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Damage Identification using Particle Filters

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Abstract

Structural health monitoring of civil engineering structures is a fundamental issue for structural safety and integrity, due to the fact that they will deteriorate after they are built and put into services. Within which, damage identification will be the most important problem. In this paper, a structural damage identification method based on particle filters, will therefore be introduced. The algorithm of the particle filter will be studied. The application of the proposed method to a lumped-mass shear frame structure will be made. The parameters of the stiffness and damping of each floor will be identified using the particle filters and analyzed. Parameters of the particle filter will be studied and their effect to the identification results will also be analyzed. Simulation of a single degree and multi-degree structure will be conduct to verify the effectiveness of the particle filter identification method. For each case, damage is deliberately introduced into the numerical model. Response signals will be collected and analyzed. Final identification results show that the proposed method can do the work very well and could be a promising approach for real applications.

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1 Introduction

As the most important part of structural health monitoring, damage identification includes four aspects, namely detecting the existence, the location, the severity of structural damage and useful life of this structure [1]. In recent years, structural identification method based on dynamic characteristics of structure tends to be a focused topic

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because of its good entirety and cost-effectiveness [2][3][4]. Due to the complexity of the engineering structures, however, the measured data and structural model of this method have strong uncertainty, hindering the application of structural identification in structural health diagnosis [5]. In this case, structural damage identification based on statistical theory is put forward.

The determination of statistical model is based on a large number of prior knowledge [6] or experimental verification. At present, statistical analysis method (especially time series analysis), regression model analysis and Bayesian theory analysis are widely used. Kalman filter is a kind of classic structures of Bayesian theorem and famous kalman filter method is established using a prerequisite that a problem can be described as linear Gaussian space model. On this basis, we can get the posterior distribution of analytical expression. Also, extended kalman filter method is also widely used when it goes to the non-linear cases.

With the increasing requirement for complexity and accuracy, filter based on Monte Carlo sampling is paid more attention to [7]. Particle filter is a method based on Monte Carlo simulation, recurrence and Bayesian estimation. As the same as other predictive filter, particle filter can be deduced from measurement space to state space through model equation [8]. Particle filter can not only effectively deal with complex nonlinear state estimation problem but also require no Gaussian distribution assumption, so it does not need any assumption when faced with more complex nonlinear model, satisfying the actual filter task more[9]. In this paper, damage identification based on particle filter will therefore be introduced.

2 Basic concept of the particle filter

Considering single-degree structure as an example and studying the performance of parameters identification of particle is the basis of further study of the particle filter algorithm. Without knowing the exact structural parameters, a wide range of the parameters are estimated in advance. Then comparing the simulated data with the observed data of samples in each time step, particles with larger weight value are saved while particles with smaller weight value are eliminated. Through this process, particles with the closest value to actual value are picked out.

Through this process, the most important is to produce the time-history response according to observed data. In this paper, all time-history responses are about acceleration. By comparing these responses that samples produce and observed, the actual value is calculated using following equation:

$$l_{i,j} = \frac{1}{\sqrt{2\pi}\sigma}\exp\left(-\frac{(x_{i,j}-x_{0,j})^2}{2\sigma^2}\right) \tag{1}$$

Among the equation, i represents sample types at each time step; j represents steps in the time interval. Assuming time interval is T and time step is t_p, then j can be calculated according to the following equation:

$$j = \frac{T}{t_p} \qquad (i = 1,2,\cdots,N_j,\quad j = 1,2,\cdots,6000) \tag{2}$$

In this paper, acceleration of Kobe earthquake is recorded in time interval [0s, 120s], time step is t_p=0.02s. Besides, the equation of weight calculation of particles is shown as Eq.3:

$$q_{i,j} = \frac{l_{i,j}}{\sum_{i=1}^{N_j} l_{i,j}} \tag{3}$$

After getting the weight of particles, average of particles' types $\frac{1}{N_1}$ can be used as screening measure (N_1 is how many types of initial samples). Particles with weight larger than $\frac{1}{N_1}$ are saved and others are eliminated. The number of samples, however, will become less and less after screening, so it comes to normalized problems and normalized equations are shown as below:

$$n_{i,j} = round\left(\frac{q_{i,j}}{\sum_{i=1}^{N_j} q_{i,j}} \cdot N_1\right) \tag{4}$$