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Urban DAS Data Processing and Its Preliminary Application to City Traffic Monitoring

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Sensors **2022**, *22*(24), 9976; <https://doi.org/10.3390/s22249976> (<https://doi.org/10.3390/s22249976>)

Received: 31 October 2022 / Revised: 5 December 2022 / Accepted: 12 December 2022 /

Published: 18 December 2022

(This article belongs to the Special Issue **Advances in Time Series Analysis** (/journal/sensors/special_issues/A_TSA))

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Abstract

Distributed acoustic sensing (DAS) is an emerging technology for recording vibration signals via the optical fibers buried in subsurface conduits. Its relatively easy-to-deploy and high spatial and temporal sampling characteristics make DAS an appealing tool to record seismic wavefields at higher quantity and quality than traditional geophones. Considering that the usage of optical fibers in the urban environment has drawn relatively less attention aside from its functionality as a telecommunication cable, we examine its ability to record seismic signals and investigate its preliminary application in city traffic monitoring. To solve the problems that DAS signals are prone to a variety of environmental noise and are generally of weak amplitude compared to noise, we propose a fast workflow for real-time DAS data processing, which can enhance the detection of regular car signals and suppress the other components. We conduct a DAS experiment in Hangzhou, China, a typical metropolitan area that can provide us with a rich data library to validate our DAS data-processing workflow. The well-processed data enable us to extract their slope and coherency attributes that can provide an estimate of real traffic situations. The one-minute (with video validations) and 24 h statistics of these attributes show that the speed and volume of car flow are well correlated demonstrates the robustness of the proposed data processing workflow and great potential of DAS for city traffic monitoring with high precision and convenience. However, challenges also exist in view that all the attributes are statistically analyzed based on the behaviors of a large number of cars, which is meaningful but lacking in precision. Therefore, we suggest developing more quantitative processing and analyzing methods to provide precise information on individual cars in future works.

Keywords: urban seismic (/search?q=urban+seismic); distributed acoustic sensing (DAS) (/search?q=distributed+acoustic+sensing+%28DAS%29); traffic monitoring (/search?q=traffic+monitoring); seismic signal processing (/search?q=seismic+signal+processing)

1. Introduction

The increase in the global population has sped up the process of social urbanization. The number of people living in the city is expected to reach 6.7 billion in 2050 according to the World Social Report 2020 from the United

Nations. The management of information and resources has become a major challenge in the rapidly expanding urban environment and has motivated the government to seek effective approaches to city management and sustainable development. Building a smart city is one of the key solutions to address these urban challenges and optimize the use of information and limited resources. Sensing technology plays a pivotal role in designing the smart city ecosystem that contains several essential components, including data collection, processing, communication, and action [1]. DAS is an emerging sensing technology that has been developing rapidly in geophysics. The DAS system contains an interrogator unit that sends coherent laser pulses into the fiber-optic cable and uses the optical phase shift of the back-scattered light to measure the small change in the length of fiber (strain or strain rate) in response to acoustic vibrations [2,3]. This technique turns a fiber-optic cable into tens of thousands of sensors that provide almost continuous (meters apart) sampling of the urban environment. **Figure 1a,b** are simple schematics about how DAS works. In **Figure 1a**, when the length of the fiber is unchanged, it corresponds to a stable phase sequence of back-scattered light. When there is a disturbance occurring on the fiber (location A), the optical path behind it will be changed. As a result, the corresponding phases are also different (see the green curves). By calculating the phase differences, we can find where the disturbance occurs. One of the most attractive features of DAS application in metropolitan areas is that the existing telecommunication infrastructure has already formed a dense network of fiber-optic cables. Hence, the DAS technique has the great potential of becoming an effective low-cost tool for real-time, long-distance, and large-scale sensing of the city.

