Initial Attempt of Acoustic Vehicle Detection under Strong Wind

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***Abstract*—Vehicle detection is one of the common tasks in the ITS (intelligent transport system). This paper presents a wind-tolerant acoustic vehicle detector relying on two microphones at a sidewalk, which is easily deployed at a low cost. Our vehicle detection system estimates TDOA (time difference of arrival) of sound signals on the two microphones to detect vehicles. A simple filter is applied prior to the TDOA estimation to overcome wind noise. Initial experiments demonstrate that our vehicle detector successfully detected vehicles with an F-measure of 0.77.**

***Index Terms*—ITS (intelligent transport system), vehicle detection, acoustic sensing.**

I. INTRODUCTION

The past decade has seen the rapid development of ITS (intelligent transport system). The main purpose of the ITS is to improve the safety, efficiency, dependability, and cost effectiveness of transportation systems.

Vehicle detection is one of the fundamental tasks in the ITS. We are developing an acoustic vehicle detector that comes with low deployment and maintenance costs [1, 2]. Our vehicle detector relies on two microphones installed at a sidewalk, which drastically reduces cost in terms of roadwork. We draw a sound map, i.e., a map of TDOA (time difference of arrival) of vehicle sound and analyze the sound map finding curves drawn by passing vehicles to detect vehicles.

Our acoustic vehicle detector, however, highly fails to detect vehicles under strong wind condition. Wind noise due to high wind spoils vehicle curves drawn on a sound map. The damaged sound map is difficult to analyze, which increases false positive detections.

We therefore present an initial attempt to overcome the strong wind in our acoustic vehicle detection system. The key idea behind the wind-tolerant acoustic vehicle detection is that our vehicle detection method detects vehicles with a part of frequency components of vehicle sound. We experimentally analyze frequency components of wind noise and design a filter to exclude the wind noise. We tested our vehicle detector with real sound data collected in a Kyushu university campus. The experiment results reveal that our vehicle detector successfully detected vehicles with an F-measure of 0.77.

II. WIND-TOLERANT ACOUSTIC VEHICLE DETECTOR

Figure 1 shows an overview of wind-tolerant acoustic vehicle detector. The wind-tolerant acoustic vehicle detector consists of a sound retriever, sound mapper, and vehicle detector.

A sound retriever is two microphones followed by filters to reduce the influence of noise. LPFs (low-pass filters) reduce high frequency environmental noise and wind noise filters reduce wind noise. The cut-off frequency of the LPFs is set to 2.5 kHz because majority of frequency components are less than 2 kHz. For a wind noise filter, we apply a high pass filter as an initial attempt because the wind noise is dominated by frequency components less than 500 Hz.

Filtered sound signals are passed to a sound mapper, where sound delay, i.e., TDOA (time difference of arrival) between the two microphones, is calculated to generate a sound map. Consider that two microphones M_1 and M_2 are installed at a sidewalk separated by distance D at L away from a target road, as shown in Fig. 2. The sound delay Δt is calculated from sound traveling distance d_1 and d_2 as

$$\begin{aligned}\Delta t &= \frac{d_1 - d_2}{c} \\ &= \frac{1}{c}\left\{\sqrt{\left(x+\frac{D}{2}\right)^2 + L^2} - \sqrt{\left(x-\frac{D}{2}\right)^2 + L^2}\right\},\end{aligned} \tag{1}$$

where c is the speed of sound in air and x be the location of a vehicle.

Vehicle position is calculated from sound delay Δt using Eq. (1). We can estimate a sound delay by finding a peak of a cross-correlation function $R(t)$ defined as

$$R(t) = \int s_1(t)\, s_2(\tau + t)\, d\tau, \tag{2}$$

where $s_1(t)$ and $s_2(t)$ are sound signals on two microphones.

Figure 3 shows an example of sound map. When a vehicle passes in front of microphones, sound delay Δt increases or

