Initial Evaluation of Acoustic Vehicle Count System utilizing Dynamic Time Warping

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1.　Introduction

Increasing attention has been focused on the intelligent transportation system (ITS) due to the change of road transportation strategy. The main purpose of ITS is to improve the safety, efficiency, dependability, and cost effectiveness of our transportation system. In the past decade, products like car navigation systems have brought the ITS to daily life. According to a market research report, ITS market is expected to grow at a CAGR of 11.57 % between 2015 and 2020, and reach $33.89 billion by 2020 [1].

With the ITS market maturing, practical problems such as cost in product installation and maintenance have been brought to our attention. Especially, cost reduction in vehicle count system is in main concern because vehicle counting is one of the fundamental tasks in the ITS. Although vehicle counters based on sensors such as infrared, ultrasound, and camera are currently available, these traffic counters are suffered from high installation and maintenance costs due to their physical restrictions on deployment.

We therefore propose an acoustic vehicle count system that comes with low installation and maintenance costs. Our vehicle count system relies on two microphones at a sidewalk. We employ a signal processing technique presented in [2] to draw a *soundmap*, i.e., a map of time difference of vehicle sound on the two microphones. To count vehicles, we develop a vehicle count technique using dynamic time warping (DTW). Because sound waves are diffracted over obstacles, we can deploy the microphones in a low height configuration with less restrictions, which drastically reduces installation and maintenance costs.

By conducting experiments in our university, we confirmed that our vehicle count system successfully counted vehicles with a precision of 0.92.

2.　Related Works

Current traffic counters are divided into two types, intrusive and non-intrusive.

The most widely used intrusive traffic counters are loop coils and photoelectric tubes. These traffic counters share the same defect that they have to be installed under the road surface. The installation and maintenance of these counters is by far the most dominating cost factor in their life cycle.

Non-intrusive counters including laser, infrared, ultrasound, radar, and video are supposed to overcome the cost problems, yet they have their own problems instead. The majority of counters are based on laser, infrared, or ultrasound. These counters are capable of single-lane detection and need to be set over the road for better performance, resulting in high installation and maintenance costs. Radar-based devices could

be installed by the roadside, which is great for cost reduction in installation and maintenance. However, radar devices will make the electromagnetic spectrum more crowded as they must transmit radio waves. Finally, video surveillance still needs human to participate in most cases because the high demand of computation power resulting in the need of expensive devices, whereas hiring someone is cheaper.

We therefore need a new solution comes at a low price and being able to keep track of the traffic flow information in a realtime manner.

3.　System Design

Figure 1 depicts an overview of our acoustic vehicle count system. Our vehicle count system consists of two microphones and three signal processing blocks: low-pass filters (LPFs), soundmapper, and vehicle counter. We install two microphones at a sidewalk of the road and record vehicle sound. The LPF removes high frequency noise and the soundmapper calculates cross-correlation between sounds on the two microphones to draw a soundmap. Finally, we apply a vehicle count algorithm using dynamic time warping (DTW).

In the following subsections, we present design details of the soundmapper and vehicle counter.

3.1　Soundmapper

A soundmap is a time series data keeping track of sound arrival time difference between two microphones. As shown in Fig. 2, we install two microphones separated by D by the road at the distance of L. Sound signals generated by a vehicle on the road reach the two microphones with different traveling distance. Let x be the location of a vehicle. The sound delay Δt between two microphones is calculated as $\Delta t = (d_1 - d_2)/c$, where c is the speed of sound in air. We therefore derive

$$\Delta t = \frac{1}{c}\left\{\sqrt{\left(x + \frac{D}{2}\right)^2 + L^2} - \sqrt{\left(x - \frac{D}{2}\right)^2 + L^2}\right\}. \qquad (1)$$

Using Eq. (1), we can locate a vehicle from sound delay. Sound delay can be derived by cross-correlation function defined as $R(t) = s_1(t) * s_2(t)$, where $s_1(t)$ and $s_2(t)$ are sound signal on the two microphones and $*$ denotes the convolution operation. The cross-correlation function become maximum at $t = \Delta t$. We use generalized cross-correlation (GCC) [3] to calculate the cross-correlation function and find a peak of the cross-correlation function to estimate the sound delay.

A typical soundmap, i.e., sound delay Δt as a function of time, is shown in Fig. 3. As a vehicle passes in front of the microphones, sound delay increases or decreases drawing
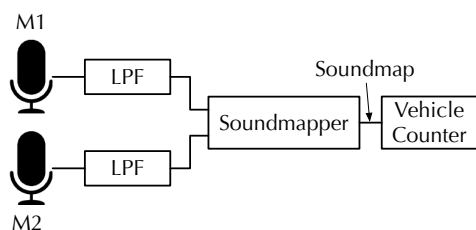

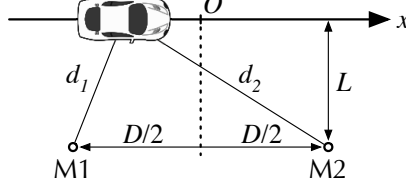Figure 1　Overview of acoustic vehicle count system
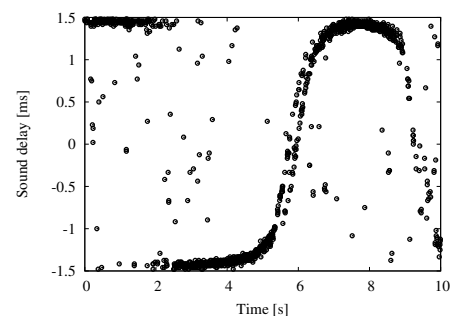

