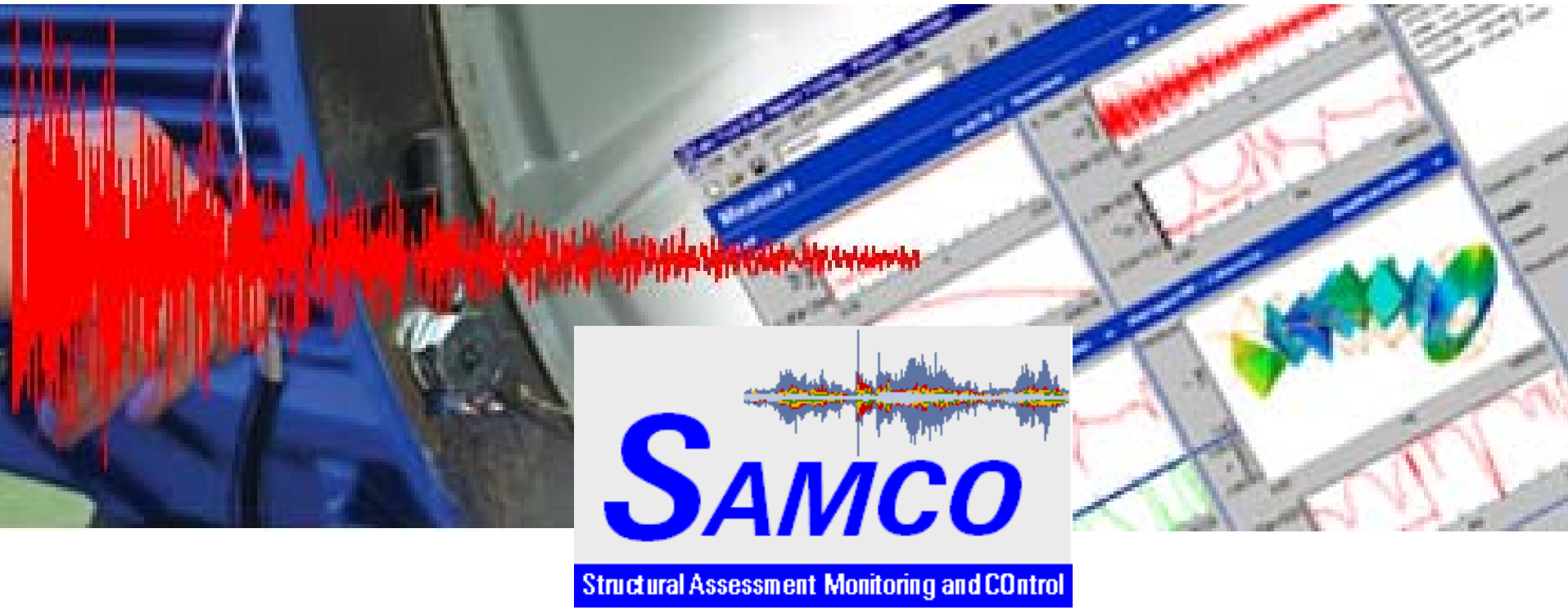
Smart processing of data from permanent monitoring systems: innovations and needs

(BRIMOS – EMASS)



Herman Van der Auweraer, Bart Peeters

5-th SAMCO Workshop, 26-27 Jan. 2004

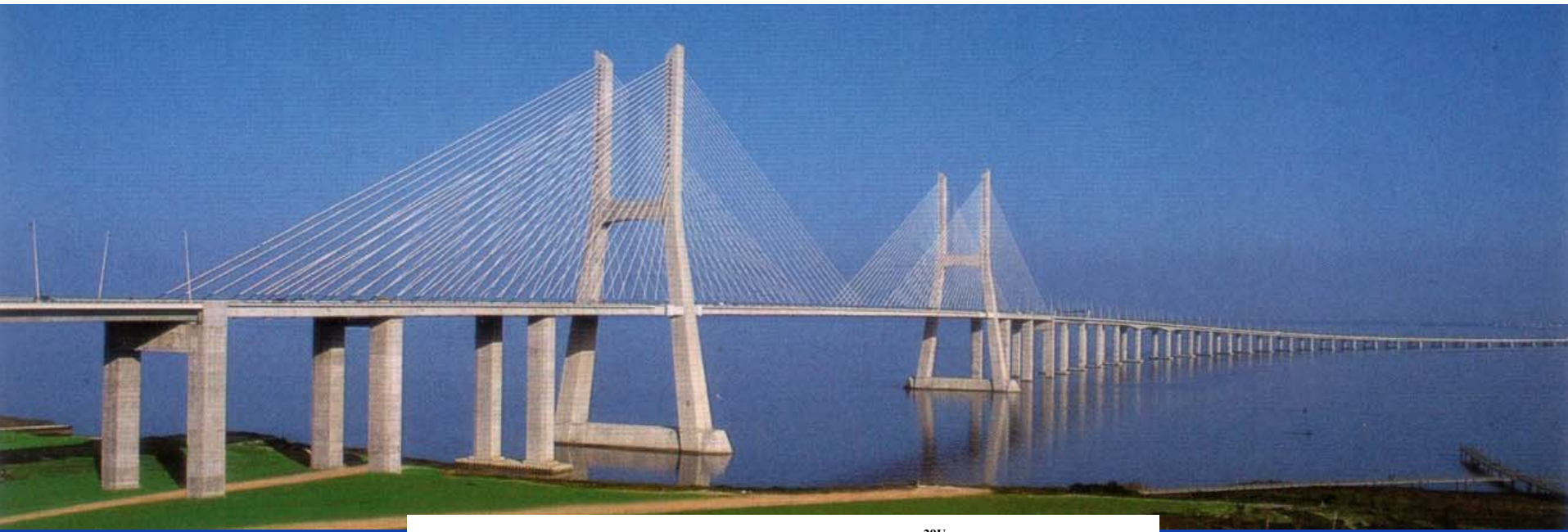
LMS INTERNATIONAL

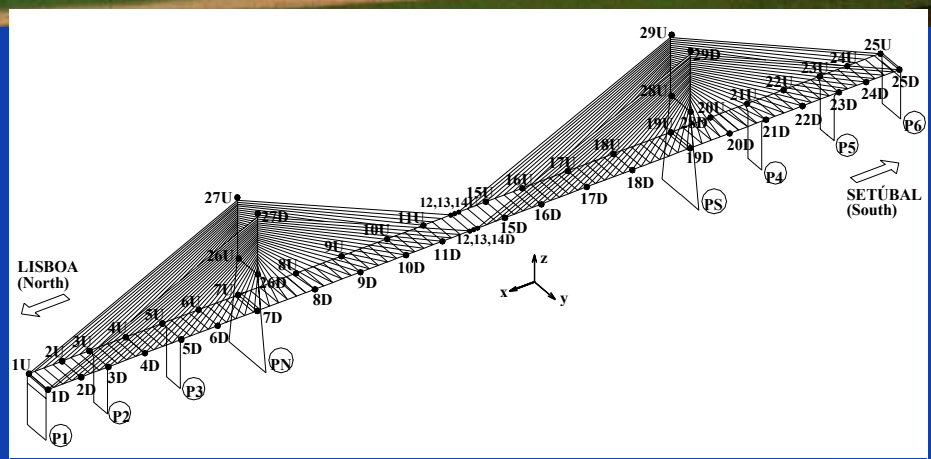
Empowering Engineering Innovation

Context
Bridge Monitoring

- Permanent monitoring systems
  - Long-span cable-stayed and suspension bridges
    - Large investment
    - Motivated by insurance companies
  - Purpose
    - Design verification
    - Event recording
      - Archive
      - Serviceability
    - Health monitoring
  - Massive amounts of data
    - Smart processing
    - Management

