Inverse Analysis for Damage Identification Using MOPSO

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Problem Descriptions

The goal of this research is to utilize piezoelectric actuator to detect damage in railway track. In this research we demonstrate the damage detection and identification mechanism.

As shown in Figure 1, the piezoelectric (PZT) transducer is attached to a metal plate. When voltage is applied, the PZT patch can serve as an active sensor to acquire the admittance data, in which the damage information is included.

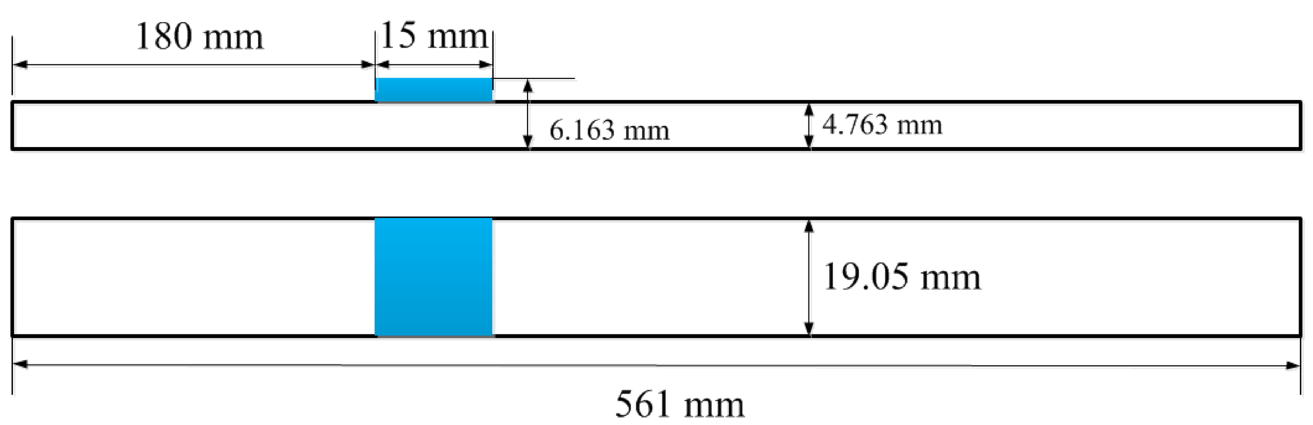

Figure 1 Geometry of Cantilever Plate and PZT patch.

From admittance change responses of the system, the damage location and severity can be identified inversely. This inverse process can be converted to an optimization problem, which is solved by **multi-objective particle swarm optimization algorithm (MOPSO).**

Admittance Data

Expression of admittance change is defined as:

$$\Delta \boldsymbol{A} = \begin{bmatrix} \Delta A(\omega_n) \\ \cdots \\ \Delta A(\omega_m) \end{bmatrix} = \boldsymbol{S}_{m\times n}\boldsymbol{\alpha}_{n\times 1}$$

where, $\Delta \boldsymbol{A}$ is admittance change vector, $\boldsymbol{S}$ is sensitivity matrix, which is obtained using finite element analysis. $\boldsymbol{\alpha}$ is damage index vector. ω is sweeping frequency. n is number of damage. As shown in Figure 2, there is a peak shifting due to damage occurrence. Therefore there is admittance change between healthy and damaged curve.

Then the m points can be sampled from that limited shifting area.

