Introduction to Structural Health Monitoring and Feature Extraction

Charles R. Farrar
Michael D. Todd

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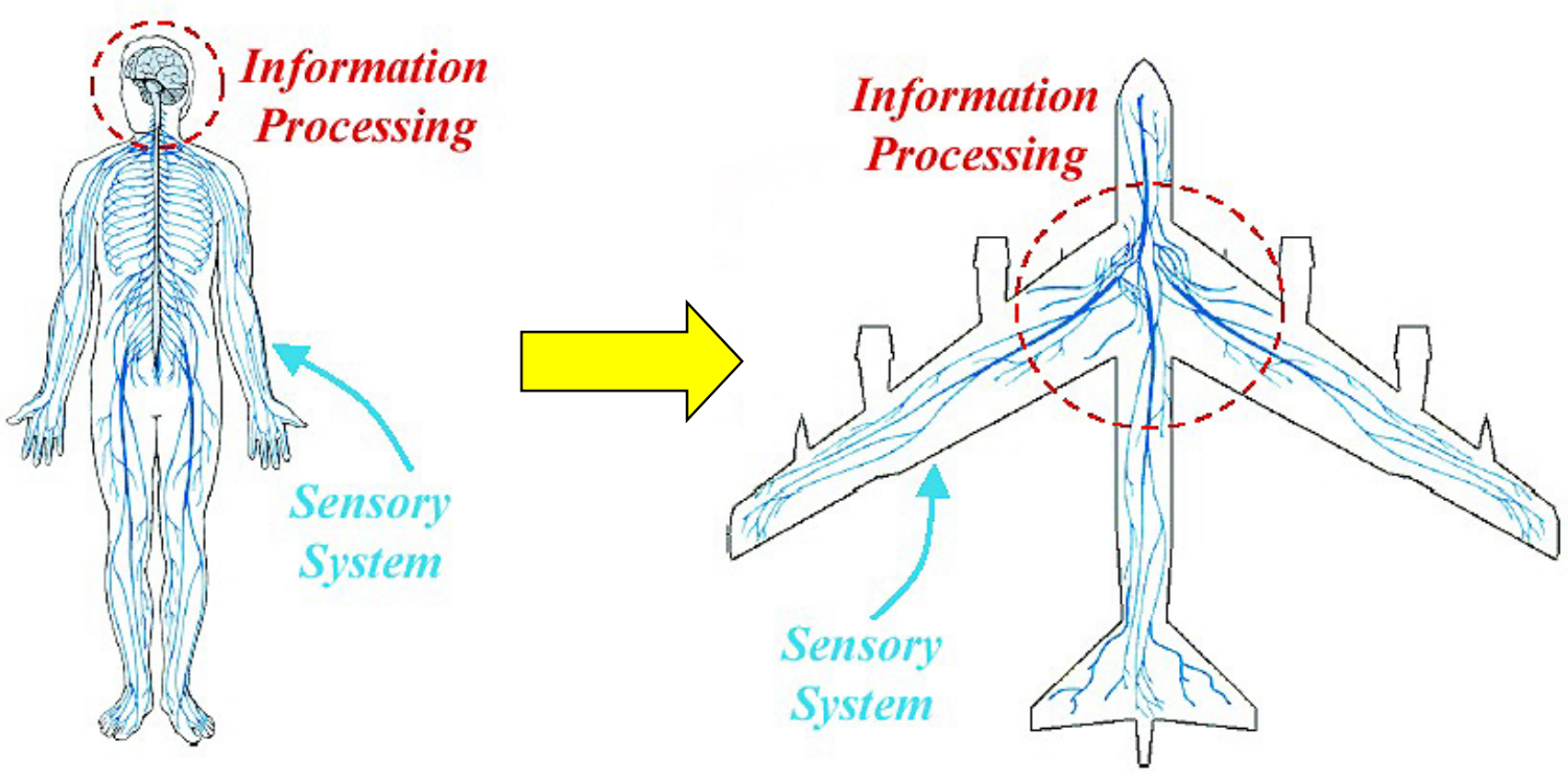
Structural Health Monitoring



