Development of an Anomaly Detection Method for Bridge Structural Health Monitoring from Multimodal Data

Context of the research

Ensuring the safety and reliability of civil infrastructures, such as bridges and viaducts, increasingly relies on advanced Structural Health Monitoring (SHM) systems to enable predictive maintenance and early warning mechanisms. Managing structural integrity is challenging due to progressive material degradation phenomena (such as corrosion, fatigue, and aging), non-stationary operational and environmental variability (including thermal effects, wind and vehicular traffic loads), and the scarcity of real-world measurements collected under damaged or critical conditions. Traditional monitoring solutions often depend on static alerting thresholds, which struggle to balance early damage sensitivity against false-alarm rates. Artificial Intelligence (AI) methods address these limitations by fusing heterogeneous multimodal data (such as vibration signals collected by accelerometers and piezoelectric sensors, video-based traffic measurements, and InSAR satellite displacements) to detect anomalies.

This thesis is framed within the Platform for Reliable Intelligent Monitoring and prognostics in Engineering (PRIME) project, funded by INAIL, which aims to design, implement, and validate a modular, scalable, and interoperable platform covering the entire monitoring value chain—from multi-source sensor data acquisition to AI-based processing, prognostics, and real-time alerting—for industrial plants and civil infrastructures.

Objective of the research

This thesis aims to develop AI and XAI methods for anomaly detection and structural health assessment of structures, such as bridges and viaducts. To achieve this, the AI method will integrate heterogeneous multimodal measurements (e.g accelerometric signals, camera-derived traffic information, and InSAR satellite displacement data), compensate for environmental variability, formulate dynamically adaptable alerting thresholds and rigorously evaluate model interpretability and robustness. The method will be tested on real data collected from the Volto Santo viaduct.

The research activities will include:

- **Literature review**: analysis of state-of-the-art techniques for multimodal data analysis and Explainable AI techniques.
- **Problem formulation**: identification of the requirements for structural anomaly detection, considering real-time operational constraints, sensitivity to early damage versus false-alarm reduction under non-stationary environmental and traffic conditions, interpretability and transparency to foster user trust.
- **Method design**: definition of the AI architecture for multimodal data.
- **Performance evaluation**: definition of specific performance metrics to assess anomaly detection sensitivity, false-alarm suppression, robustness across varying operational conditions, and output interpretability.
- **Implementation**: development of the selected method.
- **Validation**: benchmarking the proposed method against other state-of-the-art approaches.

Collaborations

- University of Bologna (UNIBO) – Project Coordinator (ARCES, DICAM, DEI, DISI)
- University of Naples Federico II (UNINA) – Department of Structures for Engineering and Architecture

- Tangenziale di Napoli S.p.A. (ASPI Group)

Research Team

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