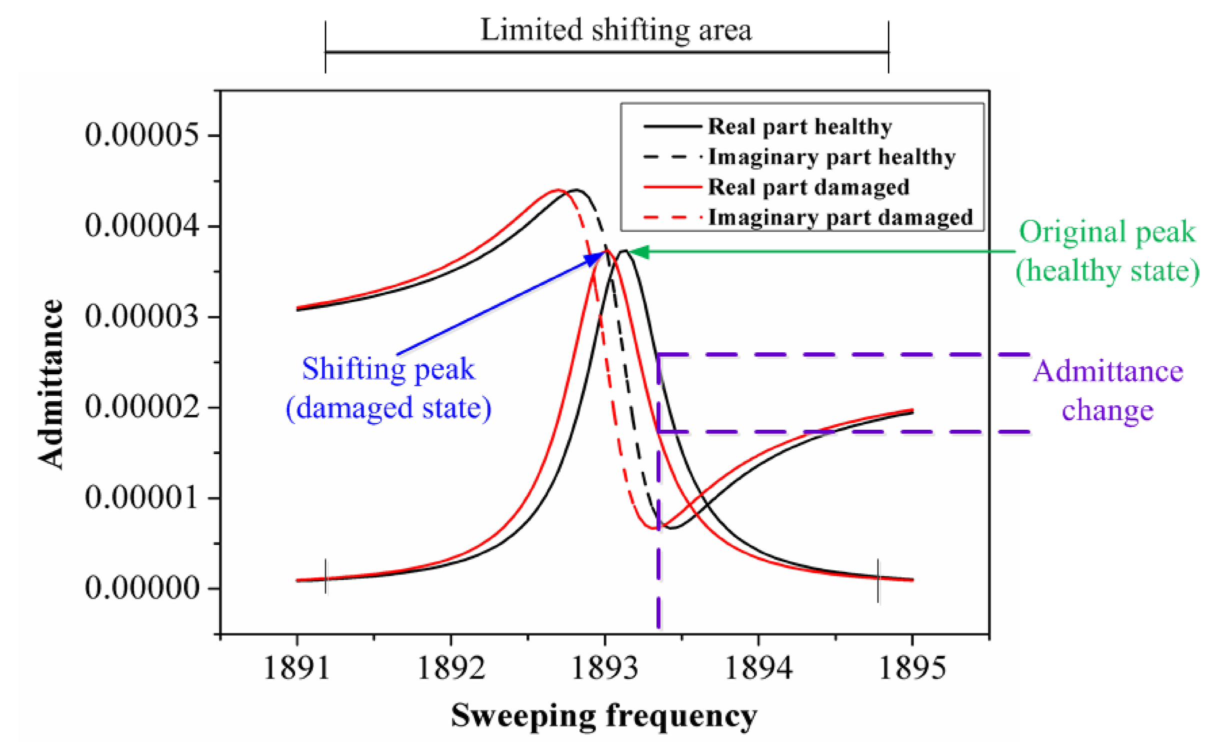

Figure 2 Admittance variation with respect to sweeping frequency.

Inverse Problem Definition

Since the sampled data points are limited or it means that m is far less than n. Then matrix inversion for $\boldsymbol{S}$ is prohibitive when solving unknowns . Therefore the inverse process is converted into an optimization problem defined as:

$$\begin{cases} \text{find} & \boldsymbol{\alpha} \in \boldsymbol{E}^n \\ \min & \left\| \Delta A - \Delta A_{meas} \right\|_2 \\ \min & \left\| \boldsymbol{\alpha} \right\|_0 \\ \text{s.t.} & \alpha_l \le \alpha_i \le \alpha_u \end{cases}$$

Here first objective function is comparison between admittance changes from finite element analysis and experimental measurements. Because the damage only affects a small area, then second objective is defined to determine the sparsity of the damage index vector.

MOPSO algorithm is used here due to its simplicity and flexibility. Each particle $x_i(t)$ can move toward to global best $g_{best}(t)$based on the two trajectory expressions, its working mechanism is shown in Figure 3.

The initialization method for the algorithm is devised as a grid space, so the particle can search at the intersection points of grid. This development is suitable for this optimization here that includes a discrete objective.