Operational Modal Analysis
Vasco da Gama Bridge





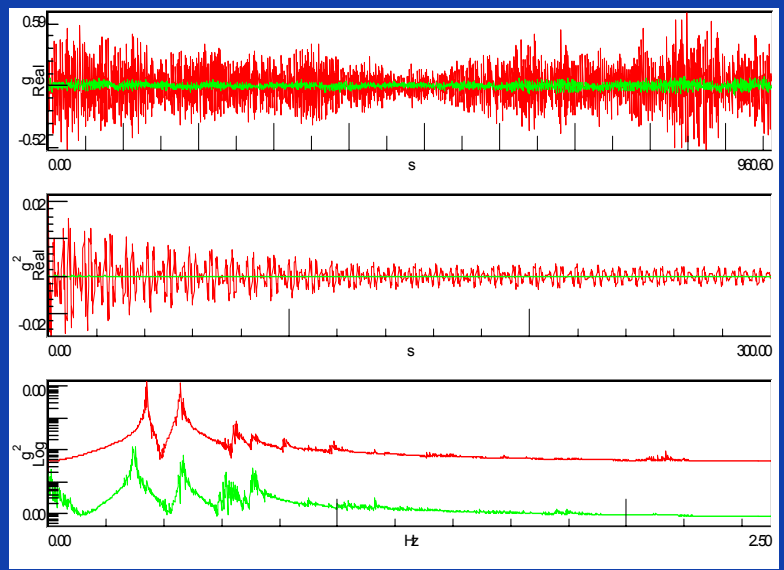
Ambient Accelerations Modes BV1 and T2

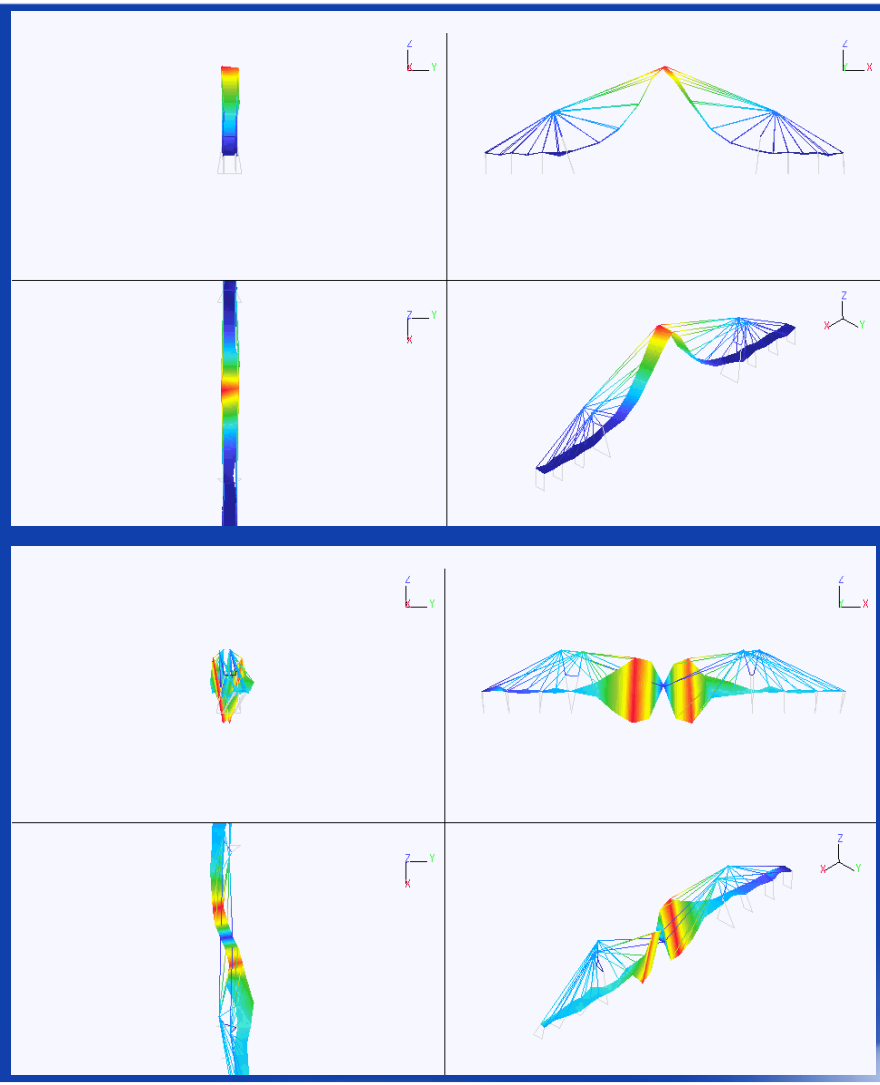
Vertical acceleration
Transversal acceleration

Time

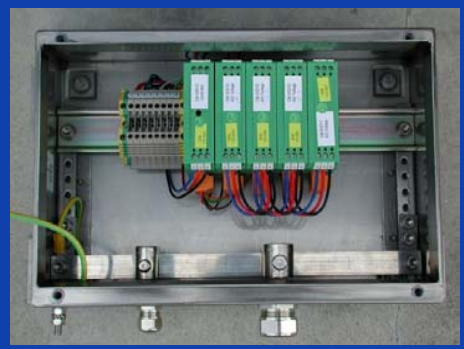
Corr.

Spec.

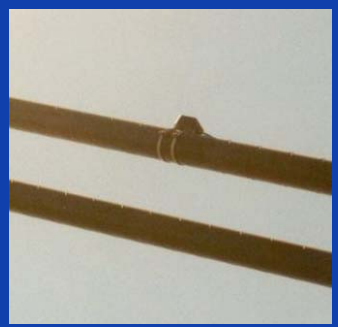


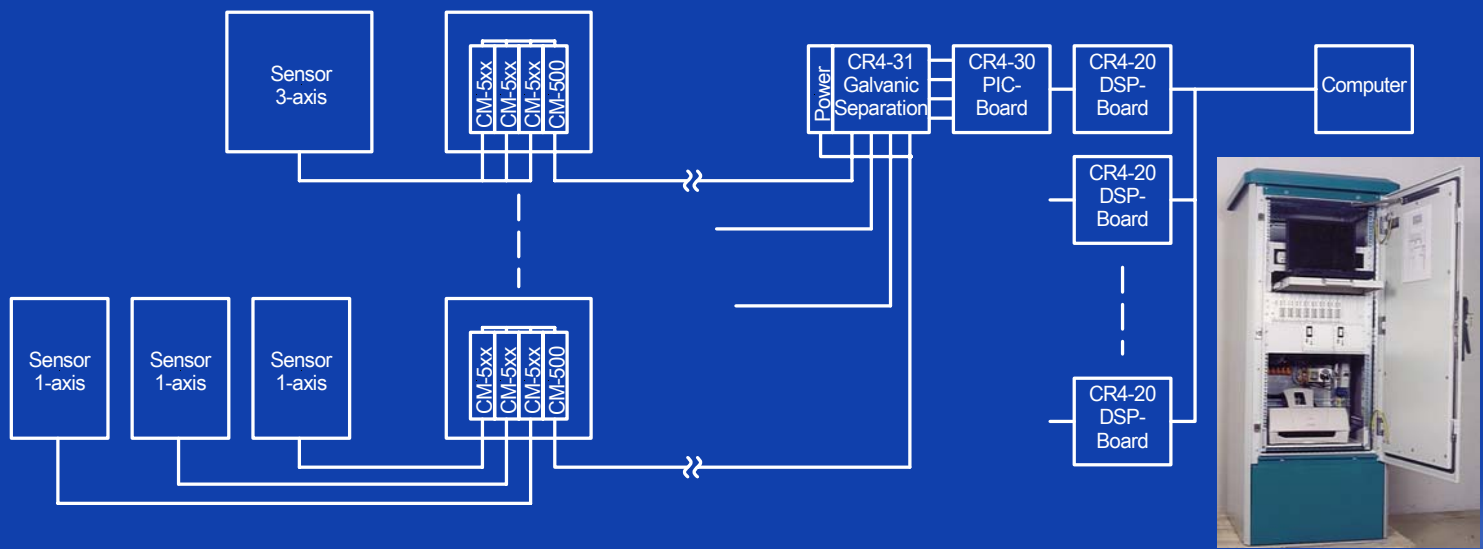


Øresund Bridge:
Continuous Monitoring System Cable Forces



GeoSIG



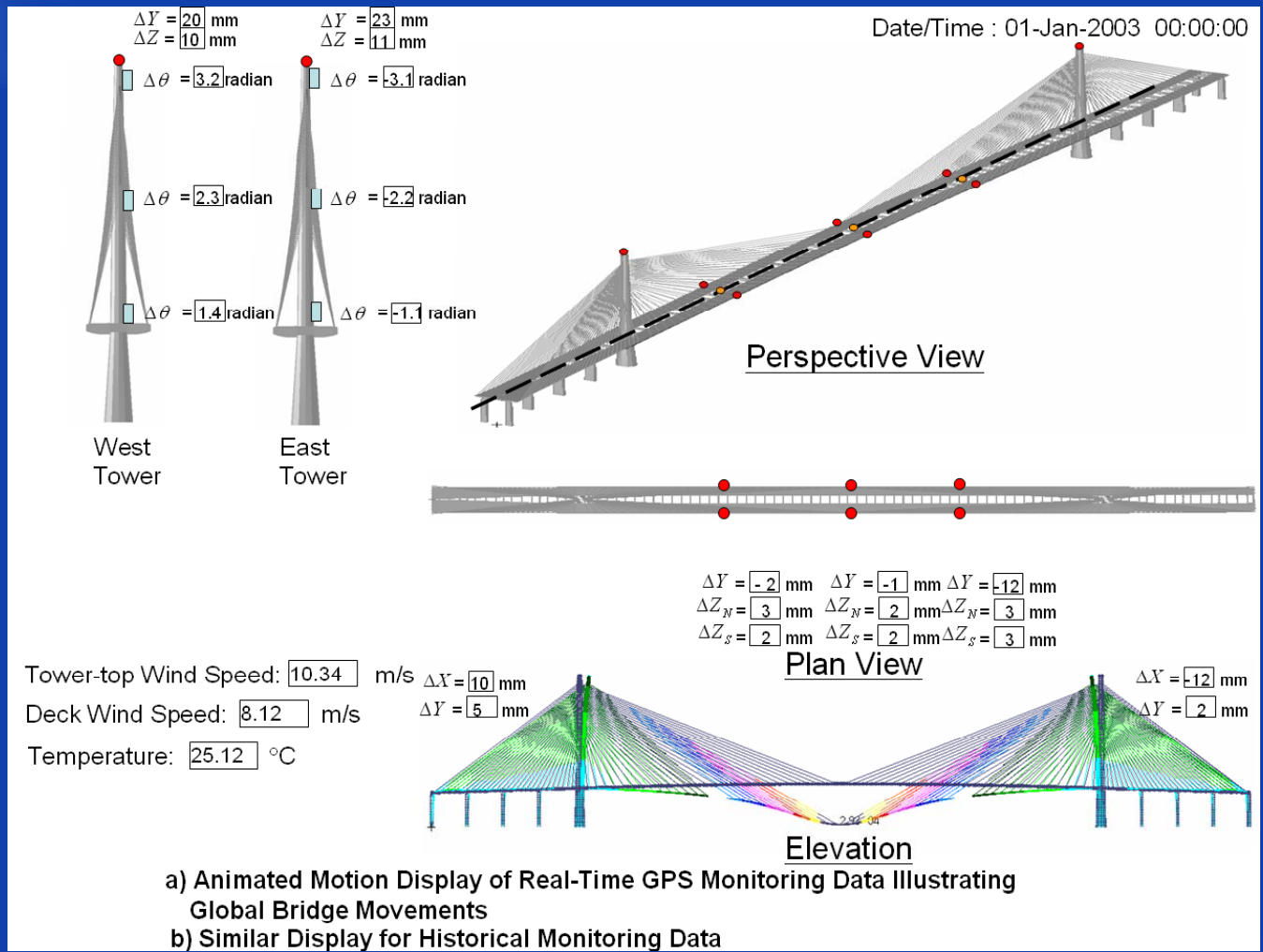


Future: Stonecutters Bridge in Hong Kong

- Stonecutters Bridge (2007)

- WASHMS: wind and structural health monitoring system
  - Wind
  - Temperature
  - Accelerations
  - Strains
  - Traffic loading
  - Humidity, rainfall
  - Displacement (by GPS)
  - Corrosion
  - **TOTAL: 1114 channels !!!**

