

Early-Stage System Change Detection Using B-Spline Signature Responses

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Abstract

Structural deterioration is an inevitable reality that threatens the safety, longevity, and functionality of civil infrastructure. Despite significant investments in structural maintenance, catastrophic failures persist due to limitations in current monitoring approaches. *Structural Health Monitoring* (SHM) refers to a family of activities that aim to identify, track, and properly address structural damage to prevent costly failures. Current research efforts include developing techniques capable of detecting structural changes at earlier stages than existing methods. Within SHM, *Impulse Response* (IR) techniques offer considerable potential because they encode dynamic structural parameters in a non-destructive, excitation-independent manner.

This dissertation advances the *B-Spline Signature Response* (BSR) as a practical IR technique for system identification under operational conditions. Two key challenges are addressed: (i) reliable recovery of an impulse response from noisy forced- and free-vibration records without assuming the restrictive at-rest initial conditions, and (ii) monitoring time-series features of the BSR to determine the presence and source of system change.

Methodologically, a *Recursive Least Squares* (RLS) formulation is developed to adaptively identify BSRs from forced-vibration data with non-zero initial conditions and noisy records. For free-vibration records, an ‘apparent B-Spline excitation’ is introduced to recover BSRs without measuring an input excitation. Building off the

ability to practically extract BSRs, change detection is performed via cross-correlation of BSRs across condition states. The cross-correlation to a baseline state degrades monotonically with change severity. The RLS-based and apparent B-Spline BSR extraction techniques, together with the correlation-based change detection, are developed, numerically verified, and experimentally validated. Numerical studies span single- and two-degree-of-freedom systems with controlled mass and stiffness perturbations; experimental validation uses a benchmark study reported in the literature of a wind-turbine blade dataset including temperature variation, added mass, and induced cracking.

Following change detection, the feasibility of source-of-change identification is investigated via analysis of a set of physically interpretable time- and frequency-domain features of the BSR. These features are monitored as the system changes to reveal unique, change-type-specific behavior that enables discrimination of different mechanisms of change (i.e., temperature variation vs added mass). Analysis of the benchmark dataset reveals repeatable feature behaviors that are consistent with expected physical effects and that show promise for future work, motivating multivariate analysis and broader validation.