Software Sharing for Structural Health Monitoring and Control

ASCE EMI Technical Committee on Structural Health Monitoring and Control

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CHAPTER 1. Structural Response Analysis and Interpretation

1.1 Modal Toolkit: Operational Modal Analysis & Data Visualization Library

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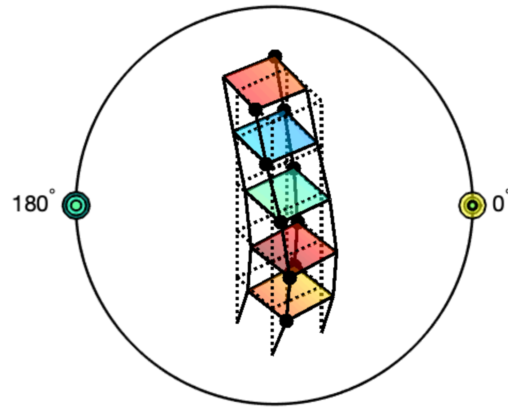
Description: Modal Toolkit is a MATLAB software library for modal analysis, specially designed for long-term ambient vibration monitoring and large-scale data processing. It is built from published state-of-the-art algorithms. Its current capabilities include:

Operational Modal Analysis

Frequency Spatial Domain Decomposition (FSDD) [1]
Covariance Based Stochastic Subspace Identification (SSI-COV) [2,3]
Uncertainty Quantification for SSI-COV [4]



Advanced Plotting and Animation

3D mode shape plotting and animation (see figure)
Time series animation
Stabilization Diagrams
Phase diagrams

Custom Classes for Data Handling

Vibedat Class: A container class for time series measurements and associated sensor metadata, with built in plotting and data manipulation functions (filters, decimation).
Modeobj Class: A container class for modal data, with built in functions for data manipulation.
Geoviz Class: A class for sensor geometry visualization. Easily import sensor layouts and visualize them, or plot and animate mode shapes.

Modal Selection and Tracking

Interactive stabilization diagrams for manual mode selection (SSI-COV)
Automated stabilization diagram interpretation via clustering (SSI-COV) [5]
Interactive Spectral Peak selection (FSDD)

Web Link to Software Repository: https://code.vt.edu/vibes-lab/modal-analysis

Specifications: MATLAB 2018b or later.

Applications: Operational Modal Analysis of Goodwin Hall Smart Building [6].

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1.2 Measurement Data Interpretation using Uncertain Models (MeDIUM)

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Description: MeDIUM is software to support interpretation of monitoring data taken from civil infrastructure systems such as bridges, tunnels and excavations. Monitoring and interpreting this data using physics-based models helps improve understanding of system behavior. However, such data interpretation, particularly when used for extrapolation prediction, requires significant expertise and technical knowledge.

Error-domain model falsification (EDMF) has been demonstrated to provide accurate solutions for model-based data-interpretation tasks. However, the use of this methodology through bespoke coding is often arduous and this can lead engineers to use other less accurate methodologies. MeDIUM simplifies and automates the use of EDMF.

MeDIUM provides functionalities that support validation and what-if analyses of data-interpretation solutions. The data-enhanced behavior models that are identified with MeDIUM enable improved assessment of current and future infrastructure performance for safe and sustainable asset management.

Implementation and Algorithm

MeDIUM is a software implementation of EDMF. This methodology was developed by Goulet and Smith [1] and has been applied for evaluation of over twenty full-scale case studies [2], [3].

In EDMF, model instances that provide predictions incompatible with measurements are falsified (rejected). Compatibility is assessed using thresholds (tolerance) on residuals between model predictions and measurements. These threshold values are computed based on uncertainty associated with the interpretation task at each measurement location. EDMF is an-easy-to-understand implementation of Bayesian updating.

Web Link to Software Repository: https://github.com/MeDIUM-FCL/MeDIUM.

Specifications: Windows 7 or later and 2GB RAM (4GB preferable)

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References

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[3] S. G. S. Pai and I. F. C. Smith, "Methodology Maps for Model-Based Sensor-Data Interpretation to Support Civil-Infrastructure Management," *Front. Built Environ.*, vol. 8, p. 1, Feb. 2022, doi: 10.3389/fbuil.2022.801583.