From Real-time Displacements to FE Model validation



a) Animated Motion Display of Real-Time GPS Monitoring Data Illustrating Global Bridge Movements

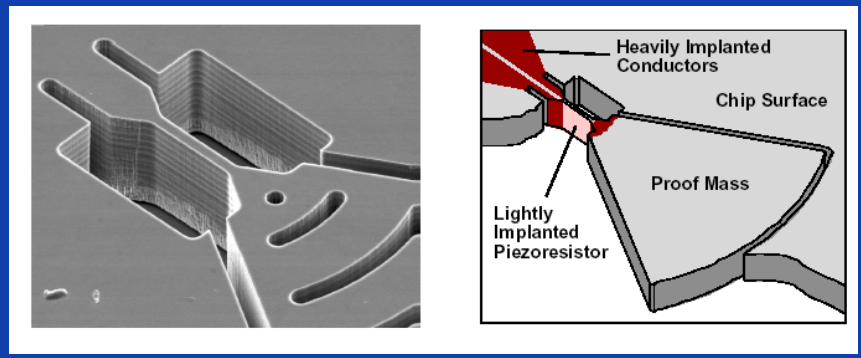
b) Similar Display for Historical Monitoring Data

Challenges for structural monitoring and damage identification

- Signal capturing and processing
  - Sensors
  - Sensor networks
  - Data transmission
  - Data processing
- Change detection
  - Signal based methods
  - Model based methods
    - Model comparison
    - Statistical Test
  - Discrimination of environmental effects
- Data management

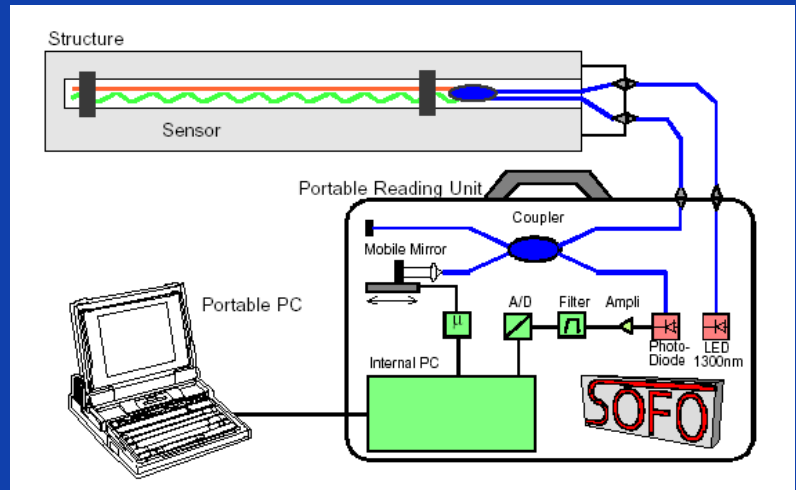
Challenges for structural monitoring and damage identification

- **Smart Sensors**
  - Use of MEMS
  - Optical sensors
  - Local digitization
  - Local processing (correction, calibration, pre-processing, FFT, ….)
  - Fusion of data types: vibration, displacement, corrosion, GPS, video, environmental, static …
  - Gradual transition to advanced sensors (need-to-have basis) -> mixed mode support approach



Sensors
Optical Fibers

- Technology
  - Interferometry using 2 fibers
    - Mechanically coupled
    - Free reference fiber (temperature)
  - Bragg gratings
    - Multiplexing
  - Other
- Can offer added value
  - Quality / stability
  - Long-term reliability
  - Installation
- Parameters
  - Strain (static + dynamic)
  - Temperature
  - Humidity
  - Corrosion



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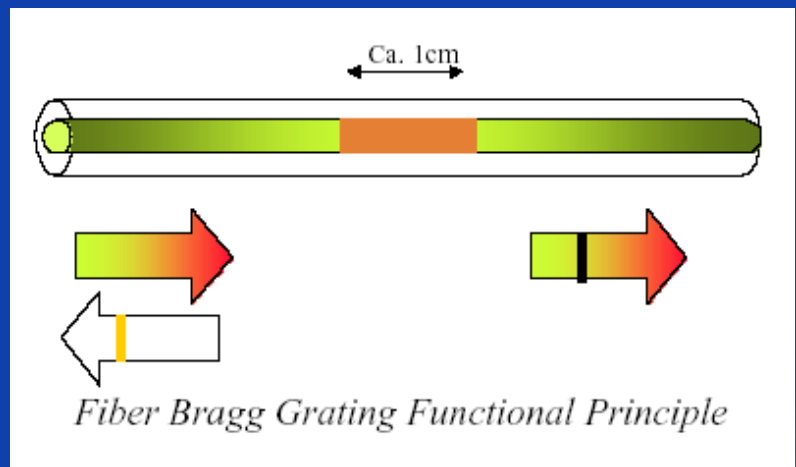

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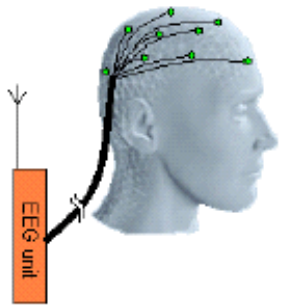
Challenges for structural monitoring and damage identification

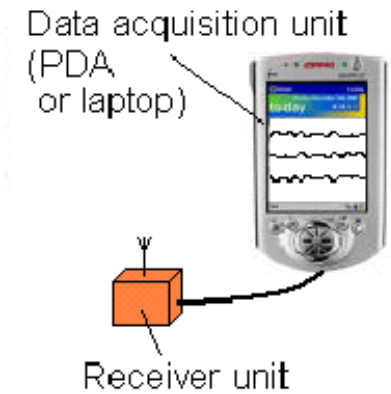
- **Bus-systems and wireless transmission**
  - Sensor network architectures
  - Data bus systems (e.g. CDMA, SPDIF,…)
  - Wireless transmission (from analog to WLAN…)
- **Critical Issues:**
  - Absolute time synchronization (through WLAN, through GPS, by cable, by predictive correction…)
  - Data transmission performance
    - Distance versus Bit rate
    - Accuracy, resolution, drop-out…
  - Power consumption and supply (cable, battery, power "scavenging") [IMEC]
  - Research topic at LMS

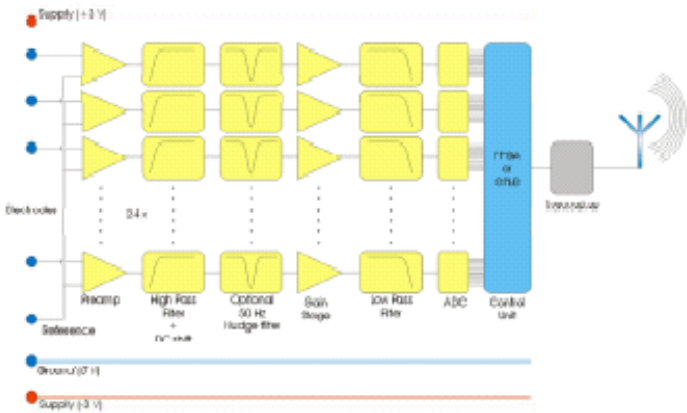
Challenges for structural monitoring and damage identification

- **Breakthrough research in high-value sectors**
  - **Medical: IMEC Human++ program**
  - **Space: NASA shuttle and ISS**
  - **Aeronautics: on-board SHM, flutter detection**
  - **Earthquake alert and analysis (NEEES, E-defense…)**
- **Develop synergies, re-use results where possible**
  - **Other EC projects**
  - **EUREKA (FLITE…)**
  - **National**
  - **International**

Example technology driver for Human++
Ambulatory EEG system







IMEC Human++ Program

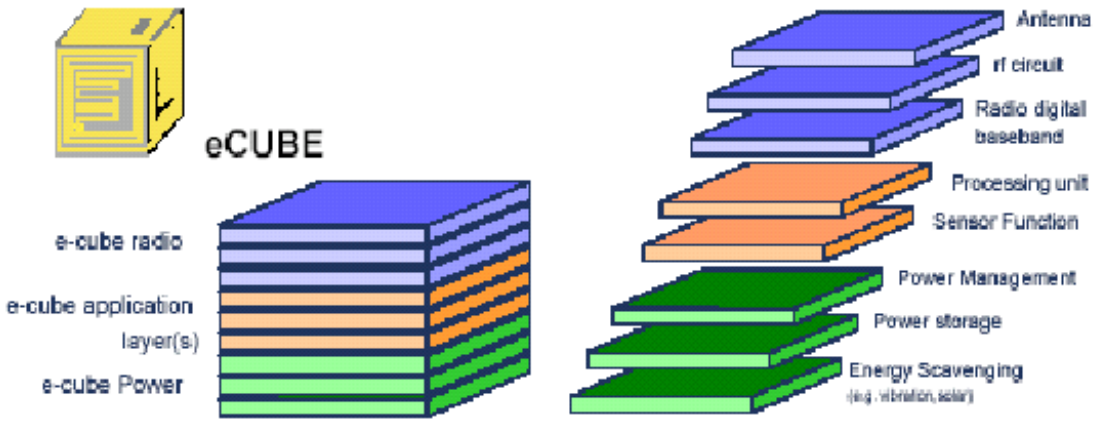
Example technology driver for Human++
Ambulatory EEG system

- Channels: 24
- Sample rate: 256Hz
- Resolution: 12 bit / sample
- Filtering
- Amplification
- FSK modulation
- Carrier: 868MHz
- Output power: -10dBm
- FEC: reed solomon
- Raw data rate: 76kbit/s
- Power consumption: 145mW
- Operational lifetime: 3 days on 4AA batteries

