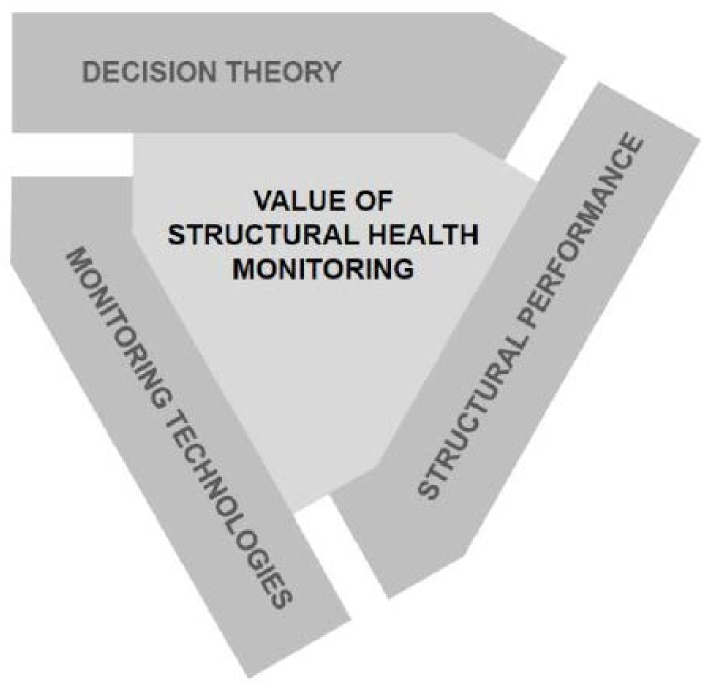
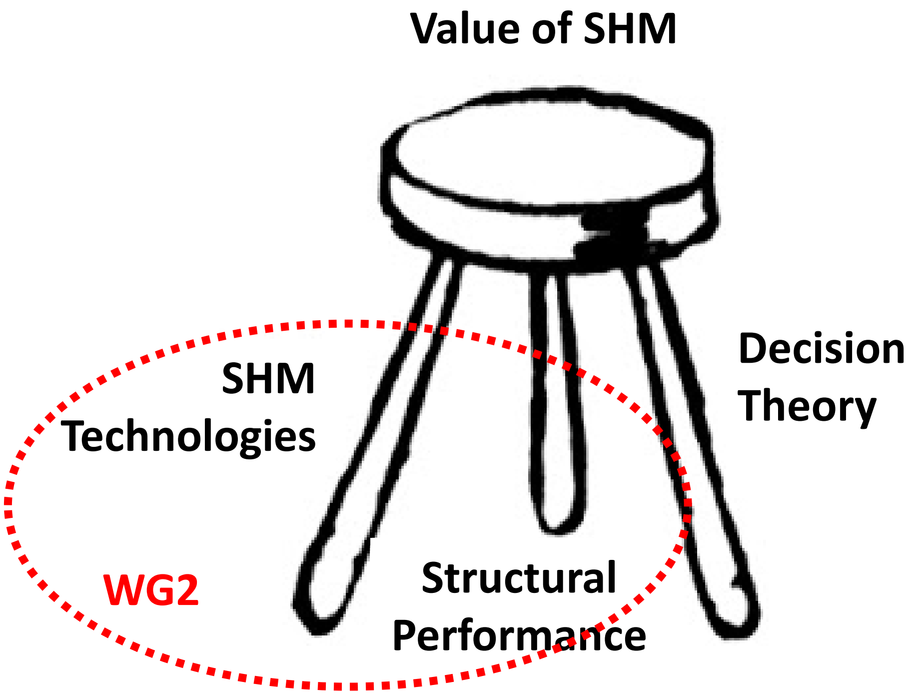
COST Action TU1402
Quantifying the value of Structural Health Monitoring



WG2: SHM Strategies and Structural Performance

COST Action TU1402
Quantifying the value of Structural Health Monitoring



WG2 Session: 5th May 2015, 8:45 to 11:00

- Introduction by the Co-leaders
- Participant contributions
  - Presentations
  - Q & A
- Concluding Discussion

