STRUCTURAL HEALTH MONITORING USING AUTOREGRESSIVE MODEL WITH TIME WINDOW

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ABSTRACT

This paper presents a new structural health monitoring algorithm using acceleration signals. Damage is defined as abrupt changes in some parameters of the considered structure. Abrupt change means that change of system parameter occurs instantaneously due to severe events such as earthquake, typhoon, crash and so on. Autoregressive model is employed to estimate whether the system is damaged or not by changes of residual errors between measured and calculated acceleration. The key difficulty of structural health monitoring system is how to handle noises, whereas measured acceleration contain a mix of information related to both the damage in the structure and the perturbations due to the environment. A time windowing technique is utilized to consider perturbations due to the environment in available measurement data. The time window advances forward at each time step to predict residual step by step to detect damage of system parameters in time domain. An generalized extreme value distribution(GEV) is also adopted to raise reliability of proposed algorithm.

AUTOREGRESSIVE MODEL

Autoregressive (AR) model[1] is utilized to evaluate structural health monitoring system using acquired acceleration signals during a long time period. AR model is widely used stochastic model that can be extremely useful in the representation of certain practically occurring series. In this model, the current value of the process is expressed as a finite, linear of previous values and a random error e_t. Let us denote the values of a process at equally spaced times t, t-1, t-2, … by x_t, x_{t-1}, x_{t-2}, … then AR model of order p is shown in Eq.1.

$$x_t = f_1 x_{t-1} + f_2 x_{t-2} + \cdots + f_p x_{t-p} + e_t \tag{1}$$

Where, f is coefficients of AR model, e_t is random error in the measured signal at time t and p is order of AR model. AR model is expressed with coefficients as weighted regressive form. There are several methods to calculate coefficients of the AR model. Least square method is utilized for estimating coefficients of AR model. The optimal solution of Eq.1 is obtained by least square method. After decision of coefficients of AR model, foregoing signals can be predicted by using definition of AR model in Eq.1. If there is no damage in the structure then residual errors are very small. Residual errors will be highly increased when some problem occurs in the structure. By using this phenomenon, AR model can be utilized in structural health monitoring system.

$$\mathbf{f}(\phi)=\left[\sum_{t=p+1}^{N}\mathbf{g}_t(x)\mathbf{g}_t^{\,T}(x)\right]^{-1}\sum_{t=p+1}^{N}\mathbf{g}_t(x)x_t$$
$$\mathbf{g}_t(x)=[-x_{t-1}\cdots-x_{t-p}]^T,\ \mathbf{f}(\phi)=[\phi_1\cdots\phi_p]^T \tag{2}$$

Where, N is total number of measured signals in considered time period. N must be greater than twice of the order p of the AR model.

TIME WINDOWING TECHNIQUE

The key difficulty in structural health monitoring is perturbation of measured accelerations by environmental factors. Measured accelerations are slightly changed according to various factors of environment such as day and night, season, temperature and humidity and so on even if there is no problem in the considered structure. Previous methods suffer from this difficulty of environmental factors. Though a algorithm perform well in experimental data, it cannot be applied in real situation with perturbed accelerations. Time windowing technique is adopted to solve this problem. Environmental factors are commonly gradually changed during very long time period. In time windowing technique, residual errors are estimated using measured signals within finite time period which is called a time window. Time window size is relatively very smaller than environmental perturbation period so it is assumed that effects of environment can be neglected within time window.

GENERALIZED EXTREME VALUE DISTRIBUTION

Decision making using residual errors in every time step sequentially must be performed whether the considered structure is sound or not. It is unreasonable to decide health of the structure by merely the magnitude of residual errors. For more reliable decision making of structural health monitoring, we must find the distribution of residual errors and pick up outliers from the distribution of residual errors in a given significant level. Outliers almost lie in the tail of the distribution of residual errors. Extreme value distribution is utilized for an accurate selection of outliers because extreme value distribution is well established for tail distribution. The three type of extreme value distribution can be expressed in generalized extreme value distribution (GEV)[2,3]. Optimization process is utilized to find three coefficients of GEV. By minimizing difference between extreme value distribution and empirical cumulative density function, the optimal distribution of residual errors can be obtained

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