Seamless Distributed Traffic Monitoring by Distributed Acoustic Sensing (DAS) using existing Fiber Optic Cable Infrastructure

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1 ABSTRACT

Accurate real-time traffic sensing is of key importance, especially in the urban environment to be able to optimize traffic flow by intelligent traffic systems (ITS). Often the high density of traffic sensors, needed to achieve an accurate real-time monitoring of important arterial roads, is difficult to implement due to technical contraints or because of installation cost. Furthermore, existing traffic sensing technology uses sensors that are only able to measure traffic flow on a cross-section of the road where they are installed (typically on a junction), giving no information on the situation in between. An alternative "seamless" measuring technology, is to use floating car data, with Google Maps being the most prominant example. This technology allows to derive traffic information over wide road sections, however it is unable to deliver real-time information, and it relies on the "cooperation" of the data providers (the fleet owner or the mobile phone users). Distributed acoustic sensing (DAS) is a relatively new technology that allows a seamless, real-time monitoring of the road traffic situation over large distances of up to 50 km using the existing telecom fiber optic cable infrastructure. We present first result of traffic speed estimation performed on a real highway with DAS, over a distance of 19 km and compare them to reference measurements from induction loops.

Keywords: intelligent traffic systems, distributed acoustic sensing, real-time, traffic monitoring, traffic sensors

2 INTRODUCTION

Roads always been the backbone of transportation in the urban environment. Therefore, permanent traffic monitoring is crucial to ensure continuous traffic flow. The data provided by real-time road traffic monitoring can potentially provide information regarding traffic jams and accidents. With such information, traffic management centers are enabled and supported to react quickly to incidents and intelligent transportation system (ITS) measures, such as the closure of a lane or temporary usage of the hard shoulder, can automatically be imposed.

Different technologies are currently used for traffic monitoring systems where sensors are either installed overhead, under, or next to the road to detect traffic flow [1]. Such sensors could be lasers scanners [2], infrared [3], radar [4], [5], ultrasonic [6], [7], magnetic [8], [9], acoustic [10] or video cameras [1], [4]. Passing vehicles can cause changes in the magnetic field that are then processed to measure the flow of vehicles [8], [9]. Acoustic-based monitoring measured by a microphone array were also proposed [10]. Another method for traffic monitoring is through crowd-sourcing of smartphone connection data [11] or from fleets of vehicles equipped with GPS systems ("floating car") [12]. Sensors installed under the road surface come with the disadvantage of high cost due to constant need for repair and maintenance while sensors placed overhead or next to the road such as cameras are susceptible to adverse weather conditions [1].

Distributed acoustic sensing (DAS) is a technology that allows a seamless, real-time monitoring of the traffic situation over large distances of up to 50 km without additonal roadside installations. It uses fiber optic cables, already installed next to the roads for data- and communication-networks (telephone, internet), as a distributed detector. The advantage is that the fiber cable infrastructure typically installed at high density in the urban environment can be reused, as it is, for traffic sensing by connecting an optical "interrogator" instrument to one end of an unused fiber. The technique allows the detection of very small changes in the optical fiber cable, such as the mechanical strain caused by microscopic deformations from vibrations of the cars running nearby.

DAS measurement results on road traffic flow have already been presented in smaller studies in the urban environment and over relatively short distances of 1000 m and were compared to measured vehicle counts [13]. In this work, we present first results of distributed acoustic sensing (DAS) for road traffic monitoring over a long distance of approx. 19 km between the location of the interrogator device and the monitored road section and we compare the derived average speed to reference speed measured with a conventional roadside loop detector.

3 DISTRIBUTED ACOUSTIC SENSING

DAS systems work by sending short laser pulses through a fiber optic cable where the light is scattered via Rayleigh scattering and the light returning to the source is analyzed to infer information. In DAS systems, optical fibers with a length up to 50 kilometers can be used. The fibers used are typically already installed in the ground, parallel to a highway, for telecommunication purposes where it can be kilometers long and any disturbances along the fiber can be measured. An interrogator device connected to one end of the fiber transmits a series of laser light pulses into the fiber cable, as shown in Figure 1.

In the glass of the optical fiber there is an effect present that causes a continuous "reflection" of the light along the fiber. Rayleigh scattering is caused by inhomgenities in the glass and is actually a different mechanism than reflection, but for the sake of simplicity one can depict the Rayleigh scattering effect as light being reflected on a myriad of microscopic mirrors embedded in the glass. Therefore, for a single laser pulse being coupled into the fiber, instead of many distinct reflected pulses a continuously distributed signal is returned from the fiber. The scattered light has the same frequency as the impinging light wave and can be analysed by optical means. The vibrations generated by the passing cars and trucks stretch and compress the optical fiber affecting its optical path length. This induces a measurable phase shift in the back scattered light which is sensed by interferometric methods. Probing the fiber with a laser pulse of high repetition frequency (2 kHz) allows to analyse the vibration spectrum produced by nearby vehicles, distinguishing them from other vibration sources and tracking their time-location trajectories along the cable. In this work we demonstrate that with these changes in the signal induced by passing vehicles, relevant traffic information can be derived.