Introduction

- Marios Chryssanthopoulos, University of Surrey, UK
  - Structural Reliability
  - Fatigue
  - Corrosion deterioration
- Geert Lombaert, KU Leuven, Belgium
  - Vibration-based Model Calibration
  - On-line Input and State Estimation for Structures
  - Structural Optimisation
- Michael Doehler, Inria, France
  - System identification; Fault detection and isolation
  - Data-driven uncertainty quantification
  - Statistical methods for vibration-based SHM

Structural Performance: Assessment & Prediction

Structural health monitoring and performance

- Definition of Structural Health Monitoring (SHM), (Farrar & Worden, 2007):
  - Structural Health Monitoring refers to the process of implementing a damage identification strategy for infrastructure.
  - Damage is to be understood in a wide sense as any changes in adversely affecting the current or future system performance.
- A distinction is made between:
  - Structural Health Monitoring: on-line global damage identification in structures.
  - Condition monitoring: rotating and reciprocating machinery.
  - Non-destructive evaluation: off-line local method after damage detection.
  - Statistical process control: process-based rather than structure-based.
  - Damage prognosis: prediction of remaining useful life of a system.

Structural health monitoring and performance

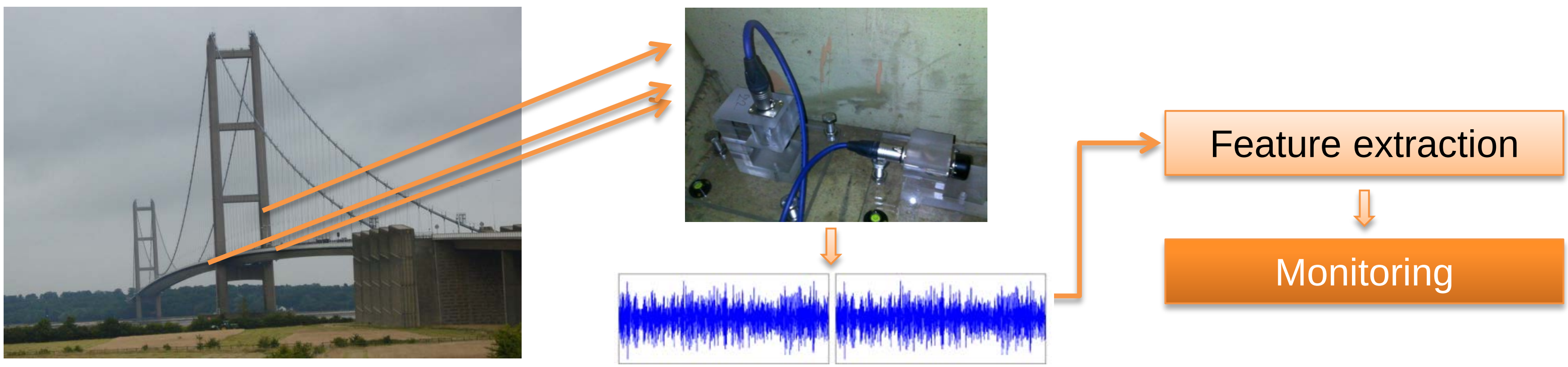
- Characterizing damage can be seen as a five-step process (Rytter, 1993):
  1. Existence. Is there damage in the system?
  2. Location. Where is damage located?
  3. Type. What type of damage?
  4. Extent. How severe is the damage?
  5. Prognosis. What is the remaining lifetime?
- Damage prognosis requires a prediction of structural performance based on (Farrar and Lieven, 2007):
  - Current state of the system.
  - Future loading environments.
  - Structural models allowing behavioral and performance predictions.
- A distinction is made between:
  - Health monitoring: identifying and quantifying damage in a system.
  - Usage monitoring: acquiring operational and environmental loading data.

Structural health monitoring and performance

- Most successful applications of SHM and damage prognosis are in condition monitoring of rotating machinery, partly explained by (Farrar & Worden, 2007):
  - Minimal operational and environmental variability.
  - Well-defined damage types at known locations.
  - Large databases with data from damaged systems.
  - Well-established correlation between damage and features extracted from data.
  - Clear and quantifiable benefits.
- Up to now damage assessment methods developed for civil engineering applications mostly do not consider damage prognosis.
- One of the key difficulties is that the data collected is often an indirect measure of damage (e.g. vibration-based methods).