CHAPTER 2. Model Updating

2.1 SMU – an open-source MATLAB package for structural model updating

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Description: Field dynamic testing with an as-built structure usually provides modal properties that are different from these generated by a finite element (FE) model (Figure 1). To update the FE model parameters, optimization problems can be formulated toward minimizing the difference between experimental and simulated modal properties. Various FE model parameters can be selected as optimization variables for model updating, such as the elastic moduli of structural members, or the stiffness values of support springs.

Figure 1. Finite element model updating

In general, optimization problems in FE model updating are non-convex with unknown number of local optima. Figure 2 illustrates the non-convexity using an objective function of only one scalar variable, whereas practical model updating problems usually have much higher-dimensional vector variables. To initiate an optimization search, randomly generated starting values of the optimization variables should be adopted to increase the chance of achieving global optimality.

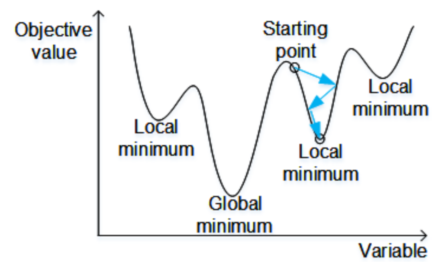

Figure 2. Illustration of a non-convex objective function with one scalar

Named SMU, a Structural Model Updating package has been developed for FE model updating by researchers at the Georgia Institute of Technology. Besides automating the random searches, the current version supports three model updating formulations, namely (1) the MAC (modal assurance criteria) value formulation, (2) the eigenvector difference formulation, and (3) the modal dynamic residual formulation. For each updating formulation, analytical Jacobian derivative of the objective function is implemented, improving the gradient search efficiency. In addition, the package supports various optimization algorithms available in MATLAB optimization toolbox, such as the Levenberg-Marquardt algorithm, the trust-region-reflective algorithms, the interior point method, *etc*. Finally, the MATLAB package contains multiple structural example problems of different sizes, which help users learn how to use the package.

Web Link to Software Repository: The open-source software package is shared online at https://github.com/ywang-structures/Structural-Model-Updating.

Specifications: MATLAB Optimization Toolbox is required.

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CHAPTER 3. Input Identification

3.1 BuildingVibe: Open-Source Codes for Occupant Localization, Identification, and Characterization Using Human-Induced Building Vibrations

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Description: BuildingVibe includes MATLAB codes to extract human occupant information (listed below) from their footstep-induced floor vibration data. Vertical velocity responses of the floor are collected using geophone sensors. The "Hardware" folder includes three iterations of the sensing nodes design and implementation documentation, as well as data acquisition codes. The "Software" folder includes:

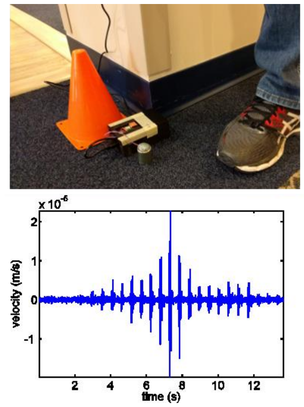

Figure 1. Human Footstep-Induced Building Vibrations

1. Step Event Detection (BOES_Step_Event_Detection): Detect human footsteps from noisy floor vibration data [1]
2. Individual Person Identification (FootprintID): Identify each person using their gait patterns and gait-induced floor vibrations [2]
3. Single Person Localization: Locate individual footsteps of a single person passing by [3]
4. Multiple People Localization (MultiPeople_Singlestep_Localization): Locate each footstep for multiple people walking simultaneously [4]
5. Human Gesture Recognition (SurfaceVibe): Identify different types of gestures on the physical surface (e.g., table, wall, floor) through surface vibrations [5, 6]

Web Link to Software Repository: The open-source software package is shared online at https://github.com/dandanpan/VibrationSensingDocumentation

Specifications: MATLAB Toolboxes and third-party libraries requirements are clarified in the readme files.

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