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Structural Health Monitoring
AN INTRODUCTION
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OVERVIEW

- Objective
- What is Structural Health Monitoring (SHM)
- Components of SHM process & Question to ask:
- Motivation for SHM
- Smart Materials and Structures (SMS)
- Process and pre-uses monitoring
- SHM as a part of system management
- Passive and active SHM
- NDE, SHM and NDECS
- Conclusions
- References
The ultimate goal is to determine the existence, location, and degree of damage in a structure if damage occurs.

A system of classification for damage-identification methods, as presented by Rytter (1993), defines four levels of damage identification, as follows:

- **Level 1**: Determination that damage is present in the structure
- **Level 2**: Determination of the geometric location of the damage
- **Level 3**: Quantification of the severity of the damage
- **Level 4**: Prediction of the remaining service life of the structure

Damage is defined as changes introduced into a system that adversely affects its current or future performance.

- Damage is not meaningful without a comparison between two system states, one is often an initial or undamaged state.
- System changes include material and/or geometric property changes, changes in boundary conditions, and changes in system connectivity.
WHAT IS STRUCTURAL HEALTH MONITORING (SHM)

- Good design, quality construction and durable and safe exploitation of structures are goals of structural engineering. However, the structures are subject to adverse changes in their structural health conditions due to potential damages or deterioration induced by environmental degradation, wear, errors in design and construction, current loads, over loads and some unexpected events like earthquakes or impacts or, simply, by their normal working life.

- A modern structure must be able to generate and communicate information concerning the changes in its structural health condition to responsible operators and decision makers, in-time, automatically or on-demand, and reliably.

- The data resulting from a monitoring program can be used to optimize the operation, maintenance, repair and replace of the structure based on reliable and objective data. Such kind of system can be named a Structural Health Monitoring system, SHM.
WHAT IS STRUCTURAL HEALTH MONITORING (SHM)

- “The process of implementing a damage detection and characterization (recognize, localize, quantify or rate) strategy for Aerospace, Civil and Mechanical engineering infra-structures, such as bridges, ships, pipelines, and aircrafts, offshore structures, to ensure the safe operation”.

- The SHM process involves the observation of a system over time using response measurements from an array of sensors, the extraction of damage-sensitive feature from these measurements, and the statistical analysis of these features to determine the current state of system health.

- A successful technology for SHM has enormous potential for application in monitoring of offshore structures and bridges subjected to fatigue, corrosion, impact and earthquakes, as well as buildings and aerospace structures subjected to severe loads or structural deterioration.

- A successful understanding and application of SHM depends on an in-depth appreciation of structural modeling, smart materials, signal processing, data acquisition techniques, and more.
COMPONENTS OF SHM PROCESS & QUESTION TO ASK:

- **COMPONENTS OF SHM PROCESS:**
  1. Operational Evaluation
  2. Data Acquisition, Fusion, and Cleansing
  3. Data Feature Extraction and information condensation
  4. Statistical-Model Development for Feature Discrimination

- **QUESTION TO ASK:**
  1. Is there damage in the system (existence)?
  2. Where is the damage in the system (location)?
  3. What kind of damage is present (type)?
  4. How severe is the damage (extent)?
  5. How much useful life remains (prognosis)?
MOTIVATION FOR SHM

- Knowing the integrity of in-service structures on a continuous real-time basis is a very important objective for manufacturers, end-users and maintenance teams. In effect, SHM:
  - Allows an optimal use of the structure, a minimized downtime, and the avoidance of catastrophic failures,
  - Gives the constructor an improvement in his products,
  - Drastically changes the work organization of maintenance services:
    i) by aiming to replace scheduled and periodic maintenance inspection with performance-based (or condition-based) maintenance (long term) or at least (short term) by reducing the present maintenance labor, in particular by avoiding dismounting parts where there is no hidden defect;
    ii) by drastically minimizing the human involvement, and consequently reducing labor, downtime and human errors, and thus improving safety and reliability.
SMART MATERIALS AND STRUCTURES (SMS)

- Conventionally, automated SHM has been attempted by measuring static displacements, or static strain, or low frequency vibration data. These techniques typically rely upon conventional sensors such as strain gauges and accelerometers, which can only extract load and strain histories. However, the advent of smart materials such as piezo-electric materials, optical fibres, shape memory alloy and magnetostrictive material, has added a new dimension to SHM, by enabling the development of miniaturized system with higher resolution, faster response and greater reliability.

- The concept of Intelligent or Smart Materials/Structures (SMS) can be considered as a step in the general evolution of man-made objects. There is a continuous trend from the use of homogeneous materials, supplied by nature and accepted with their natural properties, followed by composite materials allowing us to create structures with properties adapted to specific uses. In fact, composite materials and multi-materials are replacing homogeneous materials in more and more structures.