Structural health monitoring and performance

- Example: Vibration-based SHM of civil structures
  - Acceleration sensors measure ambient vibration of the structure
  - Data processing to extract damage sensitive features for monitoring



- Challenges
  - Strong operational and environmental variability
  - Every structure is unique
  - Typical damages and locations depend on each particular case
  - Methods for damage assessment hardly mature yet

Structural health monitoring and performance

- Obtaining the damage information from measurement data is key issue for SHM – feature extraction
- Some challenges for feature extraction in SHM
  - Continuous monitoring – no user input
  - Unknown, ambient excitation
  - Changing environmental conditions
  - Few sensors
    - Academic validation of methods uses often much more sensors than feasible in practice
    - Optimal sensor placement for desired monitoring objectives
  - Link between data and structural models
- Features estimated from data are subject to variance, need to take data-driven uncertainties into account when evaluating their change

- Goal: link of damage detection / localization / quantification information and performance

Structural health monitoring and performance

- Damage detection for SHM
  - Possible with purely data-driven methods (change detection in features)
  - Starts achieving industrial maturity

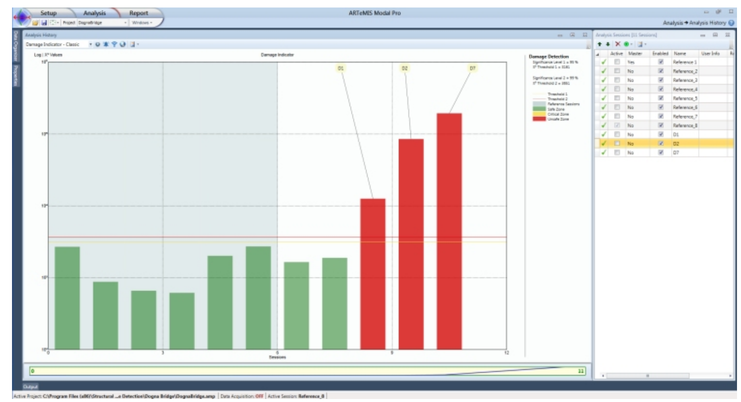


Fig.: Damage detection during progressive damage of a bridge.

- Challenges
  - After detection, is damage significant (without knowing its location and extent)?
  - Is detection information sufficient for having an impact on performance evaluation?

Structural health monitoring and performance

- Damage localization and quantification for SHM
  - Requires usually a structural model in addition to measurement data
  - Not mature for SHM systems yet

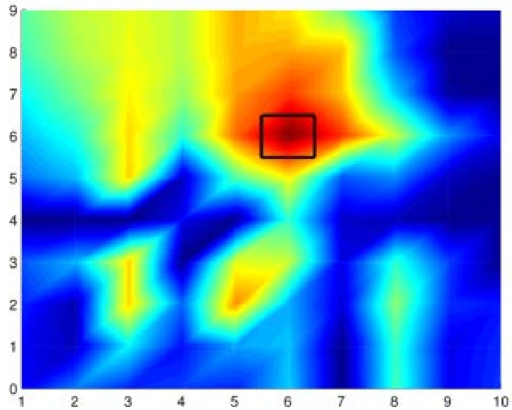


Fig.: Damage localization on a plate (simulation).

- Challenges
  - Development of localization and quantification methods that are fit for SHM
  - Link between (statistical) damage information and performance evaluation

Structural health monitoring and performance

- Overview of monitoring in Civil Engineering (Brownjohn, 2007):
  - Dams (surveillance, measurement of static structural effects and environmental conditions, identification of anomalies + dynamic response monitoring).
  - Bridges (understanding and calibrating models, wind-induced response, permanent monitoring of major bridge projects, demonstrating effectiveness of upgrading).
  - Off-shore structures (environmental and platform performance data, identification of dynamic characteristics and load-response mechanisms, non-stationary systems).
  - Buildings and towers (identify full-scale structural performance under earthquake and storm loading, condition assessment after seismic events).
  - Nuclear installations (validate and calibrate designs during performance testing, condition monitoring during operation, focus on temperature, not on structural data).
  - Tunnels and excavations (emphasis on deflections and deformations).
- A key issue for developing SHM into a system assisting infrastructure managers is an exhaustive cost-benefit analysis (Brownjohn, 2007).

