EPJ Web of Conferences **309**, 10013 (2024)
EOSAM 2024
https://doi.org/10.1051/epjconf/202430910013

Environmental Monitoring of Submarine Cable in Madeira Island

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Abstract. Distributed acoustic sensing (DAS) is a sensing technique that allows continuous data acquisition of strain rate and temperature with exceptional spatial resolution, up to few meters, for extensive lengths up to 100 km. The ubiquitous nature of optical fiber cables rendered DAS an appealing alternative for geophysical sensing, allowing cost-effective data collection with extensive spatial coverage leveraging existing infrastructure. This study presents findings from the deployment of a DAS system on a dark fiber located on the Madeira Island, Portugal. Through the implementation of 2D filtering, simultaneous analysis of data from road traffic, ocean waves, and seismic activity was achieved.

1 Introduction

Distributed Acoustic Sensing (DAS) utilizes Rayleigh backscattered light to monitor strain changes along optical fibers. This technique allows simultaneous and continuous monitoring of high-resolution acoustic phenomena at large distances, enabling diverse applications including infrastructure [1,2], sea life [3], and seismic activity monitoring [4]. Considering the ubiquitous nature of optical fiber cables, DAS allows continuous and high-resolution monitoring over large areas, enabling precise detection and characterization of seismic events, subsurface movements, and other geophysical phenomena, having the potential to revolutionize geophysical sensing.

In this work, we present the results from a deployment of a DAS system in Madeira Island between 31 January and 14 February of 2023. This deployment allowed to monitor road traffic, the ocean waves in the coastal zone, and seismic activity.

1.1 DAS Working Principle

The working principle of DAS is based on Rayleigh backscattering that is inherent of optical fibers. In DAS systems, a coherent laser pulse is typically sent over an optical fiber and the optical phase of Rayleigh backscattering is then monitored along the fiber length as a function of time. The phase of the backscattered light at each site contains information about the strain and temperature changes that occur along the fiber, which can range from meters to tens of kilometers.

Integrating of backscattered light with optical time-domain reflectometry (OTDR) or optical frequency-domain reflectometry (OFDR) enables the monitoring of vibrations along optical fibers at readout frequencies within the kHz range [5].

2 Data Acquisition

The data was acquired using a HDAS, from the University of Alcalá, with a chirped laser with 100 ns pulse width. These pulses were, then, amplified using a semiconductor optical amplifier to mitigate intra-band coherent noise. The DAS system was deployed in a dark fiber installed exclusively for research purposes located on Madeira Island. The fiber cable, GEOLAB, has a length of approximately 50 km and achieves depths of up to 3.6 km on the seafloor. The cable also goes through a residential area with high traffic before reaching the ocean shore at the 2.5 km mark. The DAS system was deployed from 31 January to 14 February 2023. The fiber signal was acquired for the 50 km length with a spatial resolution (or gauge length) of 10 m, with a total length of 5000 channels and a time acquisition frequency of 50 Hz. By performing two-dimensional linear bandpass filtering, it was possible to detect and characterize several environmental activities, such as traffic, ocean waves and tides, and seismic activity, such as earthquakes.

3 Results

3.1 Traffic Observations

The position of the fiber allows the detection of road traffic, on a residential area, for an extension of approximately 2 km. An example of traffic detection is shown in figure Fig. **1**, resultant from a band pass filter between 2 and 45 Hz to the raw data. During this period,

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multiple vehicles were detected, exhibiting velocities approximately ranging from 30 to 60 km/h.

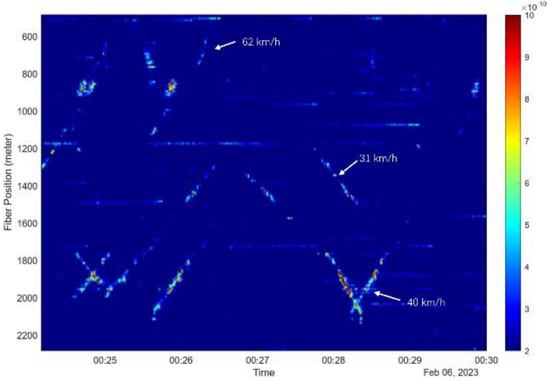

Fig. 1. Acoustic energy from road traffic, resultant for a band pass filtering of the signal between 2 and 45 Hz.

3.2 Ocean Waves and Tides

In addition to traffic observation, prior to the cable being emerged into the sea, it is also possible to observe shallow depth ocean waves. Figure Fig. **2** shows data recording in a 2D strain map between the 2.3 and 3.5 km. From the analysis of the frequency-wavenumber (*f*-*k*) power spectrum, shown in Figure Fig. **3** (left), it was possible to estimate the wave velocity to be between 7 and 15 m/s.