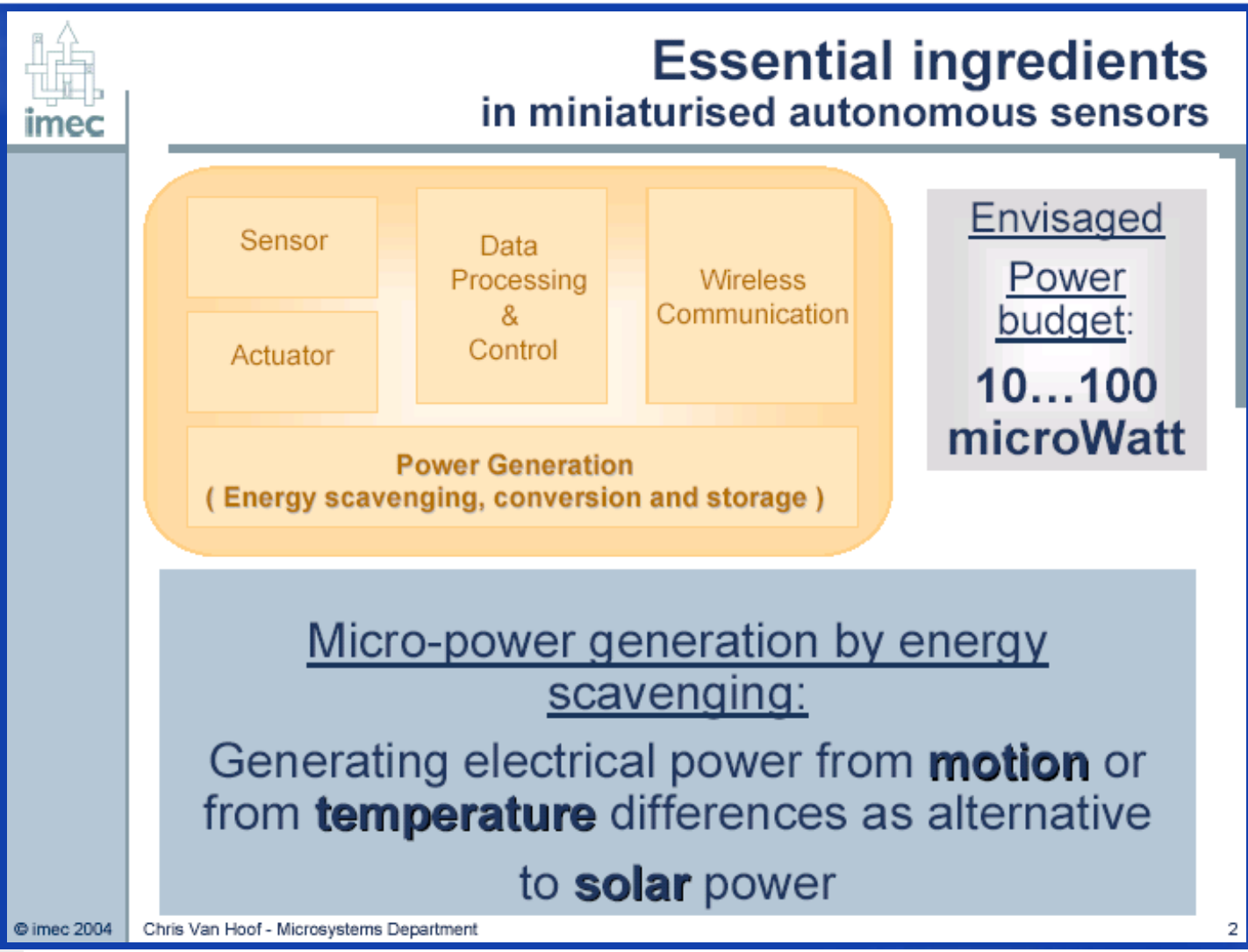
IMEC Micro-sensor and Human++ Program

Enabling technology roadmap
3D SiP intelligent cubes / ubisensors

2006 vision : 3D SiP: intelligent cubes (100mm^3…1cm^3)
lead to breakthrough in Human++ applications



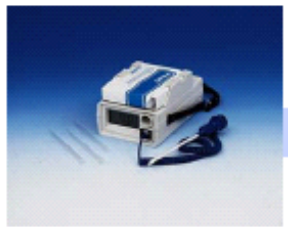
IMEC Micro-sensor and Human++ Program



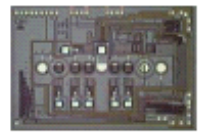
IMEC Micro-sensor and Human++ Program

IMECs view on technology driver approach:
Phased introduction of new technology

today: off-line measurements



1st generation: on-line measurements using distributed but macroscopic sensor systems

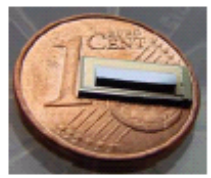


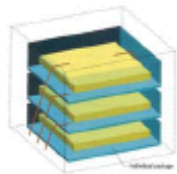
2nd generation: on-line measurements using lab-on-a-chip technologies for web-based sensor platforms

can be combined in an intermediate generation

Today: local computing
Multiple sensors, one hub

1st generation sensorweb: basic research on ULP architecture, but using established sensors and off-the-shelf microcontrollers/RF





2nd generation sensorweb: basic research on full autonomy and ultra-high-density integration using ULPminiaturized sensors

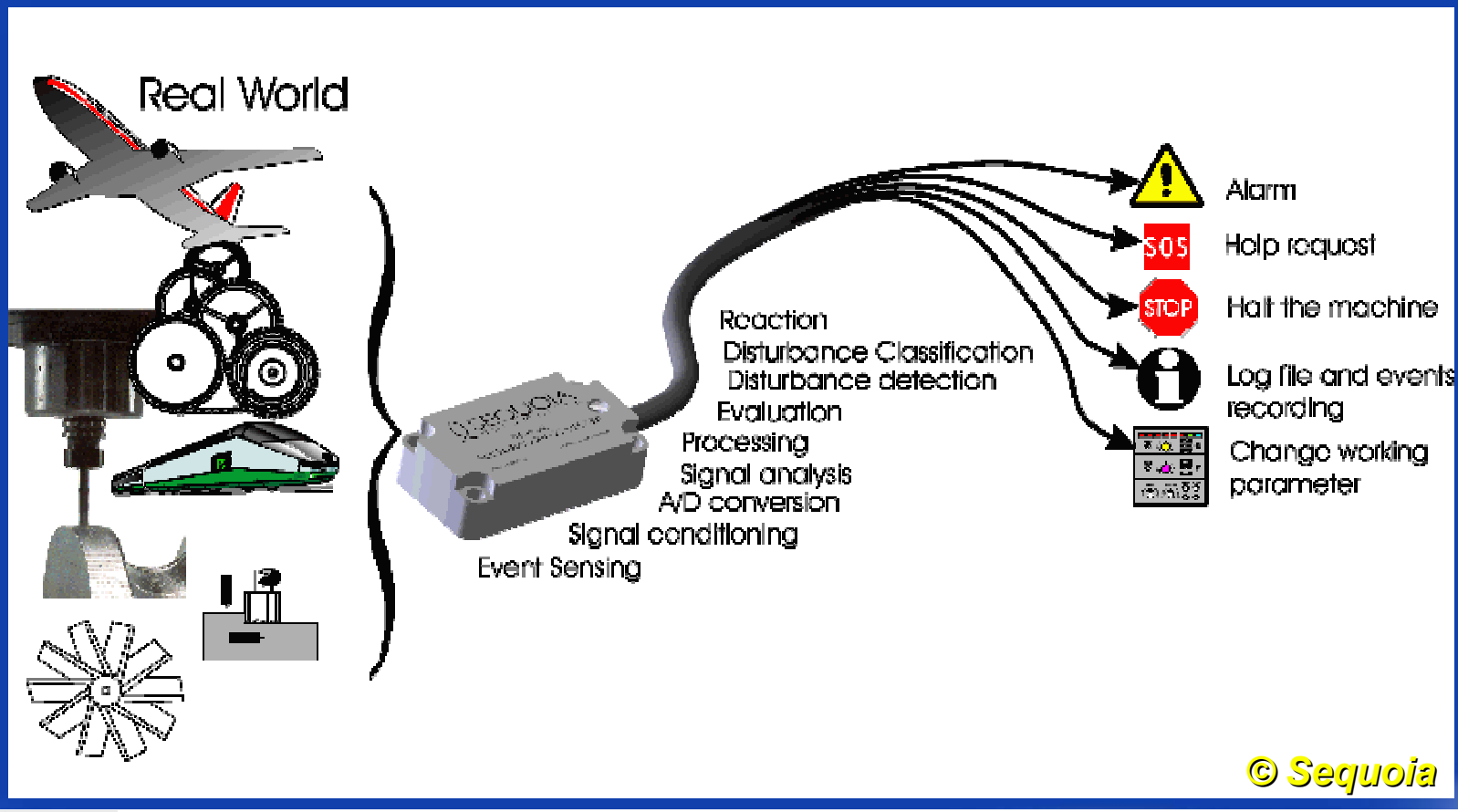
Example: Aerospace Wireless Communication

- MicroTAU, wireless tri-axial accelerometer
  - NASA Space Shuttle
  - To detect vibration of payloads during launch and landing
  - fs = 250 Hz
  - 9 min memory
- Wireless?
  - Wireless data synchronization between units (±30μs @ 250Hz)
  - Wireless data download
- Other programs:
  - IWIS (synch. 300 ns) -> ISS
  - WAIS (synch. 300 ns) -> Naval Air
  - WATS (synch. (±10μs) -> USAF