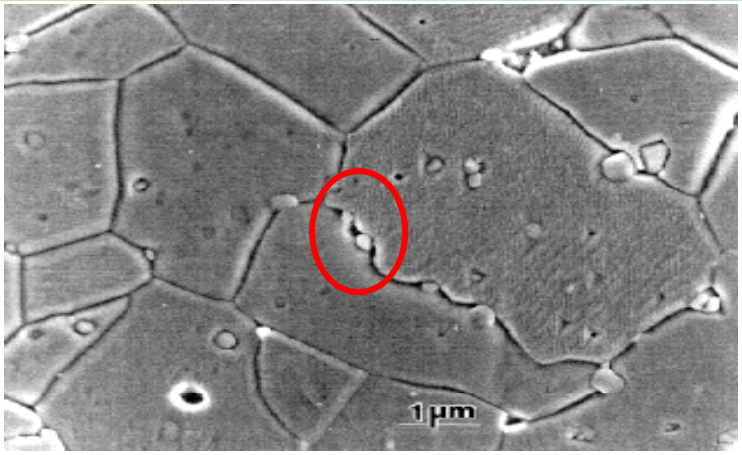
Motivation for Structural Health Monitoring

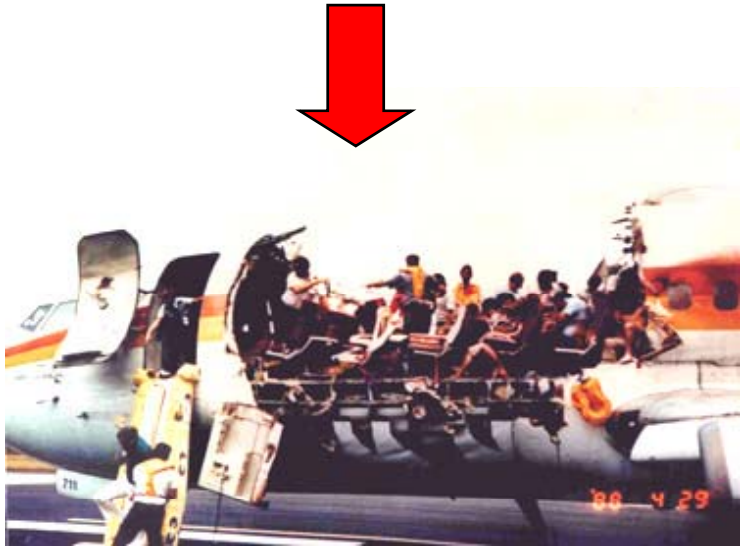
- Move from time-based maintenance to condition-based maintenance
- Combat asset readiness
- New business models
  - Manufacturers of large capital investment hardware can charge by the amount of life used instead of a time-based lease.


The potential for economic and life-safety benefits coupled with need to integrate diverse technologies makes Structural Health Monitoring a **Grand Challenge** problem for aerospace, civil and mechanical engineers in the 21st century

Definition of "Damage"

- Damage is defined as changes to the material and/or geometric properties of a structural that adversely affect its performance.
- All materials used in engineering systems have some inherent initial flaws.
- Under environmental and operational loading flaws will grow and coalesce to produce component level failure.
- Further loading causes system-level failure.
- **Must consider the length and time scales associated with damage evolution.**