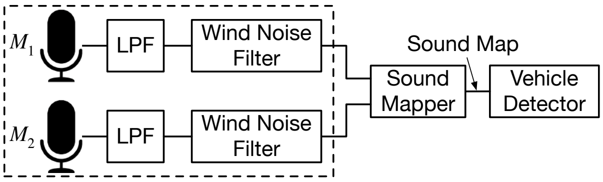

Fig. 1. Overview of wind-tolerant acoustic vehicle detector

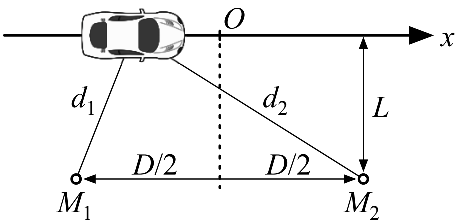

Fig. 2. Microphone setup

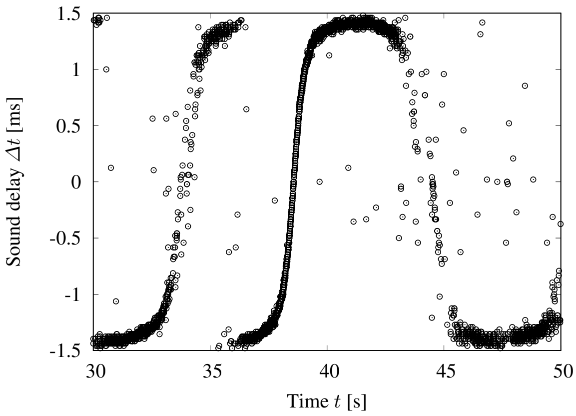

Fig. 3. Example of sound map

decreases drawing an S-curve. The direction of an S-curve depends on moving direction of a passing vehicle.

A vehicle detector finally detects vehicles using a RANSAC (random sampling consensus) robust estimation method to fit the sound delay model given by Eq. (1) to curves on a sound map. RANSAC estimates the location x of a vehicle in Eq. (1) from sound map data points.

III. Initial Evaluation

As an initial evaluation, we conducted experiments to evaluate basic performance of our wind-tolerant vehicle detection system. Figure 4 shows an experiment setup. We installed two microphones separated by 50 centimeters at approximately two meters away from the 2-lane road center. Vehicle sound was recorded for approximately 20 minutes using a Sony PCM-D100 recorder with AZDEN SGM-990 microphones. The sound was recorded with a word length of 16 bits at a sampling frequency of 48 kHz. The video monitoring the target road was recorded with a Sony HDR-MV1 video recorder, which was used as ground truth data. We also measured wind speed with a Kestrel 5500 wind speed meter during our experiment. Comparing the detection results with the ground truth, we evaluated the numbers of true positives (TPs), false positives (FPs), and false negatives (FNs). We also calculated precision, recall, and F-measure.

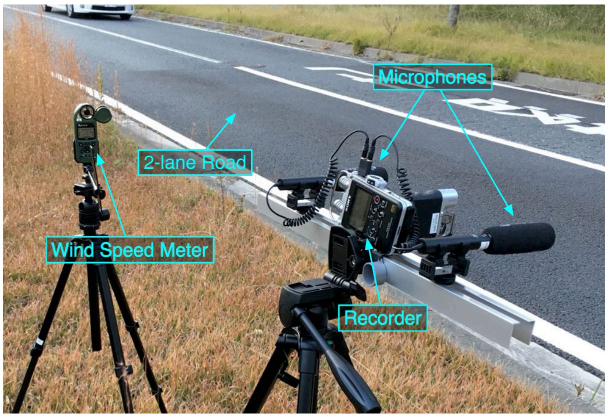

Fig. 4. Experiment setup

TABLE I
Experiment Results

(a) w/ wind noise reduction

	Left to Right	Right to Left	Total
TPs	69	37	106
FNs	15	12	27
FPs	27	8	35
Precision	0.72	0.82	0.75
Recall	0.82	0.76	0.80
F-measure	0.77	0.79	0.77

(b) w/o wind noise reduction

	Left to Right	Right to Left	Total
TPs	67	37	104
FNs	17	12	29
FPs	49	23	72
Precision	0.58	0.62	0.59
Recall	0.80	0.76	0.78
F-measure	0.67	0.68	0.67

Table I summarizes the the numbers of TPs, FPs, and FNs. Precision, recall, and F-measure calculated the numbers of TPs, FPs, and FNs are also shown in the table. We can confirm that our wind noise reduction method effectively improves vehicle detection performance. Our vehicle detector successfully detected vehicles with an F-measure of 0.77.

IV. Conclusion

This paper presents a wind noise reduction method for acoustic vehicle detection system. Wind noise is dominated by sound signals of frequency components less than 500 Hz. We therefore reduced the wind noise using a simple high pass filter in this paper as an initial attempt. Initial experiments reveal that our wind-tolerant acoustic vehicle detector successfully reduces false positive detections and achieved an F-measure of 0.77.

Acknowledgment

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