© INVOCON

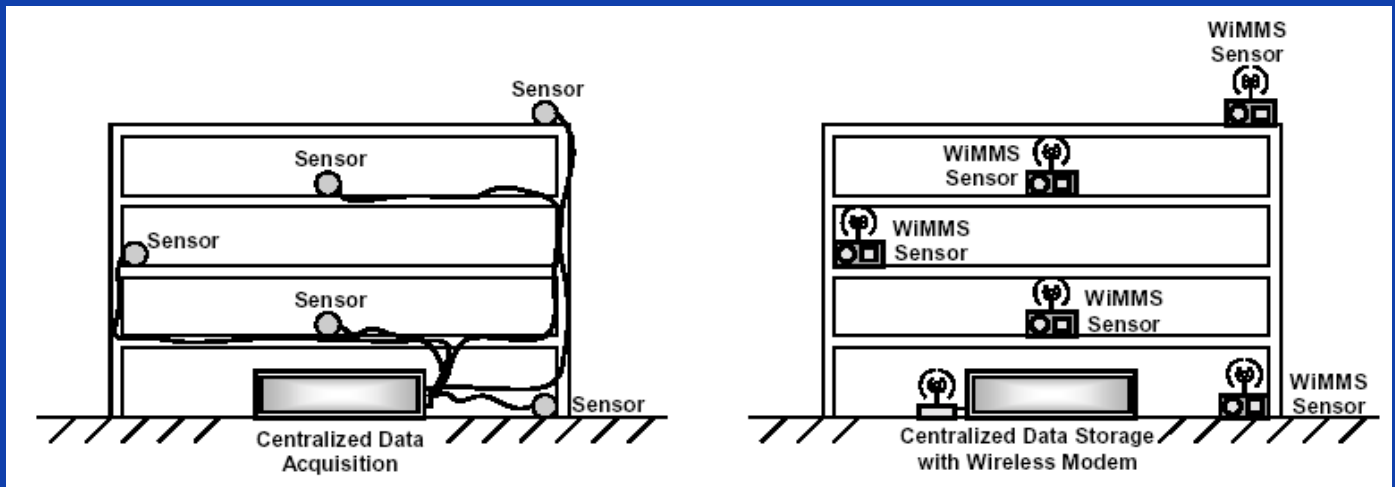
Sensor Data Collection Topologies

- Sequoia Triaxial Acceleration Computer (SeTAC) [Italy]
  - Adding data processing capabilities



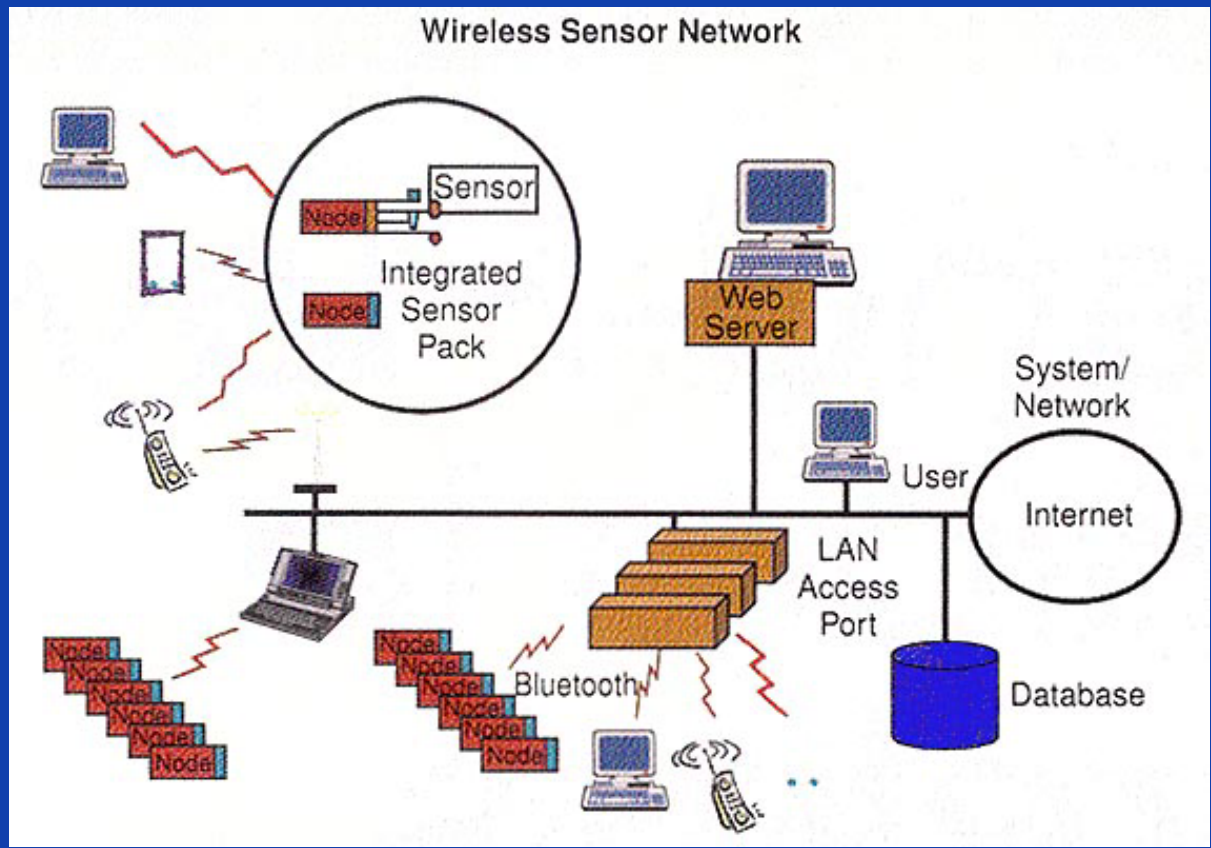
Wireless Communication

- **WiMMS**
  - Wireless Modular Monitoring System
  - The John A. Blume Earthquake Engineering Center, Stanford University
- **New technologies**
  - MEMS accelerometer
  - Embedded systems
    - Data acquisition
    - Computational power
  - Wireless communication
    - ISM band



Wireless Communication

- **Plug-and-play sensors in wireless networks**



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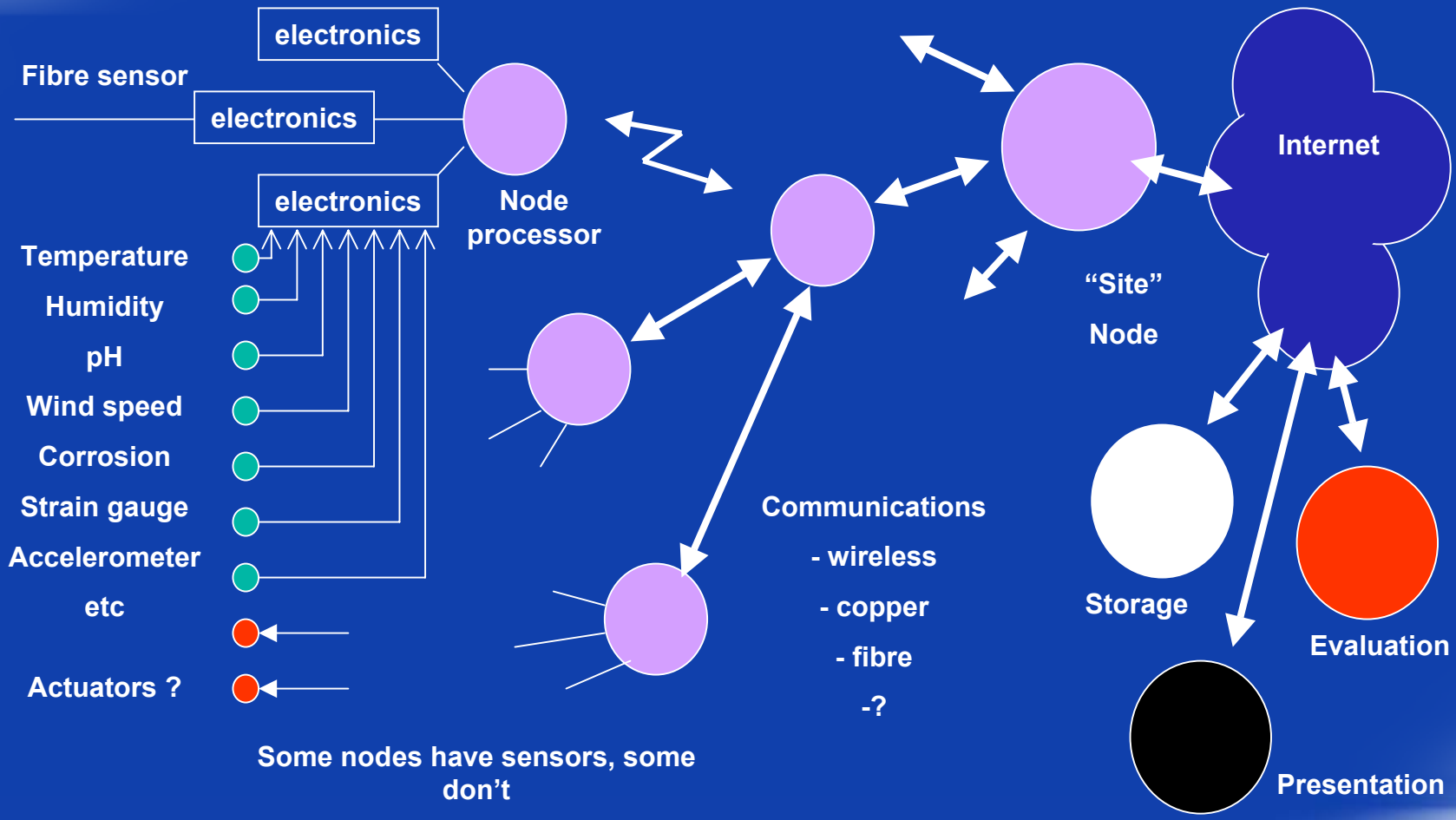
Generic Sensor Network

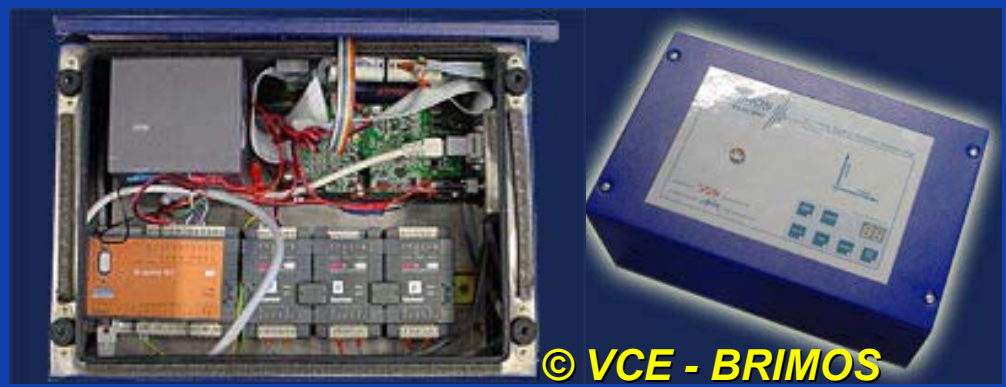


Challenges for structural monitoring and damage identification

- **Distributed data processing**
  - Local Pre-processing: FFT, features ...
  - Data reduction/compression (However, for modal analysis: at least cross-powers needed - references)
  - Local/global task distribution -> **local modal analysis?**
  - Data request – data provision services -> Internet, LAN…
  - Use of Agent Technologies (LMS)
  - Specific Architectures Research
    - Berkeley: Tiny-OS, “Motes”
    - Karlsruhe: Smart-IT / Ubicomp
    - K.U.L. / V.U.B. in Belgium
    - ……