Structural health monitoring and performance

- Development of SHM technologies occurs mostly bottom-up (diagnostic tool) whereas a top-down approach is needed for demonstrating its value (Frangopol & Messervey, 2009).
- Due to inherent uncertainties, a reliability-based framework is needed which provides a prediction based on future loading, current damage state, and an updated structural model (Farrar & Lieven, 2007).
- A life-cycle approach accounting for these uncertainties is needed to assess expected benefits from SHM (Frangopol & Messervey, 2009):
  1. Inspections based on as needed basis.
  2. Improved accuracy of structural assessment.
  3. Optimal scheduling of maintenance, repair, and replacement.
  4. Monitoring of performance thresholds.
- Performance indicators of structures may relate to (Probabilistic Model Code. Part 1 - Basis of Design):
  1. Fitness for their intended use (serviceability limit state)
  2. Capacity to withstand actions during construction and use (ultimate limit state).
  3. Avoiding consequences of damage disproportionate to accidental events (robustness).

Aim of WG2 of COST Action TU1402

1. A categorization of SHM technologies.
   - Relation between information gathered (crack length, chloride concentration) and the structural performance (remaining fatigue life, state of corrosion of rebar).
   - Collecting and representing “best practice”.
   - Methods for SHM can be categorized in many different ways:
     - Type of structure.
     - Type of data or features extracted.
     - Global or local nature of methods.
     - Model-based versus purely data-based methods.
     - …
2. Quantitative relation between quantity measured and performance indicator with consistent treatment of uncertainties.

Bibliography

- Frangopol & Messervey, Life-cycle Cost and Performance Prediction: Role of Structural Health Monitoring, Chapter 16 in Frontier Technologies for Infrastructures Engineering (Edited by S-S. Chen and A. H-S. Ang), CRC Press-Balkema-Taylor & Francis Group, Leiden, The Netherlands, 2009, 361-381.
- Farrar, C.R. and Worden, K., An introduction to structural health monitoring, Philosophical Transactions of the Royal Society A - Mathematical, Physical and Engineering Sciences, 2007, 365, 303—315.
- Brownjohn, J.M.W., Structural health monitoring of civil infrastructure, Philosophical Transactions of the Royal Society A - Mathematical, Physical and Engineering Sciences, 2007, 365, 589—622.
- Farrar, C.R. and Lieven, N.A.J., Damage prognosis: the future of structural health monitoring, Philosophical Transactions of the Royal Society A - Mathematical, Physical and Engineering Sciences, 2007, 365, 623—632.

Conclusion and next steps

- SHM already plays an important role in performance assessment
- Research on many fronts, with significant effort on:
  - Data analytics and interpretation: Data – Information – Knowledge – Decision.
  - Methodological aspects: diagnosis / prognosis, global / local, data / model, …..
  - Sector cross-fertilisation: civil engineering equivalent of ‘power by the hour’?
  - Ever increasing range of applications.
- How can WG2 contribute?
  - Categorise SHM technologies in relation to the type of performance being monitored & the type of decision being addressed.
  - Focus on possible quantitative relation(s) between performance indicator(s) and SHM parameter(s) with consistent treatment of uncertainties.
  - Establish ‘best-practice’ and provide ‘pre-standardisation’ guidance.
  - Develop a ‘road map’ for those with an interest in utilising SHM for asset management
- Objective, scope and structure of the report will be discussed this afternoon.
- Contributions welcome in developing the framework and in providing illustrative examples.

“There are two golden rules for an orchestra: start together and finish together. The public doesn't give a damn what goes on in between.”

Sir Thomas Beecham (29 April 1879 – 8 March 1961)