
Masterthesis

Single-Pass Eigenfrequency Identification of Railway Bridges via Multi-Sensor Concatenation on Instrumented Trains



TECHNISCHE
UNIVERSITÄT
DARMSTADT

Topic:

Civil infrastructure, particularly railway bridges, experiences continuous degradation from operational loads, environmental conditions, and material ageing, making their monitoring crucial for safety and economic sustainability. Structural Health Monitoring (SHM) represents a paradigm shift from periodic visual inspections to continuous, data-driven assessment of structural integrity. At the heart of SHM lies the principle that damage or deterioration manifests as changes in a structure's dynamic properties, particularly its natural frequencies (eigenfrequencies), mode shapes, and damping ratios. These modal parameters serve as the structure's "fingerprint," where even subtle shifts can indicate developing problems long before visible damage appears. Among various monitoring approaches, drive-by monitoring, using sensors on passing vehicles rather than fixed instrumentation on the structure, offers a compelling solution that transforms regular railway traffic into a continuous inspection fleet, eliminating the need for costly permanent sensor installations on thousands of bridges across the network.

In the era of smart infrastructure, precise eigenfrequency identification of railway bridges via drive-by monitoring is essential for proactive SHM and timely condition assessments. Traditional methods often rely on data stitching from single-sensor setups, which demands costly repetitions of train passages to build sufficient datasets.

This master's thesis innovates by applying sensor concentration theory to repurpose data from fully instrumented trains, fusing signals from distributed sensors to achieve superior eigenfrequency extraction accuracy, elevated signal-to-noise ratios, and noise mitigation. Sidestepping the repetition pitfalls of conventional approaches, this method delivers efficient, scalable SHM insights directly from archived multi-sensor recordings.

Our investigation leverages the Garather Bach bridge in Düsseldorf, a 16.4 m single-span steel, trough structure equipped with advanced instrumentation, including accelerometers. We draw on pre-collected datasets from the multi-sensor ICE TD train (outfitted with 32 axle-box accelerometers), where prior drive-by experiments have proven the concept's viability while highlighting opportunities for signal enhancement through concentration techniques. It should be noted that no new field trials will be required.

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Datum
24. September 2025

Key Research Avenues:

This thesis empowers you to pioneer data-efficient bridge monitoring. Potential focus areas, centered on analyzing available datasets, include:

- **Comprehensive Literature Synthesis:** Review sensor fusion and concentration theory in structural dynamics, contrasting with stitching-based traditional methods.
- **In-Depth Data Exploration:** Analyze archived experimental records from ICE TD train passages over the Garather Bach bridge to identify multi-sensor synergies and noise patterns.
- **Algorithmic Development:** Implement sensor concentration algorithms in Python or MATLAB to aggregate accelerometer signals from existing runs, optimizing eigenfrequency isolation without additional data collection.
- **Performance Evaluation:** Compare single- vs. multi-sensor concentration outcomes using the at-hand data, assessing:
 - Signal-to-noise ratio gains
 - Eigenfrequency detection precision and variability
 - Fault tolerance to sensor anomalies in real recordings
- **Ground-Truth Validation:** Benchmark results against the bridge's comprehensive instrumentation archives as reference standards.
- **Operational Sensitivity Analysis:** Probe method robustness across dataset variations (e.g., differing speeds, environmental conditions, and loads captured in existing trials).

Required Background:

- Programming skills (MATLAB/Python preferred)
- Interest in structural dynamics and infrastructure monitoring
- Basic understanding of modal analysis concepts (can be developed during the thesis)

Provided Support:

- Access to comprehensive datasets from ICE TD train measurements
- Reference implementations of basic drive-by monitoring algorithms
- Regular supervision and guidance on SHM concepts

Language: English

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