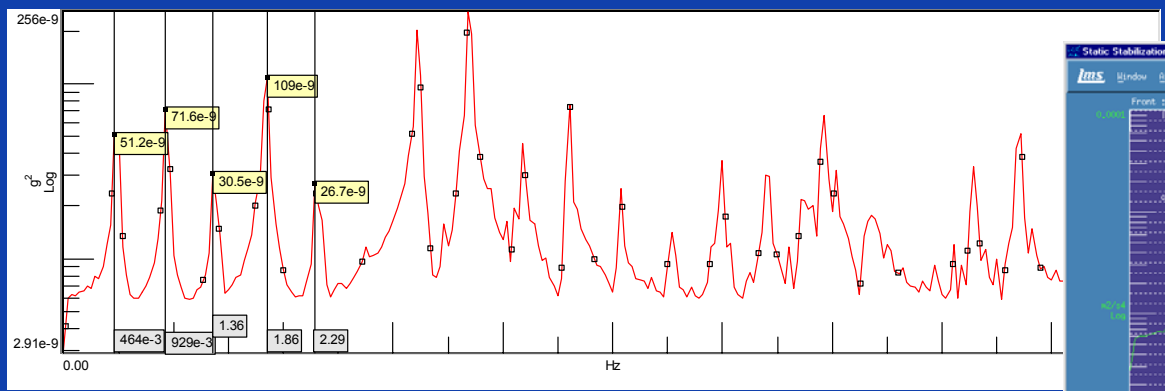
Challenges for structural monitoring and damage identification

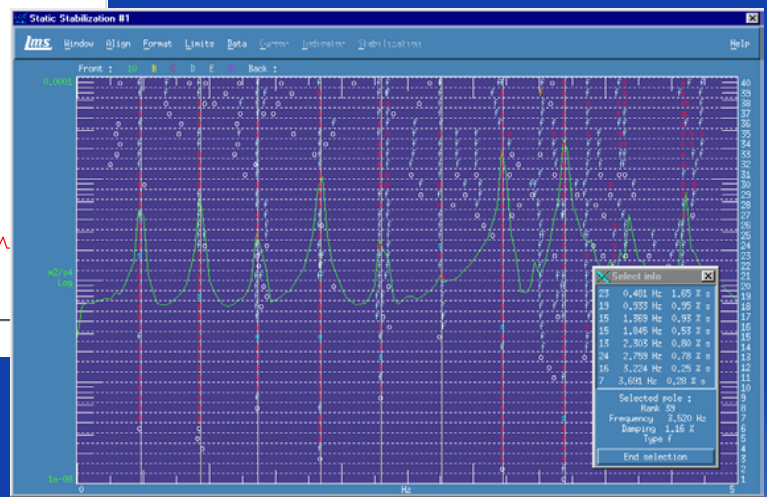
- **Research Approach**
  - Test individual solutions on existing HW platform (cfr. ex.)
  - Then prototype integration in platform to be decided



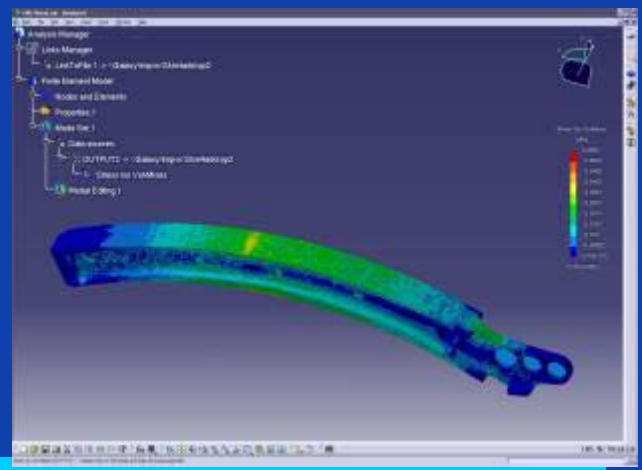
Challenges for structural monitoring and damage identification

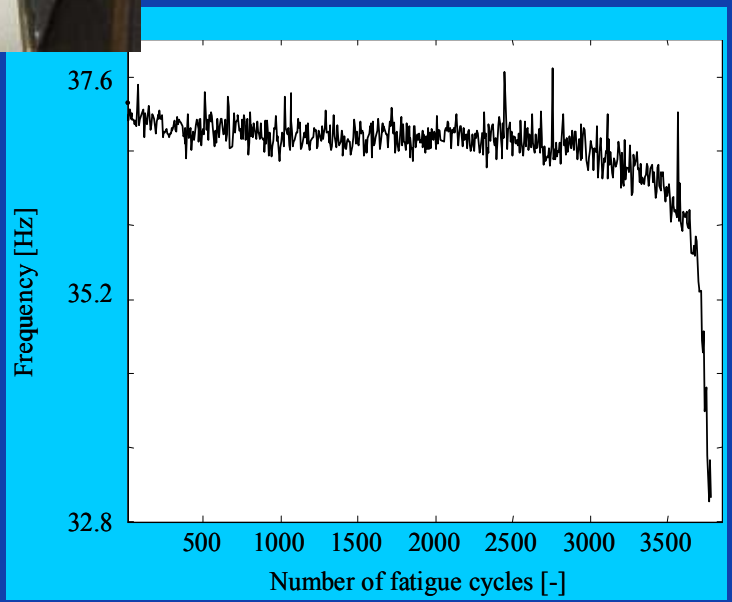
- **Change detection: current research at LMS: Model based methods:**
  - **Modal analysis -> requires automation**
  - **Statistical test -> requires good nominal model and test data [INRIA approach, flutter detection]**
  - **Discrimination of environmental effects: importance of influence assessed, but approach to deal with it??**

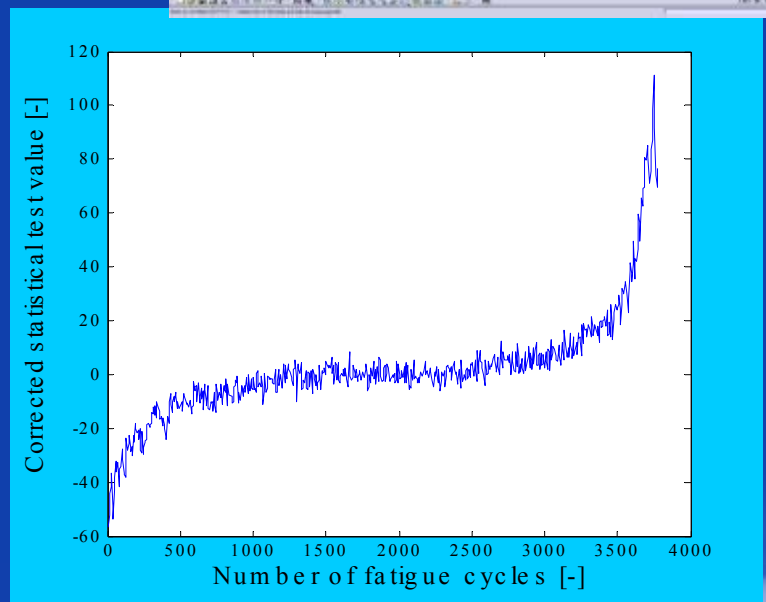




Challenges for structural monitoring and damage identification: slat track







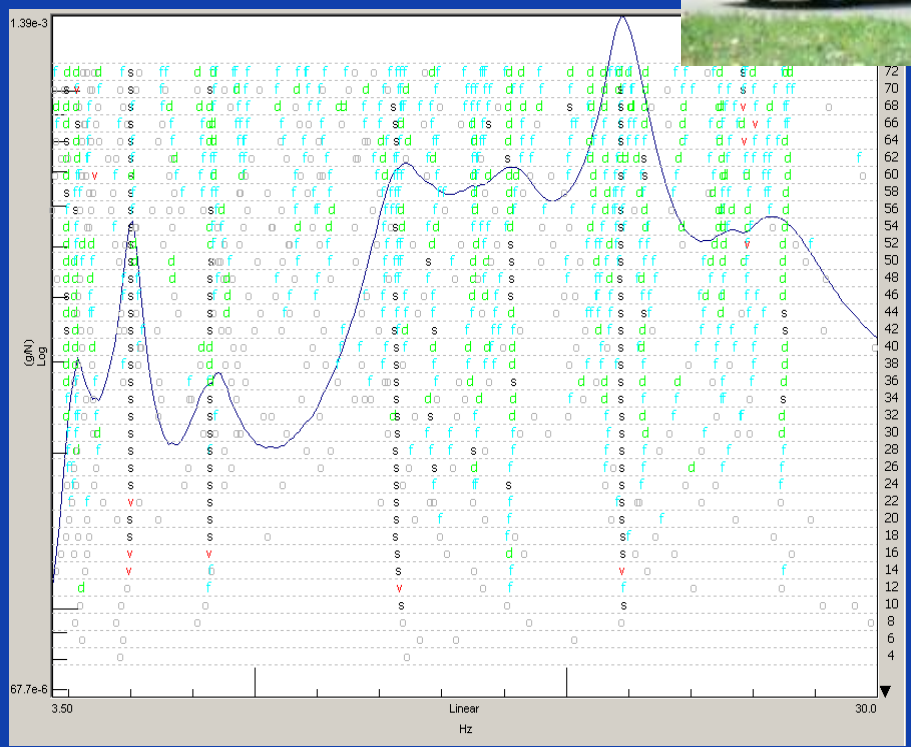
Challenges for structural monitoring and damage identification