- SHM with smart materials helps us to understand the concept of a smart structural system, it also helps us to understand its application to performance monitoring of structural systems.
SMART MATERIALS AND STRUCTURES (SMS)

- The next step consists of making the properties of the materials and structures adapt to changing environmental conditions. Classically, three types of SMS exist:
  - SMS controlling their shape,
  - SMS controlling their vibrations, and
  - SMS controlling their health.
- In effect, almost all achievements in this field are only intended to make materials/structures sensitive, by embedding sensors.
- The next step towards smarter structures would be materials/structures with embedded damage-mitigation properties. For damage mitigation, embedding actuators made of shape memory alloys (SMA) could be a solution that would induce strains in order to reduce the stresses in regions of strain concentration. These SMA actuators could be in the form of wires or films. In the field of civil engineering, the existence of self-healing concretes containing hollow adhesive-filled brittle fibers and polymer matrix composites.
PROCESS AND PRE-USES MONITORING

Sensors for Health Monitoring can be incorporated into the components during the manufacturing process of the composite. The physical parameters of the material that can be monitored during the process are varied: refractive index, visco-elastic properties, conductivity, etc. A range of techniques is available allowing their on-line monitoring: electrical techniques, electro-mechanical impedance techniques using embedded piezo-patches, acousto-ultrasonics (or optical techniques using fiber-optic sensors. It could be interesting to mix such different sensors achieving a multi-detection. The sensors can be resistive strain gauges or strain-sensitive fiber-optic sensors for the quasi-static loads and acoustic emission sensors for impact type loads.
Health Management can be defined as the process of making appropriate decisions/recommendations about operation, mission and maintenance actions, based on the health assessment data gathered by Health Monitoring Systems.

Structural usage and damage parameters are registered by sensors and used by on-board data acquisition and signal processing equipment. The data from the sensors are transformed into information, related to the structural usage, the environmental history and the resulting damage, thanks to a usage and damage Monitoring Reasoner, which contains information processing algorithms.
SHM, like Non-Destructive Evaluation (NDE), can be passive or active. The structure is equipped with sensors and interacts with the surrounding environment, in such a way that its state and its physical parameters are evolving.

**Passive SHM:** If the experimenter is just monitoring this evolution thanks to the embedded sensors, we can call his action “passive monitoring”. This sort of situation is encountered with acoustic emission techniques detecting, for example, the progression of damage in a loaded structure or the occurrence of a damaging impact.

**Active SHM:** If the experimenter has equipped the structure with both sensors and actuators, he or she can generate perturbations in the structure, thanks to actuators, and then, use sensors to monitor the response of the structure. In such a case, the action of the experimenter is “active monitoring”. The monitoring becomes active, by adding to the first piezoelectric patch, which is used as an acoustic emission detector, a second patch, which is used as an emitter of ultrasonic waves. The receiver, here, is registering signals, resulting from the interaction of these waves with a possible damage site, allowing its detection.
SHM was born from the conjunction of several techniques and has a common basis with NDE. In fact, several NDE techniques can be converted into SHM techniques, by integrating sensors and actuators inside the monitored structure. For instance, traditional ultrasonic testing can be easily converted in an acoustoultrasonic SHM system, using embedded or surface-mounted piezoelectric patches.

An intermediate solution can be found by only embedding the emitter or the receiver, the other part of the system being kept outside the structure. It may also be called Non-Destructive Evaluation Ready Material (NDERM) concept. Perhaps a better denomination might be NDE Ready Structure (NDERS) or NDE Cooperative Structure (NDECS). Such a solution is a priori interesting in two situations:

- when it is easy to position the emitter inside the structure, during the process, in a region where it is difficult, or impossible, to produce a stimulation from outside without demounting the structure;
- when it is possible to use for the detection a non-contact, full-field imaging system allowing rapid monitoring of a large part of the structure. This is possible, for instance, with techniques such as infrared thermography or shearography.
CONCLUSION

- Recent advancement in electronics components, MEMS (micro-electro-mechanical system) sensors and wireless communication have created the opportunity to monitor structures in ways that were not previously possible.
- Enhancements to the instrument will include: Support for additional fibre optic sensors: multi-element bragg arrays, long gauge, chemical sensing, electrical-type sensors, accelerometers, geophones, advance software capabilities for autonomous alarms generation and data decimation. A compact and portable 2-port FBG instrument as a tool for rapidly validating sensor instrument.
- The concept of structural health monitoring and retrofitting helps to identify a damage detection of structural system and consequently their strength restoration. Their safe performance is necessary for ensuring safety to the human and economic activities thereby, it has become important to monitor the damage for its existence, location and extent and retrofit the same to enhance its performance features.
- Based on the tremendous economic and life-safety benefits, SHM technology has the potential to offer to detect damage in structural and Mechanical infrastructures. Therefore, the development of robust technology has many elements that, make it a potential ‘grand challenge’ for the engineering community.
- The increased interest in SHM and its associated potential for significant life-safety and economic benefits has motivated the need for this theme issue. Like so many other technology fields, advancement in SHM will most likely come in small increments requiring diligent, focused and coordinated research efforts over long period of time.
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Thank You