EXPERIMENTAL VALIDATION OF VEHICLE PARAMETER IDENTIFICATION FROM BRIDGE RESPONSES BY USING PARTICLE FILTER

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1. INTRODUCTION

Bridge vibration takes place when vehicles pass over the bridges. This unpleasant vibration is highly related with vehicle parameters, including vehicle mass. Fatigue problems may occur if the bridge suffers from large dynamic responses in a long time. Traditional Weigh-In-Motion (WIM) system usually used bridge strain to identify vehicle mass indirectly (Moses, 1979). However, high cost in time and money is needed for installation and maintenance. In this paper, the method of using bridge acceleration data to identify passing vehicle's mass is discussed and the experimental validation of the proposed method is described.

2. BRDIGE-VEHICLE SYSTEM

2.1 Vehicle Model

A half-car vehicle model is employed, which represents an ordinary two-axle vehicle. This model has 4 degrees of freedom, including vehicle body vertical movement, two axle movements and vehicle body rotation, as shown in Fig. 1.

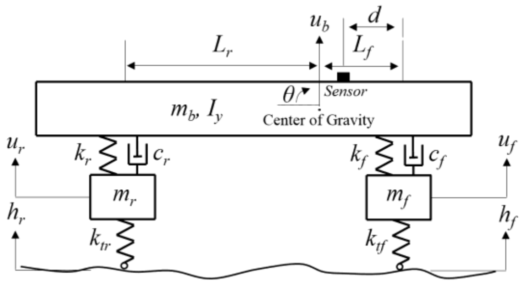

Fig. 1. Half-car model

2.2 Bridge Model

The bridge is modelled by a simply-supported beam for its simplicity. When the bridge is excited by vehicle load, the dynamic equation is expressed as in Eq. (1). Modal decomposition method is used to obtain bridge responses at different locations determined in advance.

$$m\frac{\partial^2 y(x,t)}{\partial t^2}+c_b\frac{\partial y(x,t)}{\partial t}+EI\frac{\partial^4 y(x,t)}{\partial x^4}=L(x,t) \tag{1}$$

where m is mass per length, c_b is damping coefficient, EI is flexural stiffness, $L(x, t)$ is time and space variant vehicle load and y is bridge displacement response.

2.3 Vehicle-Bridge Interaction

Vehicle-bridge interaction (VBI) describes the dynamic coupling phenomenon between a vehicle and a bridge (Zhu and Law, 2016). Non-flat bridge profile acts as the main excitation source to the vehicle on the bridge. Vehicle starts to vibrate when excited by the bridge profile and then gives dynamic load on the bridge. The bridge vibration takes place and the excitation to the vehicle is changed. In this paper, the VBI is considered through an iteration process, in which the bridge displacement is added to the profile after each iteration step. This process is shown in Fig. 2.

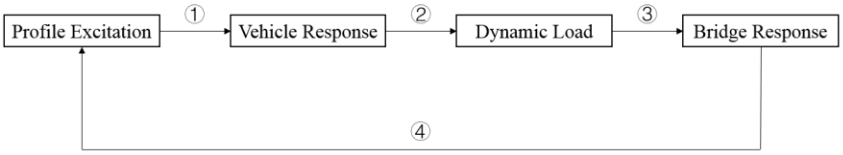

Fig. 2. Vehicle-bridge interaction

3. PARTILE FILTER

Particle filter is a sequential data assimilation method to estimate system state using measured data (Gordon et al, 1993). The idea of particle filter is to use a large amount of particles to represent the probability density function of dynamic state at each time step and estimate the optimal values of the state by sequentially introducing measured data. Two equations known as state equation and observation equation are used in particle filter step by step, as shown in Eq. (2).

$$x_{k+1}=f_k(x_k,w_k),\ y_k=h_k(x_k,v_k) \tag{2}$$

in which x_k and y_k are the state vector and observation vector at time step k and w_k and v_k are the system error and observation error following independent probability density function.

In this paper, the particle filter method is first utilized to estimate bridge profile (Zhao et al, 2017) with the consideration of vehicle-bridge estimation. The estimated profile is then considered as known value and used to identify vehicle mass. This estimation process is described in section 4.

4. EXPERIMENTAL VALIDATION

To verify the proposed algorithm, a field measurement was conducted at Tsukige bridge located in Chiba prefecture. This bridge is a 59-meter long simply supported box girder bridge and has a width of 4.7m. A Toyota hi-ace van with a mass of 1850 kg was chosen as the probe car for profile estimation and vehicle mass identification.