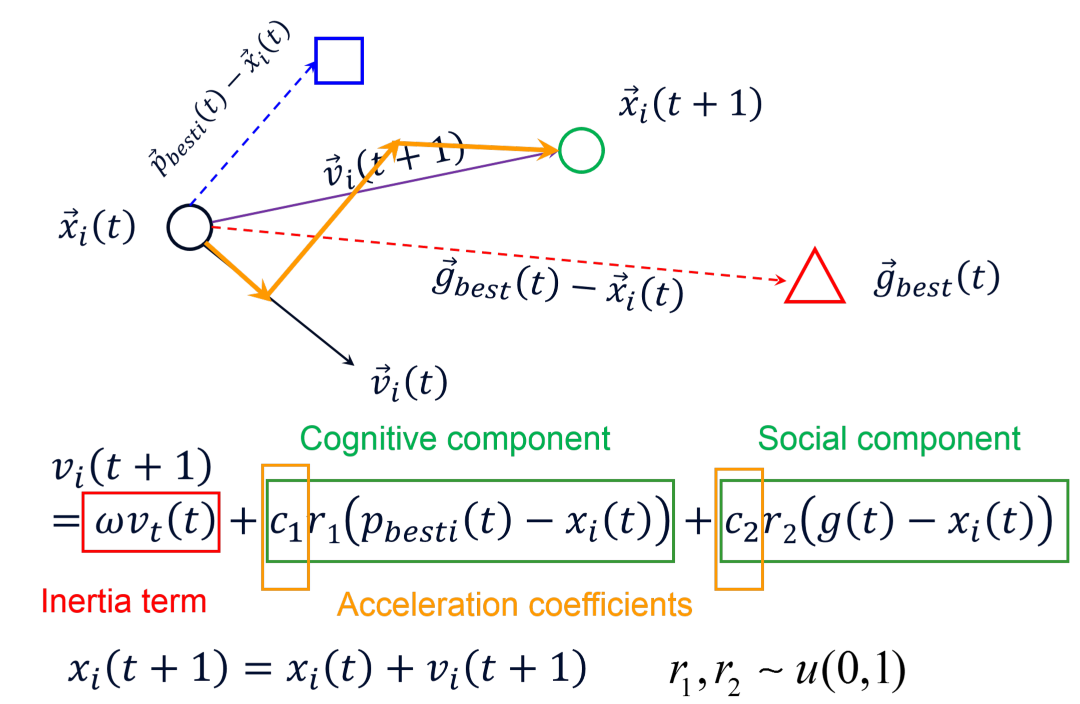

Figure 3 Diagram of PSO algorithm.

Results and Discussion

The testbed structure is divided into 25 segments for the purpose of damage identification. Two damage (stiffness reduction) cases are studied. One case with damage severity of 0.28% at segment 15. One case with damage severities of 1% and 2.8% at segments 8 and 13, respectively. The identified results are shown in Figure 4. The algorithm identifies the damage location with high accuracy for both of cases.

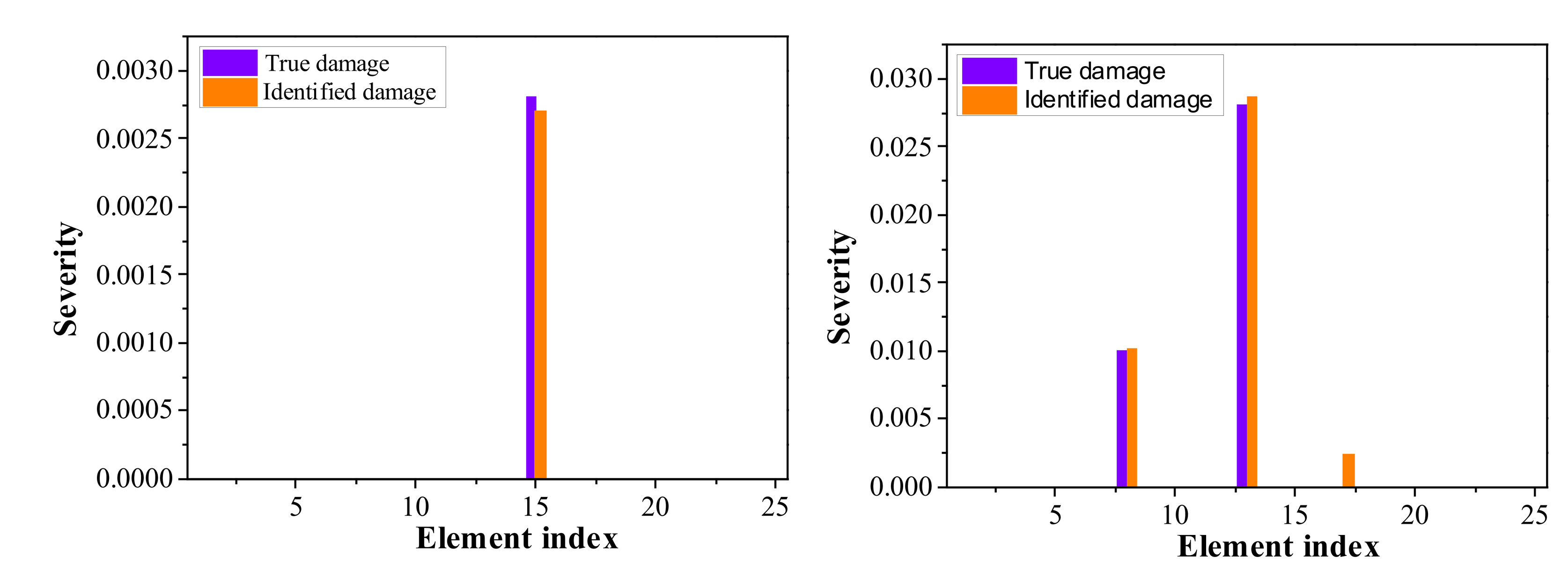

Figure 4 Identified damage location and severity.

These results demonstrate accuracy and robustness of MOPSO for piezo admittance-based damage identification. This method can be directly applied to railway track.

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