Identification of Vehicle Parameters from Bridge Acceleration Data by Using Particle Filter

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1. INTRODUCTION

Moving vehicles is one of the main sources of loads on bridges. Uncontrolled overload vehicles may result in excessive vibration and fatigue problem of bridge. Traditional Weigh-In-Motion (WIM) system usually utilizes the bridge strain data to calculate the vehicle mass (González et al, 2008), which usually incurs high cost in time and money for its installation and maintenance. This paper focuses on the extraction of vehicle parameters, including the vehicle weight, from the bridge acceleration response. A sequential data assimilation method known as particle filter is used to obtain vehicle parameters.

2. BRIDGE-VEHICLE INTERACTION SYSTEM

In a bridge-vehicle interaction system, the bridge surface roughness causes moving vehicles to vibrate, which, in return, lead to bridge dynamic response. In this section, profile roughness, a vehicle model and a bridge model are defined.

2.1 Bridge Surface Roughness

The bridge surface roughness is defined as the sum of a series of harmonics by adopting Eq. (1).

$$r(x) = \sum_{i=1}^{N} \sqrt{2G(n_i)\Delta n}\cos(2\pi n_i + \emptyset_i) \tag{1}$$

in which $r(x)$ is the surface roughness along the bridge, $G(n_i)$ is the one-sided power spectral density defined in ISO-8608 (1995). N is the total number of used waves. Δn is the frequency spacing and n_i is the i-th frequency component. $\emptyset_i$ is the random phase angle following the uniform distribution from 0 to 2π.

2.2 Vehicle Model

A four-degree-of-freedom half-car model which consists of 10 unknown parameters shown in Fig. 1 is employed. Three masses, four springs and two dampers are included in the model.

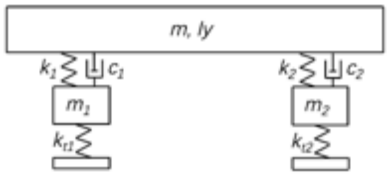

Fig.1 Half-car Model

2.3 Bridge Model

A simply-supported beam is selected as the beam model for its simplicity and good accuracy. Modal superposition is used to obtain the bridge response at different locations. The dynamic equation of the bridge model is expressed as

$$m_b(x)\frac{\partial^2 u}{\partial t^2} + \frac{\partial^2}{\partial x^2}\left[EI(x)\frac{\partial^2 u}{\partial x^2}\right] = p(x,t) \tag{2}$$

in which m_b and EI are mass per length and flexural stiffness, u is the bridge displacement, and p is the load on the bridge.

3. PARTICLE FILTER

Particle filter is a sequential data assimilation method (Nasrellah and Manohar, 2010). 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 (Lalthlamuana and Talukdar, 2015). Two equations known as state equation and observation equation are used in particle filter step by step, as shown in Eq. (3).

$$x_{k+1} = f_k(x_k, w_k), y_k = h_k(x_k, v_k) \tag{3}$$

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.

4. NUMERICAL EXAMPLES

In this section, a numerical example of identifying parameters of half-car model is given. First, the target value of each parameter is set, as shown in red line in Fig. 2. These values are assumed to be unknown during the particle filter process. For the bridge parameters, m_b = 16381kg/m, length L = 42.67m, EI = 1.67×10^{11}Nm^2, and the damping ratio of each mode is assumed to be 0.05. The first three natural frequencies of the bridge are 2.75, 11.01, and 24.76Hz. The bridge acceleration responses at mid-span, 1/4 span, and 3/4 span are calculated and are assumed as observed value. Normally, more sensors will give better results. The identification results show that all the parameters converge to the true values (see Fig. 2).