Keywords: Particle filter, Bridge vibration, Vehicle-bridge interaction, Profile estimation, Weigh-In-Motion
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4.1 Bridge Profile Estimation

The probe car was driven to pass over the bridge with sensors installed inside. Vehicle body acceleration above the front wheel and the vehicle body angular velocity is recorded. The recorded data is then integrated to obtain displacement and angle due to the requirement of observability. The estimated profile is shown in Fig. 3 and compared with the true profile measured by a portable profiler after a band-pass filter of 0.02-1.5 cycle/m. The bridge profile corresponds to the first 59 m and the rest is the road profile for the comparison purpose.

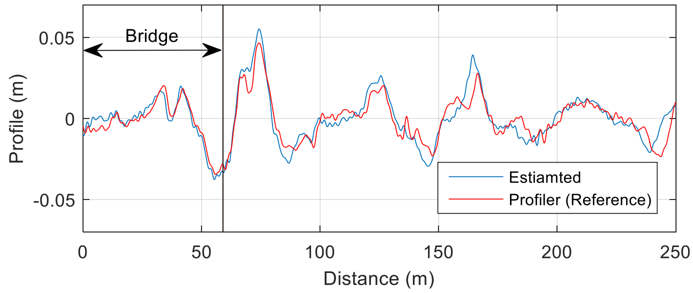
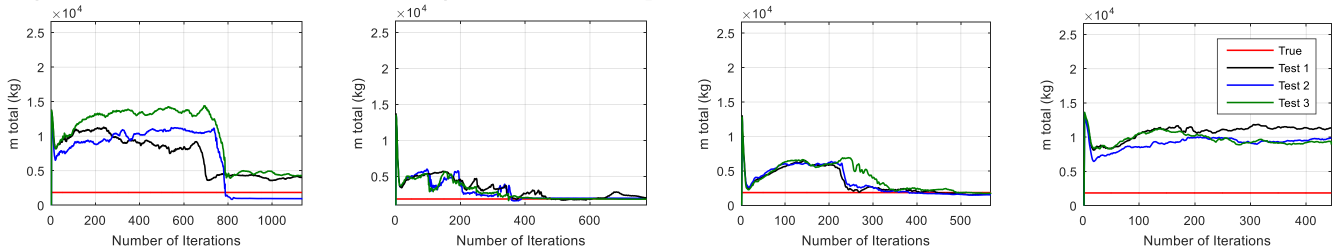


Fig. 3. Profile estimated through the particle filter method

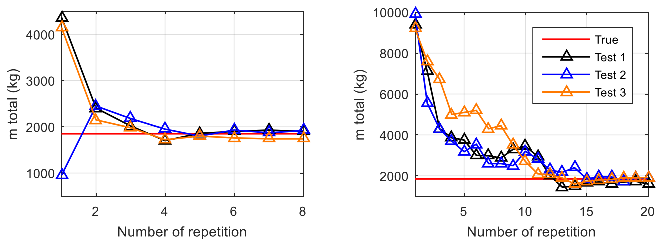
4.2 Vehicle Mass Identification

The estimated bridge profile in section 4.1 is taken as known value and used for vehicle parameter identification. Wireless acceleration sensors were located at mid-span, ¼ span and ¾ span of the bridge to measure bridge acceleration response. Three tests were conducted for each speed of 20, 30, 40 and 50 km/h. For 30 and 40 km/h cases, the vehicle mass soon converged to the true value after one round of particle filtering, as shown in Fig. 4(b)-(c). For 20 and 50 km/h cases, large estimation error were observed. The weighted global iteration method (WGI) is adopted (Hoshiya and Maruyama, 1987). The filtering process was repeated more to achieve higher accuracy. Before each repetition, the initial parameter distribution was reset to be ±15% of the converged value of last round. The results are shown in Fig. 5. The largest estimation error of 11.9% among all tests in four speed cases is observed.



(a) 20 km/h (b) 30 km/h (c) 40 km/h (d) 50 km/h

Fig. 4. Identified result after first round of filtering for 20, 30, 40 and 50km/h



(a) 20 km/h (b) 50 km/h

Fig. 5. Identified results for 20 and 50 km/h after WGI

5. CONCLUSIONS

A two-step method to identify vehicle mass from measured bridge responses is proposed. The method first uses a probe car to estimate bridge profile, which is the main excitation source to the passing vehicles. Vehicle mass identification is then conducted based on the knowledge about bridge profile. Particle filter is used in both process. The results show good accuracy compared with the true value and the proposed method is validated.

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