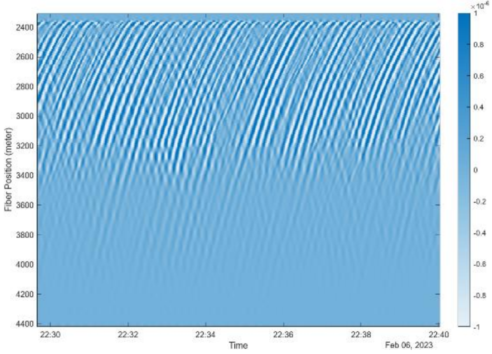

Fig. 2. Acoustic energy caused by the ocean waves on the shoreline.

3.3 Seismic Activity

It was analyzed 2h of the 5000 channels containing seismic data involving the earthquake in Turkey on 6 February 2023 with a magnitude of 7.5. By decomposing continuous raw strain data in the *f*-*k* domain (bandpass between 0.1 to 10 Hz), it is possible to decompose seismic (Scholte) waves from ocean waves, making incoherent noise such as temperature drift negligible. Figure Fig. **3** provides a comparison between ocean surface gravity waves and seismic waves. It's evident that ocean waves exhibit lower frequencies, typically below 0.3 Hz, with apparent velocities spanning from 7 to 15 m/s. In contrast, seismic waves carry greater energy, leading to higher frequencies, reaching up to 1.3 Hz, and apparent velocities ranging from 880 m/s to 6000 m/s. This disparity underscores the distinct characteristics and behaviors of these two types of waves.

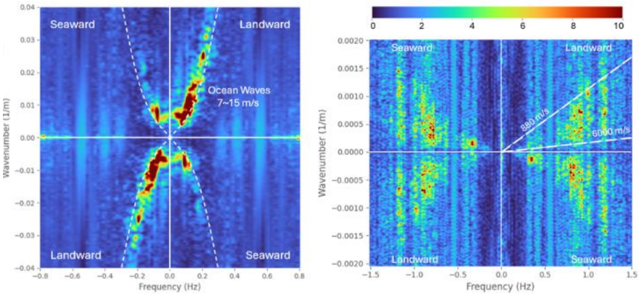

Fig. 3. Ocean surface gravity waves. It is visible that the landward propagation ocean waves are stronger than the ones propagating in the seaward direction (left side). Scholte waves ranging from 0.15 Hz to 1.3 Hz (right side).

4. Conclusions

In this study, a DAS system was installed on a dark fiber cable situated on Madeira Island, enabling for the continuous collection of strain rate data. Through the implementation of customized 2D filtering techniques, signals from road traffic, ocean waves along the coastline, and seismic activity were successfully captured. Notably, the system detected an earthquake with a magnitude of 7.5, originating 37 kilometers west-northwest of Gaziantep, Turkey. These findings underscore the advantages of DAS in obtaining real-time data with exceptional spatial resolution across extensive geographic regions.

Acknowledgements

HFM acknowledges financial support from the MCIN/AEI/10.13039/501100011033 and European Union «NextGenerationEU»/PRTR under grants RYC2021-035009-I, CNS2022-135925, CPP2022-009772. This paper builds on work done within the "SUBMarine cablEs for ReSearch and Exploration | SUBMERSE" - EU funded project (HORIZON-INFRA-2022-TECH-01 Grant agreement 101095055), and we acknowledge the support provided by the SUBMERSE partners.

References

1. Y. Yang, H. Zhang, Y. Li, IEEE Sens. J. **21**, 19453 (2021)
2. H. Liu, J. Ma, W. Yan, W. Liu, X. Zhang, C. Li, IEEE Access **6**, 68968 (2018)
3. L. Bouffaut, K. Taweesintananon, H. J. Kriesell, R. A. Rørstadbotnen, J. R. Potter, M. Landrø, S. E. Johansen, J. K. Brenne, A. Haukanes, O. Schjelderup, F. Storvik, Front. Mar. Sci. **9**, (2022)
4. E. F. Williams, M. R. Fernández-Ruiz, R. Magalhaes, R. Vanthillo, Z. Zhan, M. González-Herráez, H. F. Martins, Nat. Commun. **10**, (2019)
5. M. R. Fernández-Ruiz, M. A. Soto, E. F. Williams, S. Martin-Lopez, Z. Zhan, M. Gonzalez-Herraez, H. F. Martins, APL Photonics **5**, (2020)