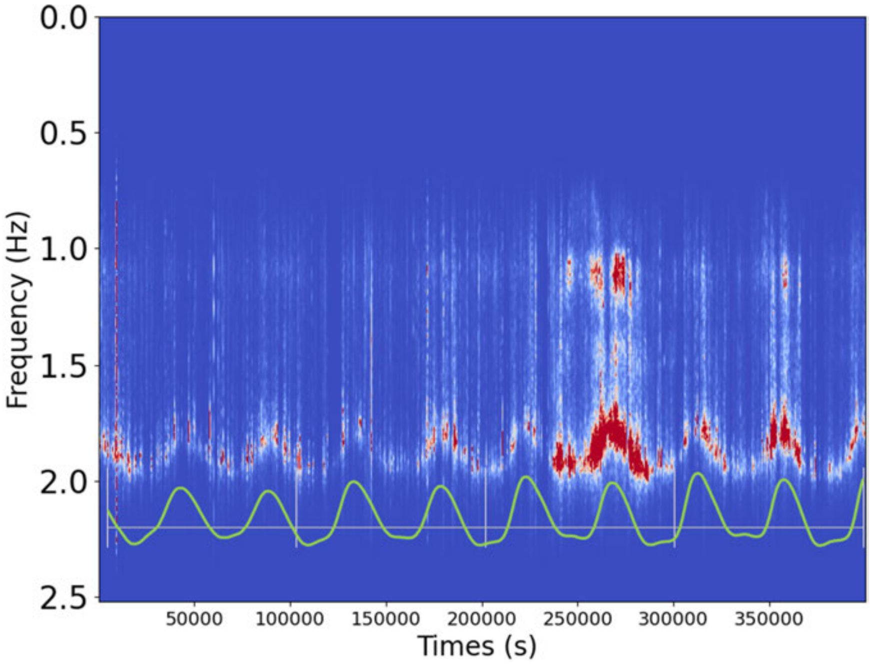

Figure 2 *Spectrogram of a single channel of the left pole in the deeper water showing frequency oscillations with a period of 12 hours and 25 minutes. Sharp peaks and smooth troughs are visible between 1.75 Hz and 2 Hz. For visualisation purposes, the nearby tidal-station measurements are plotted in green underneath the oscillations.*

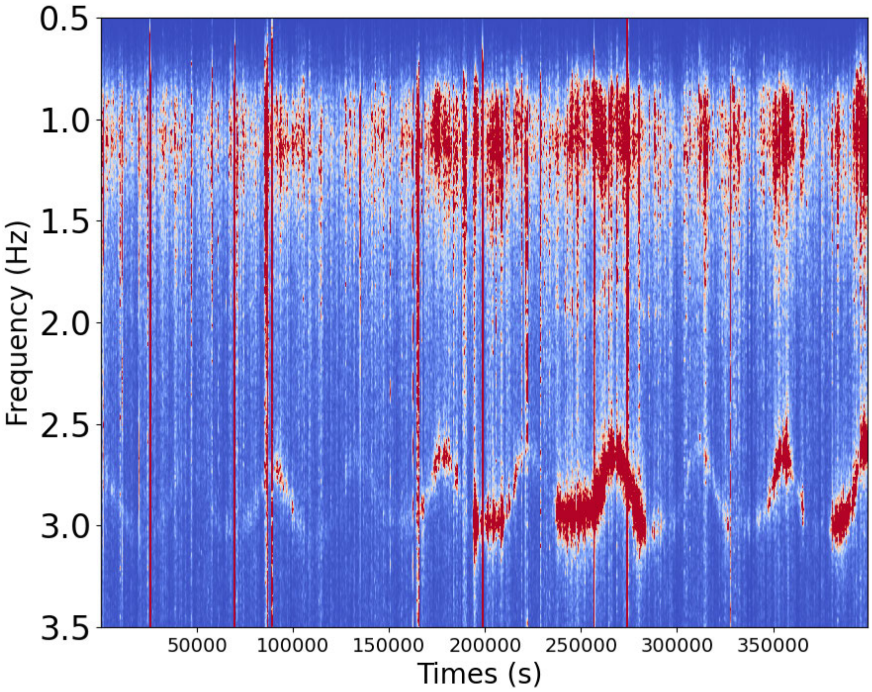

Figure 3 *Similar to Figure 2, but for the right pole , which is shallower and closer to the shore. Here the frequency oscillations occur between 2.6 Hz and 3 Hz.*

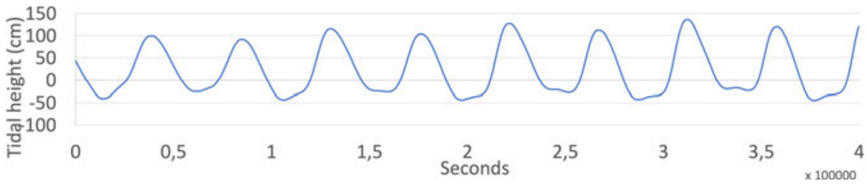

Figure 4 *Tidal heights measured of 400 000 seconds by a tidal-station nearby the DAS setup.*

the spectral oscillations are a result of constructive interference in our poles, likely generated by the wind. DAS could be a very attractive alternative for tidal monitoring in shallow marine environments, ports and waterways. DAS could potentially resolve spatial resolution problems with tidal monitoring, which is currently cost-prohibited, at a relatively low expense by wrapping a fibre around a pre-existing structure such as a docking pole. Furthermore, DAS can be used remotely and continuously, allowing for better model calibrations or local tidal fluctuation monitoring. This monitoring system could help determine if a ship has enough water clearance to dock and, in turn, increase the occupation rate.

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