Design and Implementation of Train Detector using Rail-Side Microphone

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***Abstract*—For prevention of railroad crossing accident, we need to detect both trains and vehicles. In this paper, we propose an acoustic train and vehicle detection system that shares microphones to detect trains and vehicles. In our previous work, we have developed a vehicle detection system using stereo microphones. Here we present a train detection system using a microphone. Proposed system analyzes frequency components of the sound signals acquired by a railside microphone. The system calculate probability of train existence using logistic regression model and apply a hysteresis thresholding with two thresholds to detect train passing. Simple filtering based on train length is also applied to increase robustness to noise including vehicle passing sounds. We conducted experimental evaluations and confirmed that our train detection system successfully detected trains with F-measure of 0.987 and Recall of 1.0.**

***Index Terms*—Train detection, Acoustic sensor, Microphone**

I. Introduction

Railroad accident cause not only human damages but also social problems such as train delay, so prevention of railroad accidents is highly required. An accident between a train and vehicle at railroad crossing is one of the most common train accidents in Japan.

In order to prevent such railroad crossing accidents, we need to detect both trains and vehicles. Existing methods of train and vehicle detection, however, are separately installed, which implies that we need multiple systems to simultaneously detect trains and vehicles on a railroad crossing. Therefore implementation of such system is not sufficient in rural area. In rural area, We need a new low-cost approach that detects both trains and vehicles using a single sensor to apply the detection system.

We are developing a train and vehicle acoustic detection system that shares a microphone array to detect both trains and vehicles. The system analyzes sound signals of both trains and vehicles derived by a microphone array near a railroad crossing to detect trains and vehicles. Microphone is a cost-effective device, which places few physical restrictions on installation location of the detection system because sound signals are diffracted over obstacles.

In this paper, we present a train detection system using a microphone because we have developed a vehicle detection system using stereo microphone in our previous work [1, 2].

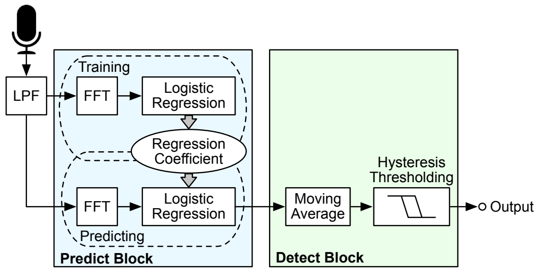

Fig. 1. Overview of train detection system

II. Acoustic Train Detection System

Figure 1 illustrates an overview of the train detection system. The train detection system consists of predict and detect block to analyze the sound signals acquired from a micro phone installed by a railway crossing. The LPF(low pass filter) is applied prior to the analysis to reduce the influence of high frequency environmental noise. The predict block calculates probability of train existence based on frequency components of sound signals acquired from the microphone.

In a predict block, we use a logistic regression model to estimate probability of train passing.

Logistic regression model is given by

$$P(Y=1|\mathbf{X}) = \frac{1}{1+e^{-\mathbf{AX}}}, \tag{1}$$

where $\mathbf{X} = {}^t[1, x_1, x_2, \ldots, x_n]$ is an input vector and $\mathbf{A} = [a_0, a_1, a_2, \ldots, a_n]$ is a regression coefficient vector.

Frequency components less than 1kHz of train passing sound, derived by the FFT (fast Fourier transform), is used as feature values in the logistic regression model.

On a training phase, regression coefficients are calculated by minimizing a cost function $C(\mathbf{A})$:

$$C(\mathbf{A}) = \frac{1}{N}\sum_{i=1}^{N} \log P(Y=Y_i|\mathbf{X}_i), \tag{2}$$

where $\{X_i, Y_i | i = 1, 2, \ldots, N\}$ is a training data set derived from the FFT.

On a predicting phase, feature values are extracted from test data. The probability of train passing is calculated by

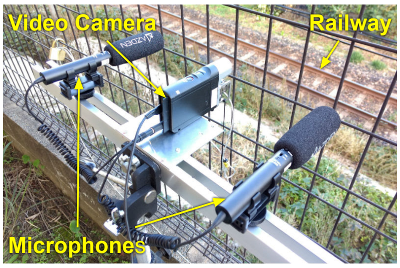

Fig. 2. Experiment environment

substituting the feature values in the logistic regression model. We finally apply a threshold to determine whether train is passing.

In a detect block, MA(moving average) over train passing probability derived from the predict block is calculated to reduce false positive detection due to noise such as vehicle sound. Considering train passing time, we apply MA over five-second data. To detect train passing, we perform hysteresis thresholding with two thresholds. If the averaged probability exceeds the higher threshold, the system detects a train head. If the averaged probability falls below the lower threshold, the system detects train tail.

III. Evaluation

We conducted experiment to evaluate performance of proposed train detection system. Figure 2 shows an experiment environment. We installed microphones near a railway and recorded train sound for approximately 10.5 hour. Video monitoring the railway was also recorded as ground truth data. We used 3.5-hour data for training and the remaining data was used for test. During our experiment, we observed 56 trains passed. The recorded sound data is analyzed by our train detection system. Comparing the detection results with ground truth, we evaluated the number of true positives(TPs), false positives(FPs), and false negatives(FNs). Using the numbers of TPs, FNs, and FPs, we also evaluated a precision, a recall, and F-measure defined as:

$$\mathrm{Precision} = \frac{\mathrm{TP}}{\mathrm{TP}+\mathrm{FP}}, \quad (3)$$

$$\mathrm{Recall} = \frac{\mathrm{TP}}{\mathrm{TP}+\mathrm{FN}}, \quad (4)$$

$$\mathrm{F}_{\mathrm{measure}} = \frac{2 \cdot \mathrm{Precision} \cdot \mathrm{Recall}}{\mathrm{Precision}+\mathrm{Recall}}. \quad (5)$$

Table I summarizes the evaluation results. We confirmed that our train detection system detected trains with an F-measure of 0.987. The system detected all passing trains. One false positive detection was caused by three noisy motorcycles passing successively.

Figure 3 shows the regression coefficients corresponding to each frequency component. As show in Fig. 3, the most impactive frequency component is 987Hz, and the least impactive frequency component is 47Hz. To evaluate impact of each frequency component, we consider the percentage of each corresponding regression coefficient to the sum of the

TABLE I
Experiment results

TPs	FNs	FPs
39	0	1
Precision		0.98
Recall		1.0
F-measure		0.99

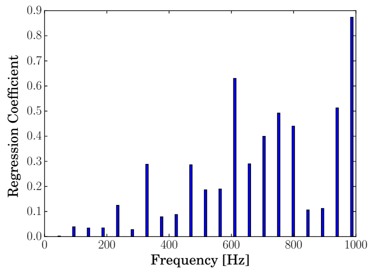

Fig. 3. Regression coefficient

regression coefficients. Frequency of 987Hz account for about 16% of the influence on train passing probability, Frequency of 47Hz account for about 0.04% of the influence.

Also we can confirm that the higher frequency component tend to effect greatly on train detection.

IV. Conclusion

In this paper, we presented an acoustic train and vehicle detection system. In our previous work, we developed a vehicle detection system using stereo microphones. Therefore we present a train detection system using a microphone. Proposed system analyzes frequency component of train sound using logistic regression to calculate the probability of train passing. Then, moving average and hysteresis thresholding is applied to detect train passing. We conducted experiment evaluation to demonstrate the detection performance of our train detection system. We confirmed that our train detection system successfully detected trains with an F-measure of 0.987 and recall of 1.0. Also we evaluated regression coefficients corresponding to each frequency component.

Acknowledgment

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