Nondestructive identification of multiple flaws in structures using a combination of XFEM and topologically adaptive Enhanced Artificial Bee Colony (EABC) optimization algorithm

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INTRODUCTION
In this paper, we propose a new computational framework based on the Extended Finite Element Method (XFEM) and a topologically adaptive Enhanced Artificial Bee Colony (EABC) algorithm, namely XFEM-EABC algorithm to detect and quantify multiple flaws in structures.

The concept is based on recent work that have shown the synergy between XFEM, used to model the forward problem, and a Genetic-type Algorithm (GA), used as the optimization scheme, to solve an inverse identification problem and capture the "best" flaw parameters. The key idea in this scheme is that XFEM alleviates the need for re-meshing the domain in each forward analysis during the optimization process. While previous work only considered quantification of a single flaw, we propose an adaptive algorithm that can detect multiple flaws by introducing topological variables into the search space which turn on and off flaws during run time. The identification is based on a limited number of strain sensors assumed to be attached to the structure surface boundaries. Each flaw is approximated by a circular void with three variables: center coordinates and radius. In addition the proposed EABC is improved by a guided-to-best solution updating strategy and a local search operator of the type of the Nelder-Mead simplex type that shows faster convergence and superior global/local search abilities than the standard ABC and classic GA algorithms.

BACKGROUND/THEORY/METHOD

Inverse problem
The inverse problem is summarized as follows: Given Ω, T, T0, u, E, L and some specific measured response (strain ε in this work), one’s objective is to find T that can be described by a set of parameters θ. It can be formulated as an optimization problem in which the objective is to minimize the difference between the measured and simulated data.

\[ g(θ) = \sum_{i=1}^{N} |g_i(θ) - d_i| \]

In this work, circular voids are used to approximate the true flaws in structures: \( (x_i, y_i, r_i) \). In general, the identification problem can be summarized as:

Find \( θ \in S \) such that \( g(θ) = \min \)

where \( S \) is the feasible \( m \)-dimensional parameter search space which can be generally written as:

\[ S = \{ θ = (θ_1, θ_2, ..., θ_m) \mid θ_1 ∈ [θ_{1min}, θ_{1max}] \} \]

where \( θ_j \) is the number of topological variables \((j = 1, 2, ..., n_v)\), \( r_j \) is the topological variable. \( θ_j \) can be written as:

\[ θ_j = (x_j, y_j, r_j, t_j) \]

In the present work, circular voids are used to approximate the true flaws in structures with \((x_i, y_i, r_i)\). The identified domain of \( S \) can be written as:

\[ S = \{ θ = (θ_1, θ_2, ..., θ_m) \mid θ_1 ∈ [θ_{1min}, θ_{1max}] \} \]

where the number of topological variables \((k = 1, 2, ..., n_v)\); \( t_k \) is the topological variable. \( θ_j \) can be written as:

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Two approaches of determining the number of flaws:
Two approaches of determining the number of flaws based on the EABC algorithm are illustrated in Figures 3.

RESULTS

The purpose of the example is to study convergence behavior of the EABC algorithm (proposed as improvement in this work) compared to classic GA and standard ABC algorithm.

Example 1: Detection of a single flaw within a rectangular plate

![Figure 2: Detection of a single flaw within a rectangular plate](image)

Example 2: Detection of three non-regular-shaped flaws within an arch-like plate

![Figure 3: The EABC-based flaw detection scheme for one single independent run](image)

![Figure 4: Detection of three non-regular-shaped flaws within an arch-like plate](image)

![Figure 5: The identified number of flaws \( \theta \)](image)

CONCLUSIONS & FUTURE WORK

This work presents a novel computational scheme, namely topologically adaptive XFEM-EABC algorithm, for solving inverse problems for identification of multiple flaws in structures through a limited number of strain measurements. Numerical results show the performance of the XFEM-EABC algorithm is robust even with artificial noise involved in measurements. Overall, the satisfactory results are encouraging for potential implementation of this algorithm in the field of multi-flaw voids detection.

Nevertheless, experimental studies and real applications are required for further exploration of the proposed strategy regarding different sensor availabilities and placements. Continuous work will also further explore the detection of multiple flaw geometries besides voids, such as cracks.

REFERENCES