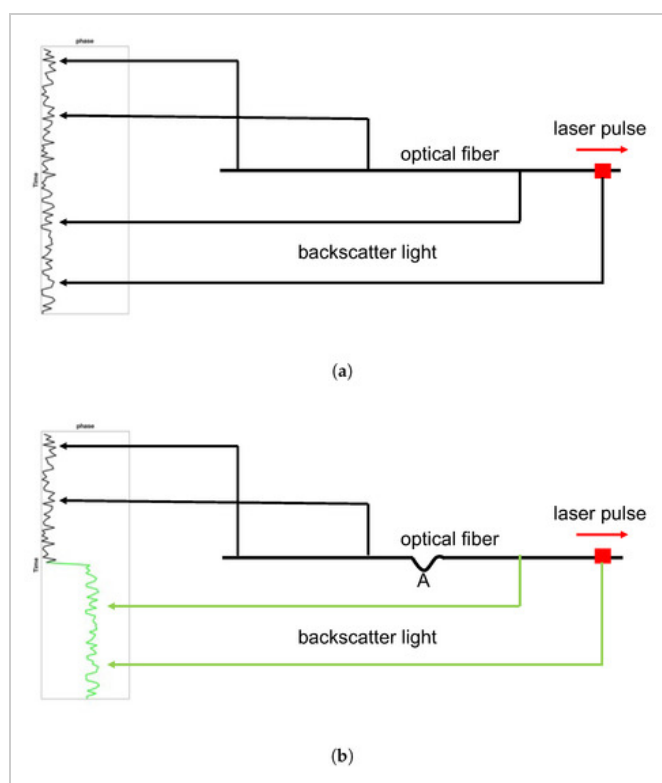


Figure 1. DAS schematic. (a) The situation of no disturbance occurring. (b) The situation with disturbance occurring on the fiber. The green color stands for the changed light paths and phases.

The utilization of DAS in urban environments is an emerging field in geophysical applications. The pioneering investigations of urban DAS were conducted on the campus of Stanford University using a 2.45 km long fiber-optic cable placed in the telecommunication conduits [4]. Later studies were conducted in a more urban-like environment, including Palo Alto, CA [5] and Pasadena, CA [6,7,8] and Sacramento, CA [9] and Perth, Western Australia [10]. The applications of urban DAS have focused on aspects such as near-surface imaging [4,11,12] and monitoring

[13–14], city traffic tracking [5,8], earthquake detection [15,16] and identification of other characteristic signals [6,17,18]. These earlier studies have demonstrated a number of promising usages of DAS in the urban environment. In this study, we acquire the DAS data in the metropolitan area of Hangzhou, China, a city with over 12 million population. Our study scales up the current practice of DAS acquisition to the city scale. This offers a unique opportunity to examine the potential and challenge of DAS in a more typical urban environment.

The high complexity and large volume nature of the urban DAS data require developing an efficient analysis workflow to better utilize the data and exploit the rich information of the urban environment. In this work, we conduct a preliminary study of the DAS data processing strategy and its potential application. We focus on the most abundant signals in DAS recordings, which are traffic signals from moving vehicles. Several earlier studies have adopted various processing strategies to extract urban traffic signals. Liu et al. [19] used an improved wavelet threshold and a dual-threshold algorithm to detect traffic flow. Van den Ende et al. [20] used a deep-learning-based deconvolution approach to improve the temporal resolution and detection accuracy of car signals. Wiesmeyer et al. [21] employed the Hough transform borrowed from the image processing field to estimate vehicle flow and the average speed of large vehicles. Thulasiraman et al. [22] adopted clustering algorithms and Kalman filtering techniques in data mining and signal processing literature to identify and track vehicles. More recently, Wang et al. [8] adopted the 4th root slant stacking method to estimate the mean vehicle speed and volume for each ten-minute data segment. These studies highlight the opportunities and challenges of the DAS system in urban traffic monitoring. However, few of these mentioned works have focused on the data processing and analysis of a metropolitan city (more than ten million in population) that has more challenging data, which is the current research gap.

Compared to the other works mentioned above, the innovation of our paper lies in that (1) Hangzhou is a huge city with over 12 million population. This makes the data conditions extremely complex, maybe more complex than any other work. Thus we design a unique processing workflow to deal with this kind of complex DAS data. (2) We propose to use two effective attributes (slope and coherency) to reflect the traffic situations, which have not been found in other papers.

This paper is organized as follows. We first briefly introduce the acquisition and characteristics of the urban DAS data in Hangzhou. Then we introduce in detail our processing workflow that integrates several computationally efficient algorithms to tackle various issues in urban DAS data. Next, we demonstrate two examples of real-time traffic tracking and daily status monitoring using the processed data. Finally, we discuss the potential applications of urban DAS based on the current work and point out several promising future research directions.

2. Hangzhou DAS Data Acquisition and the Dataset

We conducted two days of DAS data acquisition in the city of Hangzhou. The interrogator was mounted on a server cabinet in a local data center. We used the AP-sensing equipment that allows simultaneous recording of two channels for a maximum distance of 50 km. We selected two telecommunication fiber-optic cables that are deployed along the roadside that roughly follow an E-W direction (**Figure 2**). These two lines are specifically selected considering: (1) the quality of the fiber-optic cable with a relatively low (<0.3 dB/km) light loss rate; (2) a relatively long monitoring distance of over 20 km; and (3) the diverse urban environments that the cable sampled. The north line extends northward first and then eastward along the Yuhangtang Rd and terminates near the Hangzhou East railway station, with a total length of 24.8 km. The south line goes directly eastward along the Xixi Rd and Tianmushan Rd, both having several construction sites for subway and underground tunnels. The total length of the south line is 18.1 km. The DAS system recorded continuously at a time sampling interval of 0.0005 s (2000 Hz) and a spatial sampling interval of 2.45 m. The gauge length was set to 10 m during the entire acquisition