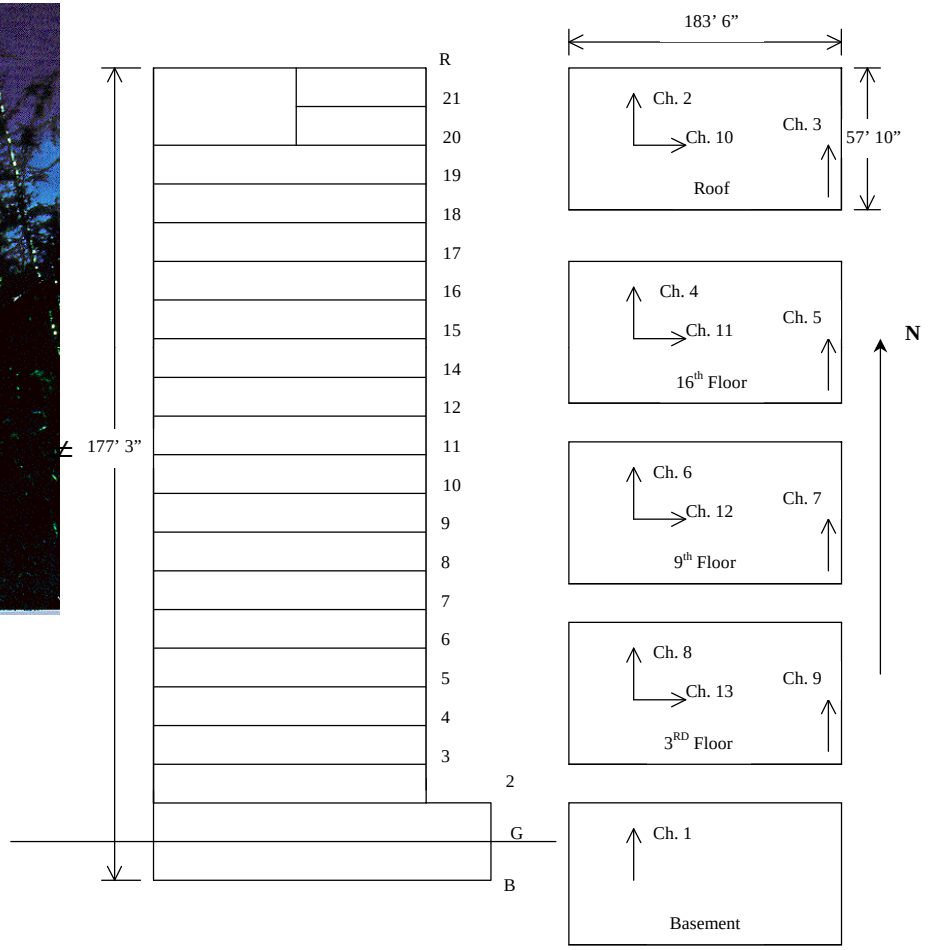




Classifying Damage Identification Methods

- **Damage Identification**
  - **Microscopic flaw/damage identification**
    - Used to develop material failure models
  - **Incipient, macroscopic, material/component level damage**
    - Non-destructive evaluation (local, off-line inspection)
    - Wave-propagation-based **structural health monitoring** (more global, on-line)
  - **Component damage/failure – system level damage**
    - **Structural health monitoring**
    - Condition monitoring (applied to rotating machinery)
    - Health and usage monitoring systems (HUMS, Rotor craft)
    - Statistical process control (monitors system processes where damage can be one cause of loss of process control)
- **Damage Prognosis**
  - **Adds prediction of remaining life capability to SHM**

Structural Monitoring ≠ SHM



Structural monitoring is not used to make decisions regarding system operation and maintenance

SHM is a Problem in Pattern Recognition

The Structural Health Monitoring Process

1. Operational evaluation

   Defines the damage to be detected and begins to answer questions regarding implementation issues for a structural health monitoring system.

2. Data acquisition

   Defines the sensing hardware and the data to be used in the feature extraction process.

3. Feature extraction

   The process of identifying damage-related information from measured data.

4. Statistical model development for feature discrimination

   Classifies feature distributions into damaged or undamaged category.

- **Data Cleansing**
- **Data Normalization**
- **Data Fusion**
- **Data Compression**

(implemented by software and/or hardware)

Introduction to Features

- What is a Feature?
  - A feature is some characteristic of the measured response that is extracted via signal processing, parameter estimation or some other signal inspection technique
  - Feature extraction transforms “data” into “information”
  - It is desirable to have examples of the features from both damaged and undamaged structures
- Primary Characteristics of features
  - **Sensitivity** - Feature should ideally be very sensitive to damage and completely insensitive to everything else (rarely occurs)
  - **Dimensionality** - Want the feature to have the lowest dimension possible
  - **Computational Requirements** - Features should be computable with minimal assumptions and CPU cycles
- Want to use the simplest feature possible that can distinguish between the damaged and undamaged system

