Vehicle Identification on Passing Lane Road using Bridge Acceleration Responses

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1. INTRODUCTION

Recently, vehicle-bridge interaction based approaches are widely used for bridge damage detection including techniques like vibration modal analysis. These approaches basically measure the bridge acceleration responses to extract modal parameters from free vibration regions [1]. During multiple vehicle traffic status, free vibration region is selected after the last vehicle has passed from the bridge. However, last vehicle identification either in driving lane or passing lane is difficult due to influence of the preceding vehicles.

In conventional systems, last vehicle identification is based on threshold-based approaches, which are specific to driving lane & are sensitive to identify presence of vehicle on passing lane. For example, a traffic status, where a truck & a car is present on driving & passing lane respectively, car vibration amplitude is buried in truck's vibration, thus difficult to identify car presence. To solve such problem, this paper proposes an unsupervised approach to identify the presence of vehicle on passing lane using acceleration responses, in a case, where vehicles are present on each lane of the bridge.

2. PROPOSED METHOD

The proposed method consists of 3 steps, first is feature extraction from acceleration signals, second step is cluster estimation and third step is vehicle identification by post-processing estimated clusters. The acceleration response is measured by 2 accelerometers shown in Fig. 1a(i), S1 & S2, located at bottom-side of bridge's concrete slab near entry-point of each lane.

In first step, frequency spectrum is calculated by applying short-term Fourier transform on each signal. The frequency spectrum is frequency-wise normalized by dividing amplitude sum of each frequency. A frame-wise sum of normalized spectrum is shown in Fig. 1a(ii) which shows peak-type pattern near axle location, because vehicle axle passing over sensor-point generates impulsive force that consist of higher frequencies, thus having higher normalized amplitudes. At each time-instant, maximum of frame-wise sum of normalized spectrum of S1 & S2 is selected, with an assumption that vehicle is passing over any one sensor position. In parallel, a binary matrix B shown in Fig. 1a(iii) is calculated, where value 1 represents presence of maximum value between frame-wise sum of normalized spectrum of S1 & S2. These maximum values are scaled in a pre-defined range to maximize the effect of peaks. Next, a time-repetition feature is generated, i.e., repetition of time-index value by its scaled magnitude value. A histogram of time-repetition feature shown in Fig. 1a(iv), illustrates high density of feature values near each vehicle presence.

The second step assumes each vehicle's response to fit a Gaussian distribution, as shown in Fig. 1a(iv) two vehicles passing over a bridge can be visually identified from time-repetition feature values. The clusters are estimated by applying Dirichlet process Gaussian mixture model [2] on time-repetition feature with assumption that estimated number of clusters i.e., Gaussian mixtures represent the number of vehicles.

In third step vehicle on which lane is identified, which requires start & end time of each vehicle and column-wise mean of corresponding rows of binary matrix B. To obtain start & end time, mean & standard deviation ($\mu \pm 3\sigma$) of each estimated Gaussian mixture is used. A column-wise mean of row-wise sliced matrix B is calculated, where row-wise sliced matrix B corresponds to start & end time of each vehicle. When column-wise mean value of sliced matrix B is greater than a pre-defined threshold, vehicle is detected in that lane corresponding to column, which again correspond to the sensors S1 or S2 of the matrix B. When the mean value in both the columns is below the pre-defined threshold, presence of a vehicle is detected in both of the lanes.

3. EXPERIMENTAL RESULTS

The experimental test was conducted at a real bridge to evaluate the proposed method. The passage of vehicles over the bridge is defined as an event, where each event is categorized by the number of vehicles in each lane by visually selecting from the recorded video files. In this paper we limit number of events, which consist of vehicles on both lanes of the road. In Fig. 1b & 1c top & side view of experiment setup is shown respectively. Accelerometers S1 & S2 are placed at bottom-side of entry-point of lane1 & lane2 of the bridge concrete slab respectively.

Table 1 illustrates the results of our offline evaluation, where, vehicle count (first column) represents number of vehicles present in each event & event count (second column) represents total number of events for each particular vehicle count. Our evaluation metric, accuracy in percentage (third column), represents number of events that were correctly estimated by the proposed method. It can be seen that proposed method identified vehicle in passing lane of the road in approximately 95% events out of total 240 events. In remaining 5% error events (traffic status of 2, 3 & 5 vehicle count), we examined that vehicles are either completely parallel or passing vehicle vibration is small, when compared to driving lane vehicle.

