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Optimization method based on Generalized Pattern Search Algorithm to identify bridge parameters indirectly by a passing vehicle

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ABSTRACT

Generalized Pattern Search Algorithm (GPSA) has rarely been investigated for structural health monitoring, but may have potential application in civil engineering, because it does not require any gradient information of the objective function. Meanwhile, indirect identification is an attractive concept that recognizes the bridge parameters by the vehicle responses. This paper proposes a theoretical indirect identification method based on optimization method, and the implementation is performed by the GPSA. Firstly, the GPSA theory is investigated, and a simple example is employed to describe the process of the algorithm. Secondly, a theoretical indirect identification method is proposed, based on the optimization method rather than the conventional transforms from time domain to frequency domain. The proposed method can identify the parameters of the vehicle–bridge system, including the bridge stiffness and the 1st frequency. Based on the optimization method, the feasibility and accuracy of GPSA are demonstrated with 0.06% of errors. The GPSA shows good robustness in the identifications with various noise levels, and the maximum error is about 3.30% and can be accepted for the engineering application even with a SNR 5 noise level. The computation time relies only on the function evaluation times, and is not positively related to the noise level. Thirdly, the performance of GPSA is compared with that of Genetic Algorithm (GA). The accuracy of GPSA and GA are approximately equivalent with various noise levels. Compared with GA, GPSA needs fewer iterations and much fewer evaluations, therefore is more efficient in the identification with an almost consistent accuracy with various noise levels.

1. Introduction

Generalized Pattern Search Algorithm (GPSA) is a typical direct search method [1], proposed by Torczon in 1997 [2], and is reviewed by Lewis in 2000 [3]. GPSA does not require gradient information of the objective function, which inherits the superiorities of direct search methods. This differs from the general optimization methods, e.g., Genetic Algorithm (GA), which search for the optimal points based on the information of the gradient or higher derivatives.

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GPSA is widely researched in the applied mathematics and computation [4–6], and shows prospects in many engineering fields, e.g., nano-materials [7], electronics [8,9] and magnetic field [10]. In civil engineering, especially in structural health monitoring with possible un-derivative or un-continuous data, GPSA definitely shows great potential as an application.

Indirect identification, extracting the 1st bridge frequency from the vehicle responses, is theoretically proposed by Yang in 2004 and 2005 [11,12], explored experimentally by Yang in 2005 [13], and further investigated for parametric analysis [14] and inspected on Empirical Mode Decomposition (EMD) in 2009 [15]. The concept of indirect identification seems novel and attractive to bridge health monitoring, since the sensors are placed on a moving vehicle rather than on the bridge. With the indirect identification concept, the bridge health status is indicated in a more time-saving, cost and labor saving manner.

Presently, the main focus of indirect identifications is the structural frequency, which is the most basic parameters to indicate the bridge health status. The works are based on the transforms from time domain to frequency domain, e.g., Fast Fourier Transform (FFT) [11,12] or EMD [15]. Meanwhile, O'Brien identified the bridge damping, and performed another parametric analysis in 2009 [16].

In other words, only frequency information and damping are identified in these works. Other bridge parameter, e.g., the bridge stiffness, which demonstrates the health status more directly, cannot be achieved by the existing methods.

In this study, a novel theoretical indirect identification method is proposed, based on the optimization method. The indirect identifications of the proposed method are accomplished by the GPSA. The accuracy, efficiency and robustness of the identifications are discussed, and the results are compared with another optimization method, GA.

We highlight two aspects of this study:

1. A theoretical method is proposed for indirect identification in bridge health monitoring, in which more parameters can be identified indirectly besides the frequencies and the damping.
2. A new and effective algorithm for optimization problems, GPSA, is utilized in civil engineering.

2. Theory background

2.1. GPSA: a derivative-free optimization algorithm

GPSA is based on a simple concept that is easy to be implemented and is efficient when computed. It uses a sequence of points to approach a globally optimal point. The algorithm polls a set of points, called a mesh, around the current point of each iteration. The mesh is formed by adding the current point to a scalar multiple of vectors, called a pattern. The objective function value is calculated, and the poll is considered to be successful if the function value is smaller than the previous one [1–3,17–21].

One of the GPSA was presented by Torczon, which is adopted in this paper. The algorithm has the maximal positive basis set $2N$ vectors, where N is an independent variable. The algorithm can be summarized as follows:

Let $\in R^n$, $\Delta_0 > 0$, $\varepsilon > 0, = 0$.

Step 1. Compute $f(x_k)$.
Step 2. Determine an iterate s_k using an exploratory movement algorithm.
Step 3. Compute $\rho_k = f(x_k) - f(x_k + s_k)$.
Step 4. If $\rho_k > 0$
then $x_{k+1} = x_k + s_k$.
Otherwise, $x_{k+1} = x_k$.
Step 5. Update C_k, Δ_k, $k = k+1$.
where x_0 is the initial point,
Δ_0 is the initial step length,
ε is the threshold residual,
k is the step number.

If an improved mesh point is found, i.e., $f(x_k + s_k) < f(x_k)$, then $\Delta_{k+1} = \Delta_k$, where $\lambda_k \in (1, +\infty)$, as the mesh may be coarse. Otherwise, if x_k is a mesh local optimizer, then $\Delta_{k+1} = \theta \Delta_k$, where $\theta_k \in (1, +\infty)$. The whole process is preliminarily demonstrated in the following example.

2.2. GPSA investigation by a simple example

A simple example can be hypothesized as follows:

$$\min f(x) = x_1(x_1 - x_2 - 7) + 3x_2(x_2 - 1)$$

The initial point in this example is assumed to be:

$$x_0 = [0 \quad 0]$$