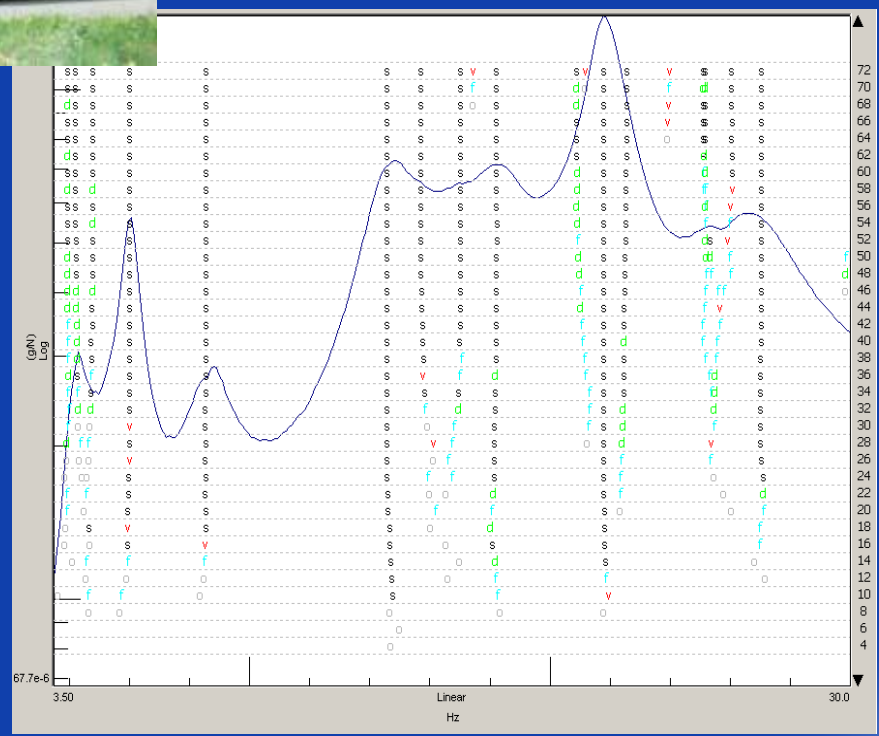
- **Modal analysis automation research at LMS**
  - Robust and repeatable modal identification
  - Minimizing user interaction
  - Improved mathematical pole discrimination
  - I/O PolyMAX method: discrete-frequency domain method with superior stabilization behaviour
  - Now being researched for OMA application
  - Multi-patch data synthesis
  - Decision methodology:
    - Clustering
    - Rule-based
    - Neural Networks