Keywords: Bridge health monitoring, Traffic status, vehicle identification, Non-parametric Bayesian.
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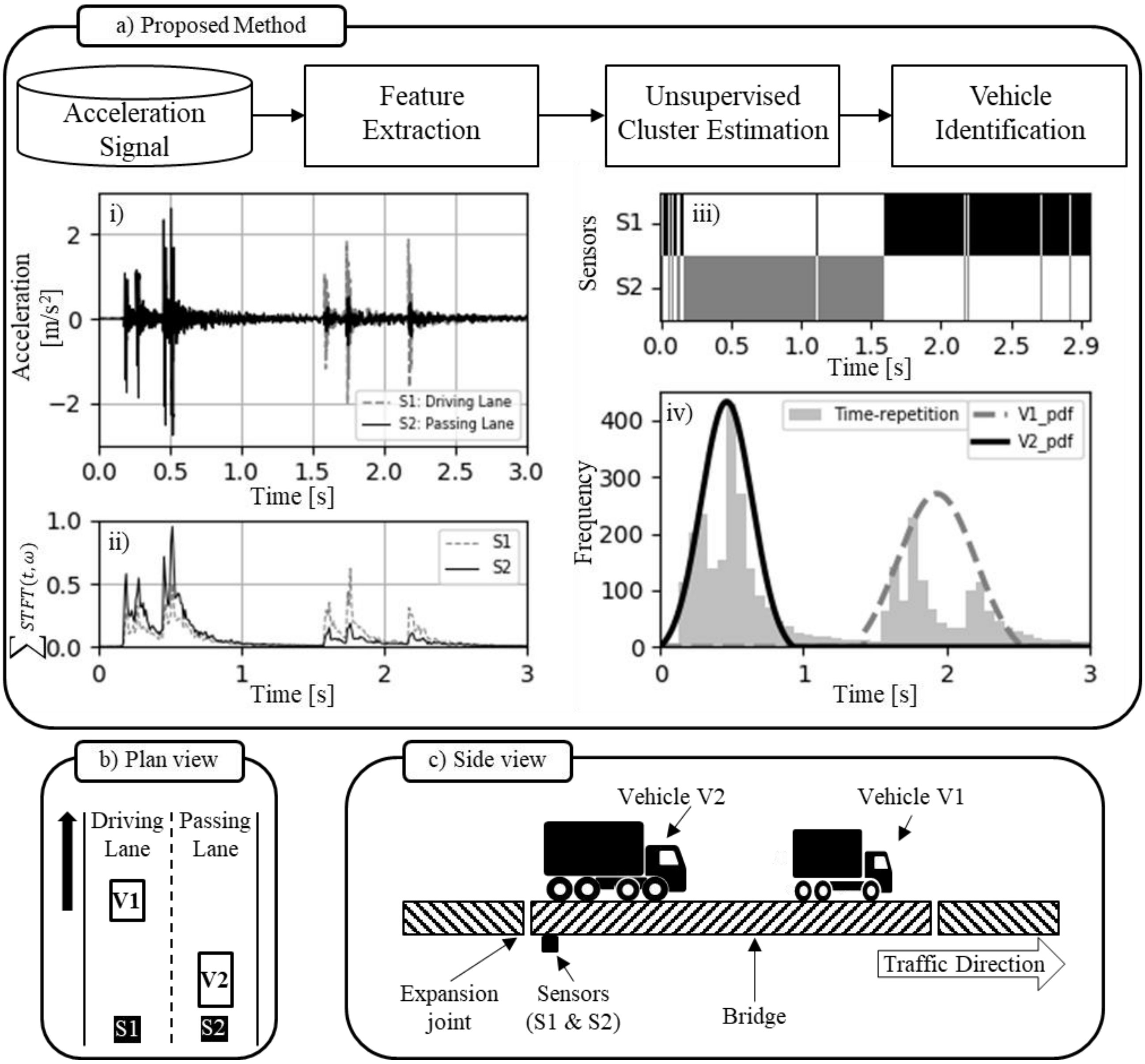

Figure 1: a) Block diagram of proposed method, following a); (i) Measured acceleration signals S1 & S2 ii) Frame-wise sum of normalized frequency spectrum iii) Binarized matrix of frame-wise sum iv) Histogram of time-repetition feature and estimated Gaussian densities; b) Top and c) Side view of measurement layout and traffic status

Table 1: Results for vehicle identification method with various traffic status

Vehicle count	Event count	Accuracy[%]
2	96	91.7
3	65	93.9
4	33	100.0
5	23	95.7
6	11	100.0
7	5	100.0
8	7	100.0
	240 (Total events)	94.6 (Micro-average)

4. CONCLUSIONS

A method for vehicle identification on passing lane road using bridge acceleration responses has been proposed. The time-repetition feature was extracted from the bridge acceleration responses to automatically estimate the presence of vehicles on the bridge. Experimental results showed that proposed method identified vehicle on passing lane with 94.6% accuracy in 240 events. In future, we plan to improve our method to identify completely parallel vehicles on the bridge considering small vehicle vibrations.

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6. REFERENCES

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