Figure 2　Acoustic sensor setup

Figure 3　Example of soundmap
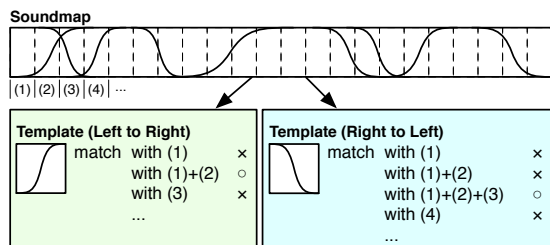
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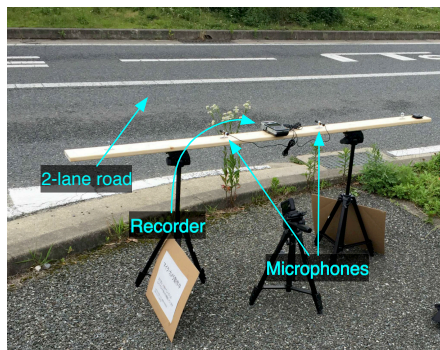
Figure 4 Vehicle count using DTW

Figure 5 Experiment setup

an S-curve; direction of the vehicle decides the direction of the S-curve.

3.2　Vehicle Counter

Our vehicle count algorithm is a template matching using dynamic time warping (DTW). The DTW is an algorithm for measuring similarity between two temporal sequences which may vary in time or speed. An S-curve on soundmap varies in time dimension due to the variation of vehicle speed. Our vehicle count algorithm easily adapts to the vehicle speed variation using DTW.

Prior to apply the vehicle count algorithm, we need to prepare templates of vehicle soundmap. Because the direction of an S-curve on soundmap depends on the vehicle direction, we prepare templates for each vehicle direction and separately apply the algorithm.

Figure 4 shows an overview of our vehicle count algorithm. To compare a soundmap with the template, we first divide the soundmap into fixed-length chunks. Comparison is performed between the first chunk and the template. If the chunk unmatches the template, i.e., DTW distance is bigger than a threshold, we combine the chunk with the next chunk and compare again. When the combined chunks match the template, vehicle is detected. We go on to the next chunk to detect more vehicles.

Although the DTW-based count algorithm is effective to adapt to vehicle speed variation, detection results include many errors because of the simple shape of an S-curve. We therefore apply a simple filtering method based on L2 norm of the soundmap sequence to reduce error detections.

4.　Evaluation

As an initial evaluation, we conducted experiments in our university evaluating the basic performance of our vehicle count system.

Figure 5 shows an experiment setup. The target road has two lanes; one side one lane. Two microphones were installed approximately two meters away from the road center. Distance between the two microphones was 50 centimeters. We recorded vehicle sound for about 25 minutes using an OLYMPUS ME30W recorder with PCM-D100 microphones. Sampling rate of the sound was 48 kHz. We also recoded video monitoring the road, which is used as ground truth data.

Figure 6 shows a detection example of vehicles moving right to left. Vertical red lines indicate detected vehicles. Using
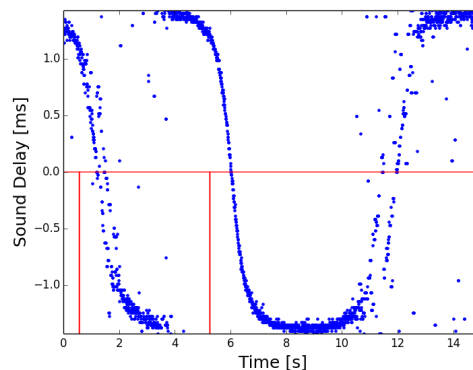

Figure 6 Example of vehicle detections (right to left)

Table 1 Experiment results

	TP	TN	FP	FN
Left to Right	32	—	4	7
Right to Left	63	—	4	14
Total	95	109	8	21

such a figure, we counted vehicle detections for each vehicle direction and sum the results to derive a total result.

Comparing the vehicle detections derived by our system with the actual number of vehicles derived by a camera, we evaluated the number of true positives (TPs), true negatives (TNs), false positives (FPs), and false negatives (FNs). Note that the number of inter-vehicle intervals are counted as the number of true negatives, which is only defined for the total result. We calculate accuracy, precision, recall, and F-measure using TPs, TNs, FPs, and FNs.

Table 1 shows the number of TPs, TNs, FPs, and FNs. Accuracy, precision, recall, and F-measure were calculated to be 0.88, 0.92, 0.82, and 0.87, respectively. The experiment result reveals that our vehicle count system exhibit high accuracy with small number of false detections and achieved high F-measure value. False negative detections were mainly caused by consecutive vehicle passing; two vehicles were detected as one vehicle. Our vehicle count algorithm performs template matching with non-overlapping windows, resulting in a false negative detection on the second vehicle.

5.　Conclusion

In this paper, we present an acoustic vehicle count system using dynamic time warping (DTW). Our vehicle count system relies on two microphones at a sidewalk and draw a soundmap, which is a map of time difference of vehicle sound on the two microphones. We developed a simple vehicle count algorithm based on template matching on the soundmap using DTW. We conducted experimental evaluations in our university and confirmed that our vehicle count system successfully counted vehicles with a precision of 0.92 with small number of false positive detections. However, the simple vehicle algorithm was suffered from a consecutive vehicle count problem. Further research is required to solve the consecutive vehicle count problem.

Acknowledgment

References

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