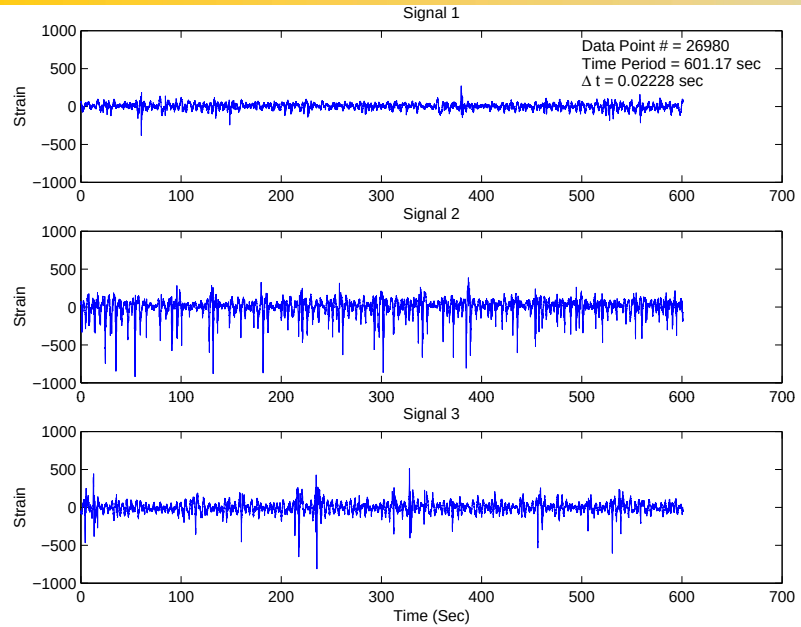
Feature Extraction

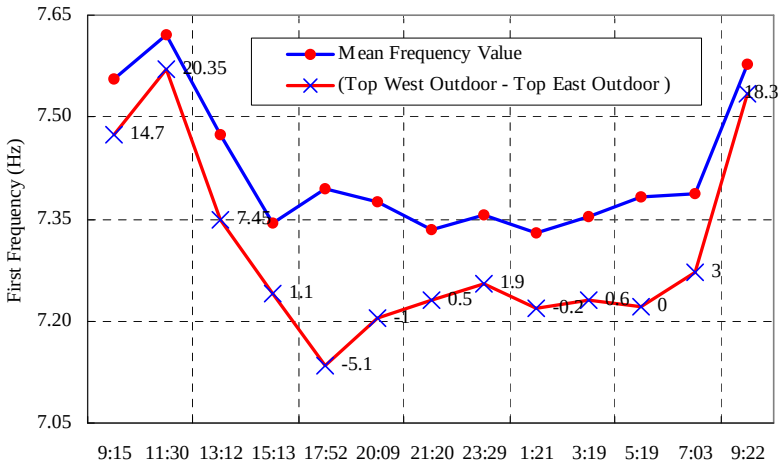
- Approaches to identifying damage-sensitive features.
  - Past experience
  - Component and system testing
  - Numerical analysis to simulate damaged system response
- Features types.
  - Absolute (derived from single data source, e.g. modal frequency)
  - Relative (derived from multiple data sources, e.g. mode shape)
- Damage sensitive features fall into three categories.
  - Waveform or image comparison
  - Model parameters
  - Residual errors between measured and predicted response.

Feature Extraction

- Want many samples of low-dimension feature vectors.
- The need for low-dimension feature vectors often necessitates some form of information condensation (e.g. compression of accel.-time histories into modal properties).
- Apply data fusion techniques to extract features from multiple and possibly heterogeneous sources (estimation mode shapes).
- Quantify feature's sensitivity to damage.
- Ideally, the features should change monotonically with damage level.
- Identify and quantify sources of feature variability.
- Incorporate feedback from data acquisition and statistical model development portions of the process.

Data Normalization





Features are Used to Answer the Following:

1 **Is the system damaged?**
- Group classification problem for supervised learning
- Identification of outliers for unsupervised learning

2 **Where is the damage located?**
- Group classification or regression analysis problem for supervised learning
- Identification of outliers for unsupervised learning

3 **What type of damage is present?**
- Can only be answered in a supervised learning mode
- Group classification

4 **What is the extent of damage?**
- Can only be answered in a supervised learning mode
- Group classification or regression analysis

5 **What is the remaining useful life of the structure? (Prognosis)**
- Can only be answered in a supervised learning mode
- Regression analysis