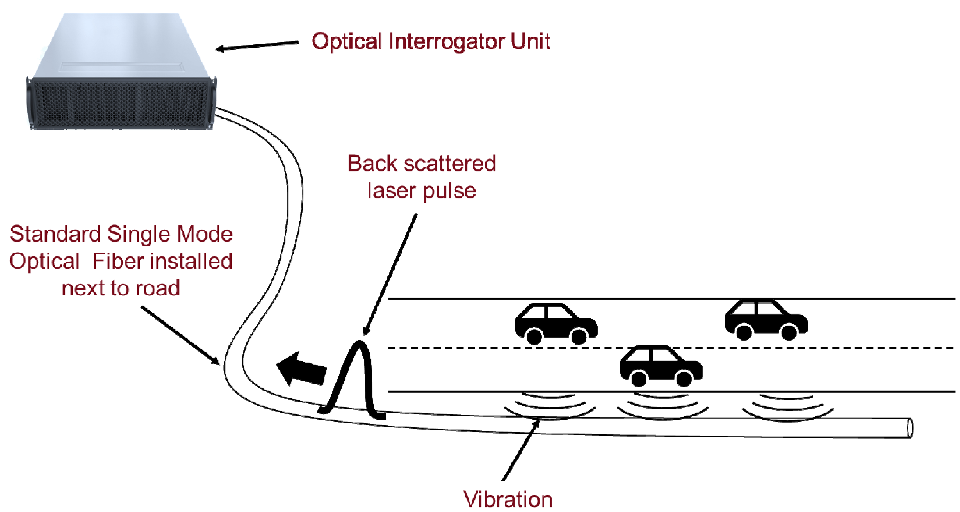

Fig. 1: Principle of the DAS measurement for traffic situation monitoring.

4 EXAMPLE TRAFFIC MONITORING RESULT

We have performed traffic flow measurement from a highway section of approx. 600 m length and with 19 km distance from the interrogator device, recorded over 60 minutes, with the fiber optic cable being installed next to the road. From the image representation of the spectral power of raw DAS signals the trajectories of the vehicles running on the road have been identified. After threshholding of the spectral power diagram, we obtain a binary 'image' of vehicle tracks as a time-location diagram (cf. Figure 2). From this representation we have extracted the incident angles of the tracks that represent the vehicles' speed. We have used image processing techniques, specifically Hough transformation, to extract the angles from the image data and averaged the speed results over 1 minutes time intervals.

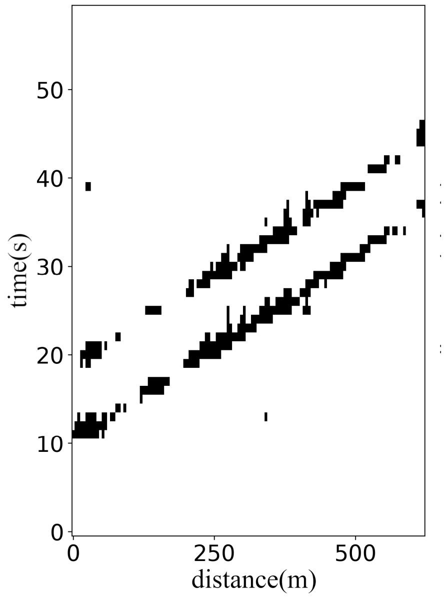

Fig. 2: Binary image vehicle trajectory representation of two vehicles produced from raw DAS data.

Comparision with loop counting data reveiled that the DAS signal mainly contained the truck trajectories. The resulting estimation has therefore been compared to the average speed reference of the trucks. Figure 3 shows that the majority of the deviations in the 1 minute averages between speeds from DAS trajectories and measured truck speeds is below ±10 km/h .

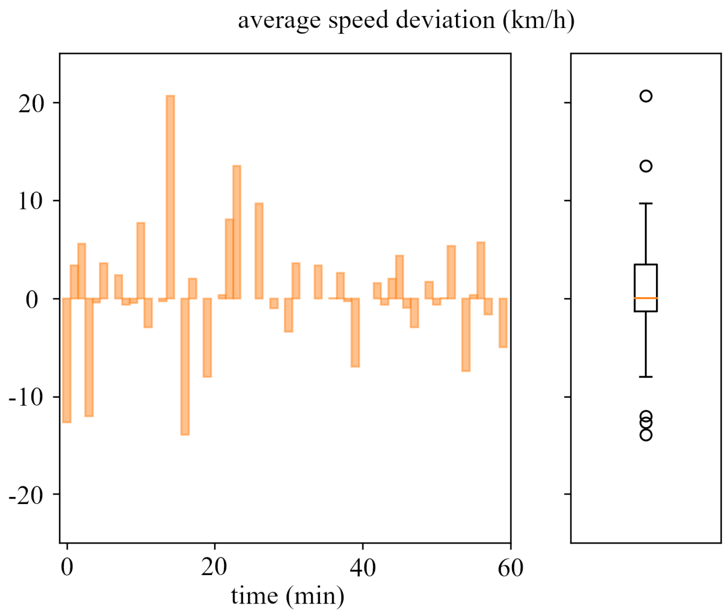

Fig. 3: Average 1-min. speed deviation between DAS speed estimation and reference induction loop data for trucks. The boxplot is based on interquantile range with whiskers = 1.5 and line depicting median point.

5 CONCLUSION

In this paper we demonstrated the potential of distributed acoustic sensing (DAS) for traffic situation monitoring applications using existing fiber optical infrastructure for telecommunication. Real-time traffic

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information on average vehicle speed has been estimated and compared to reference data from induction loops. The results show that the majority of the 1-minute time intervals showed less than 10 km/h deviation from the reference value. Given that DAS systems only require the installation of an interrogator device connected to one end of an existing fiber-optic cable infrastructure, the presented solution requires low-cost road-side maintenance and installation. An additional advantage of a DAS-based traffic situation monitoring system is its long-range capabilities with minimal sensors required. Even though our current algorithm was only able to detect trucks near the fiber-optic cable, we plan to further improve the sensitivity of the detection algorithm to reliably detect passenger vehicles and also vehicles on lanes farther away from the cables.

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