Keywords: Moving vehicles, Weigh-in-motion, Parameter identification, Particle filter, Bridge acceleration response
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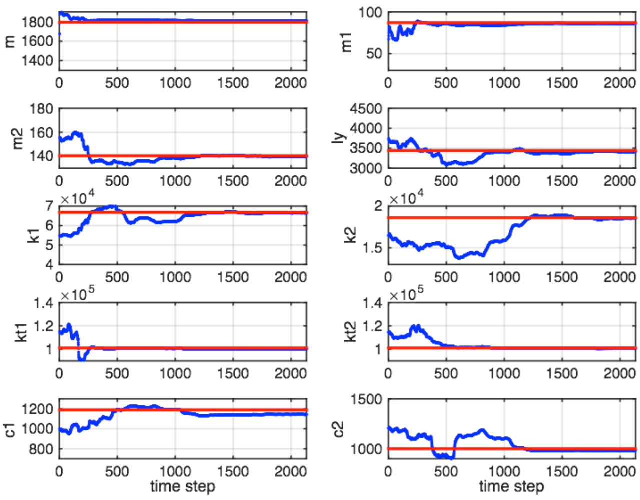

Fig. 2 Identification result of half-car model

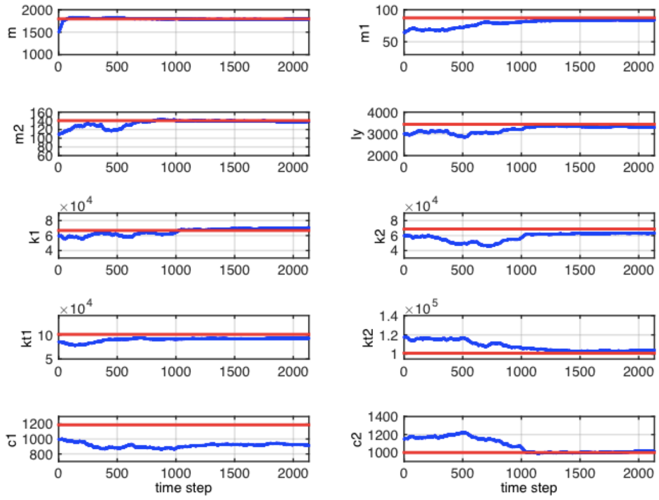

Fig. 3 Identification result with sensor and surface roughness noise

5. ROBUSTNESS AGAINST NOISE

Field test data is usually contaminated with noise. The response calculated from Eq. (2) is then added with artificial white noise following a zero-mean Gaussian distribution with standard deviation of 5% of the acceleration response amplitude. The noise is also added to the surface roughness; the noise shares the same spectral shape as the surface profile while the noise is scaled down to 10% of the roughness. The system error w_k and observation error v_k in particle filter are assumed to follow independent zero-mean Gaussian distribution and the standard deviation is empirically set at 20% and 0.2% of measured acceleration response respectively. The identified result is shown in Fig. 3.

It is shown that not all parameters converge to target value after first filtering. This process is then repeated with initial distribution set as the last step of first filtering. The errors after each filtering of identified results are shown in Table. 1.

Table. 1 Identification Errors

	m	m_1	m_2	Iy	k_1	k_2	kt_1	kt_2	c_1	c_2
1st	0.25%	3.61%	1.42%	3.28%	4.75%	8.18%	8.03%	2.36%	22.35%	1.30%
2nd	0.25%	0.29%	0.36%	1.25%	1.76%	1.64%	1.10%	0.51%	3.36%	0.70%

When the roughness noise is set as 20% and the standard deviation of sensor noise is set as 30% of the acceleration response amplitude, which is a very high level of noise, the result shows that the stiffness and damping parameters have large errors but the identified mass parameters are still reasonably accurate. The identified error is shown in Table. 2.

Table. 2 Identification Errors with high noise

	m	m_1	m_2	Iy	k_1	k_2	kt_1	kt_2	c_1	c_2
Error	1.67%	6.82%	5.00%	7.06%	13.51%	10.99%	9.90%	7.92%	13.03%	15.00%

6. CONCLUSIONS

In this paper, particle filter technique was used to identify ten unknown parameters of a half-car model. The surface roughness is generated from ISO-8608 as the input of the bridge-vehicle coupling system. The bridge response is simulated and sequentially introduced to the filter. The identified results match well with the target values.

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