Polymax I/O: Porsche 911 Targa Carrera 4
Fully Trimmed Car

LSCE

PolyMAX

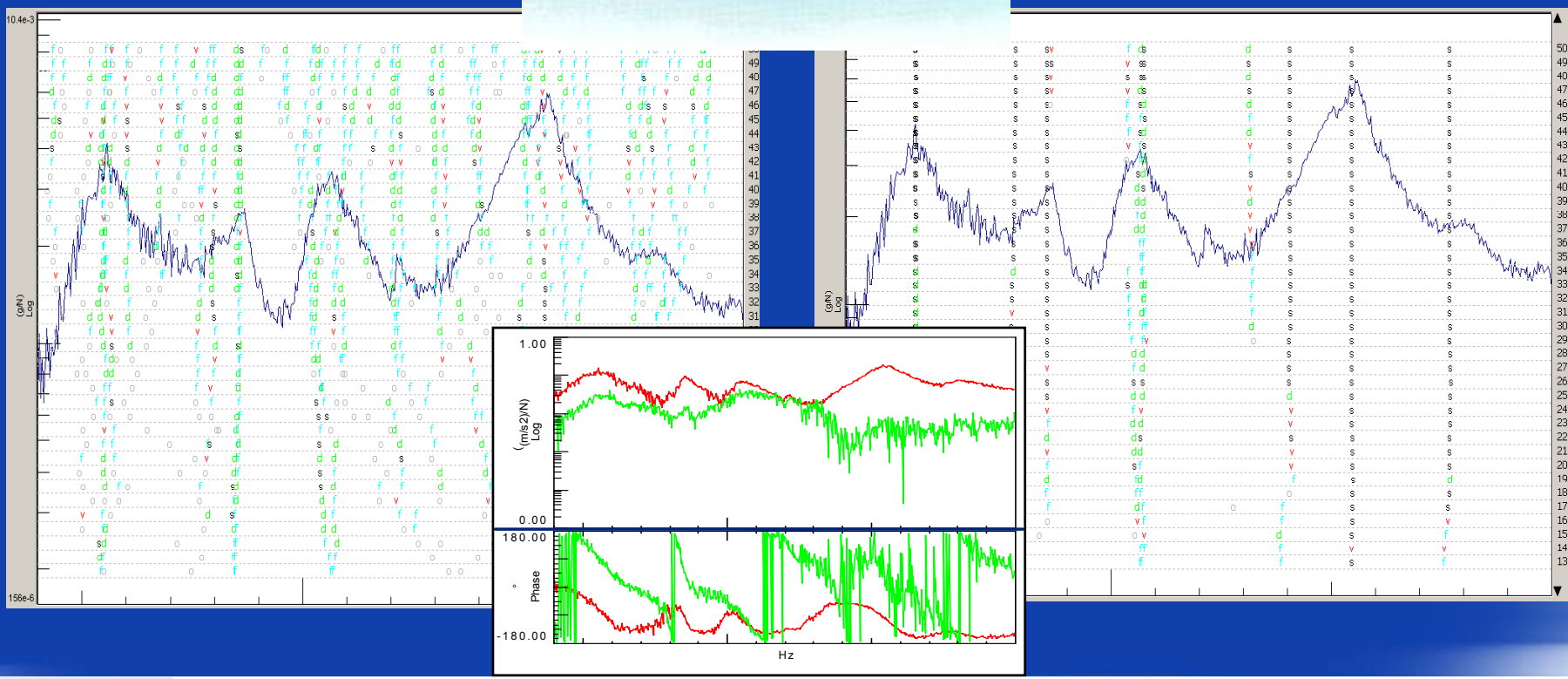




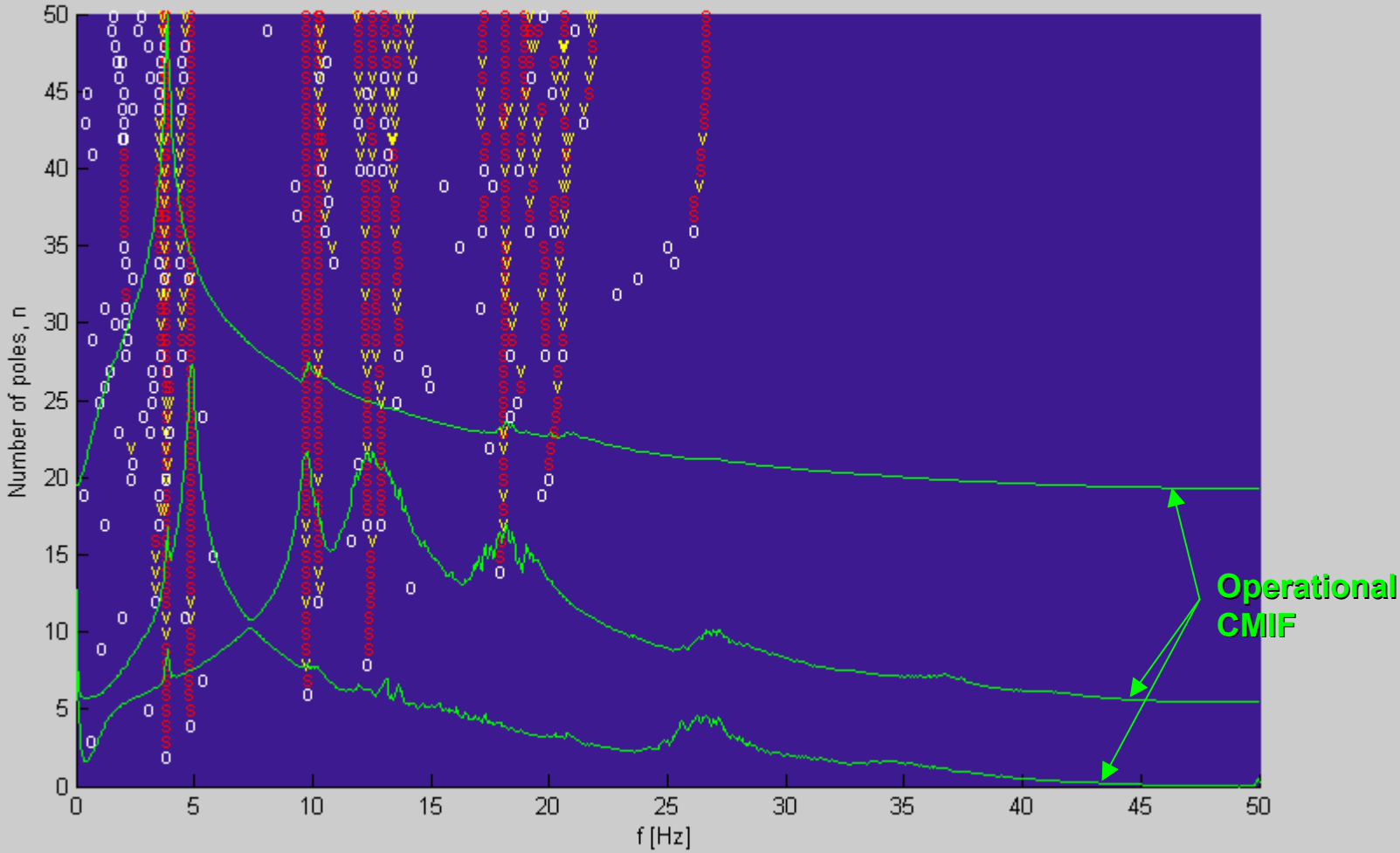
Polymax I/O: Aircraft In-flight Testing

LSCE

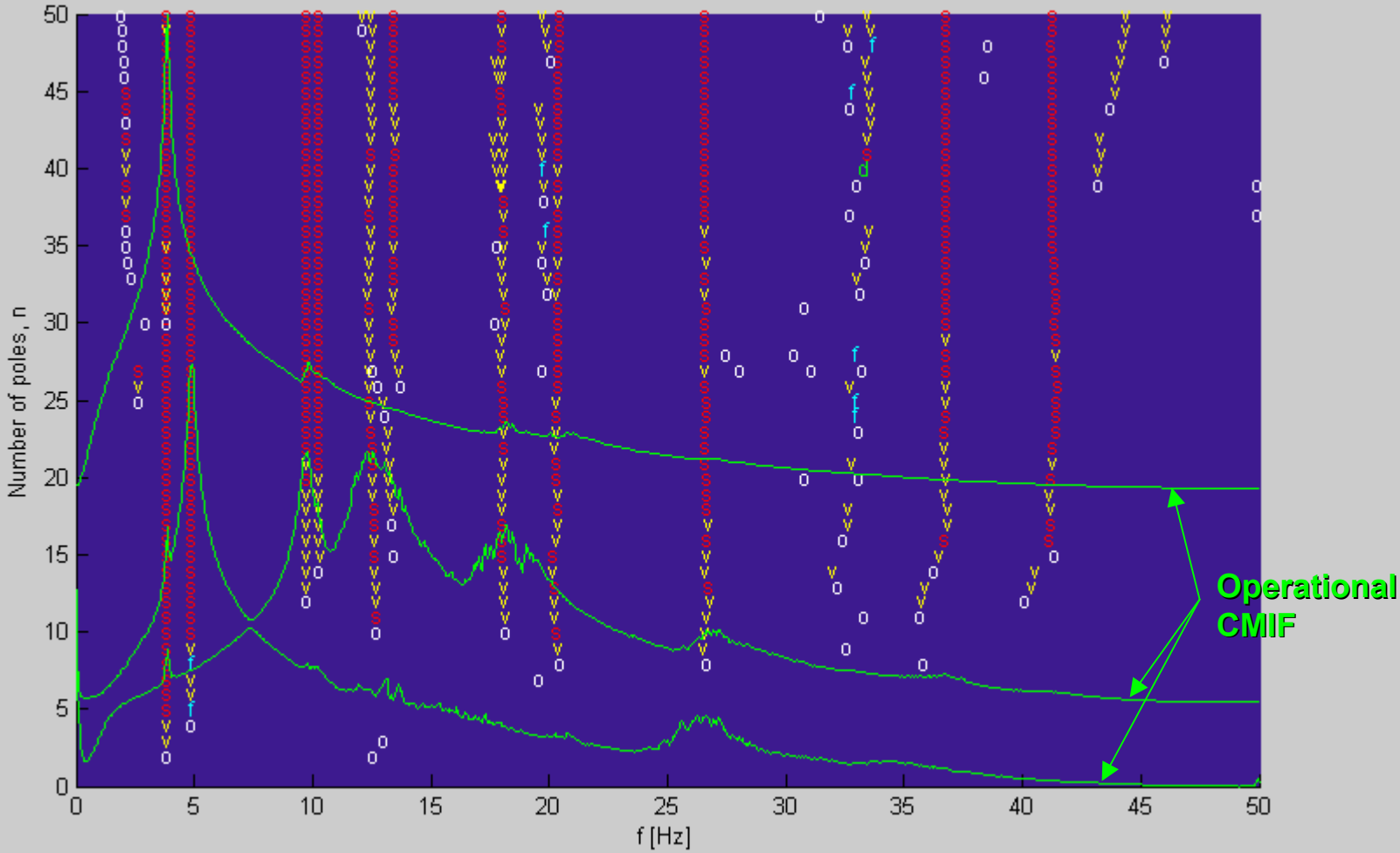
PolyMAX



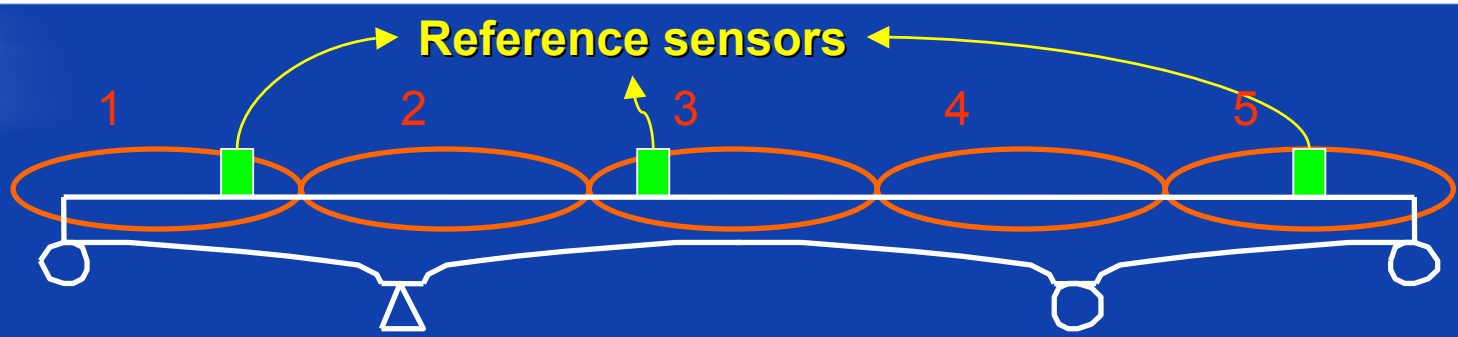
Stochastic Subspace Identification (BR)
Z-24



Operational PolyMAX
Z-24



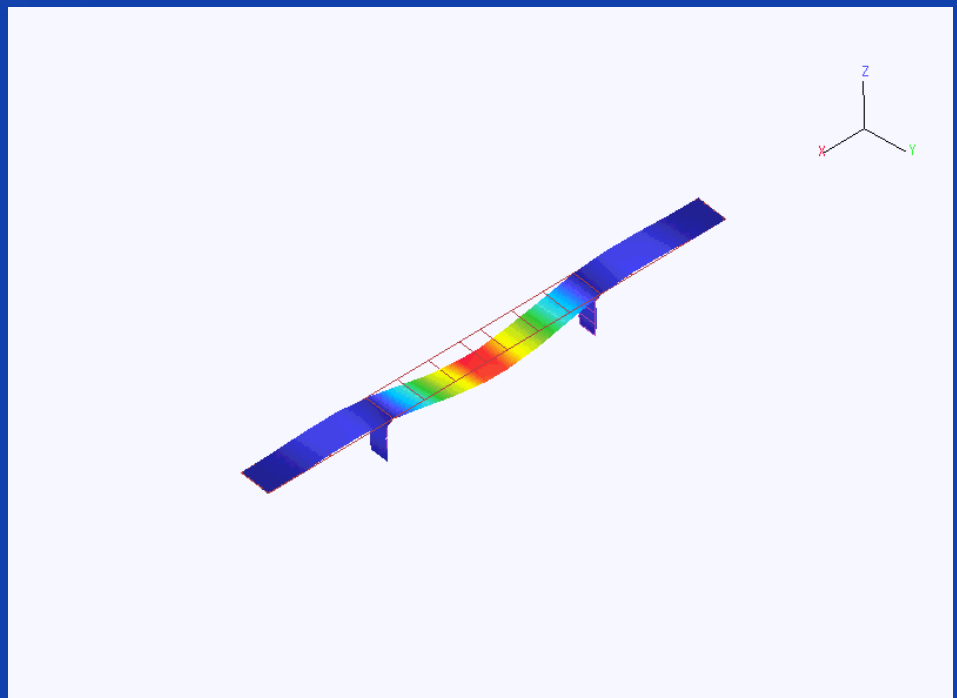
Operational PolyMAX
Multi-Patch Processing



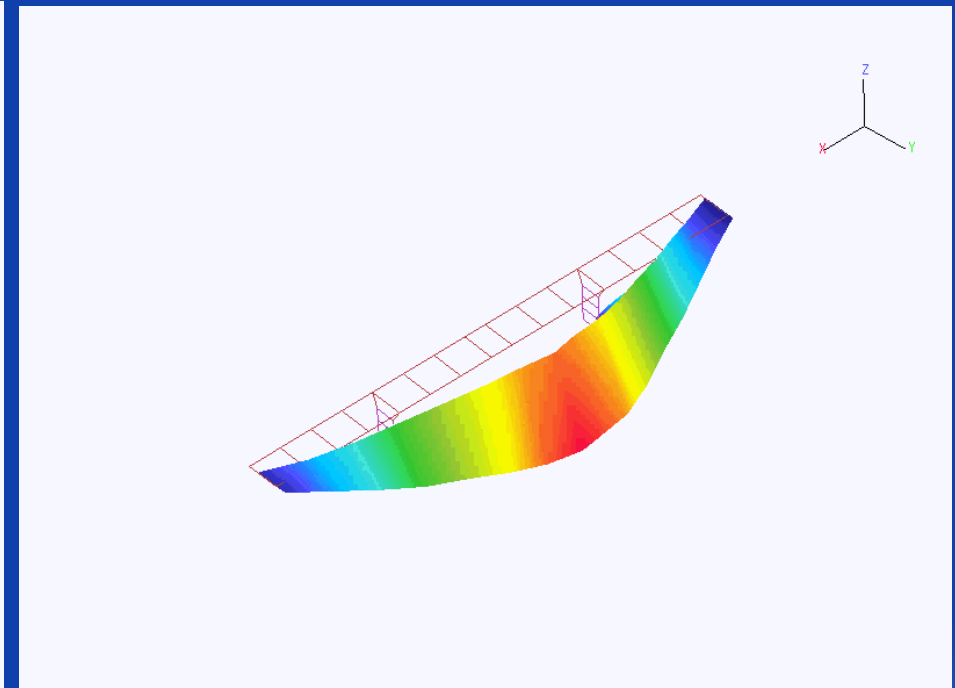
- Method 1: Independent processing
  - Merging shapes by computing LS modal scaling factors between reference sensors
  - Averaging eigenfrequencies and damping
- Method 2: Combined processing, scale shapes afterwards
  - All half spectra are stacked (the reference sensors appear many times)
  - Only 1 set of modal parameters
    - Rescale shapes as in method 1
- Method 3: Combined processing, scale data on beforehand
  - Scale half spectra based on averaged spectra between the references
  - No need to scale shapes after identification

Z24-Bridge

Mode 1

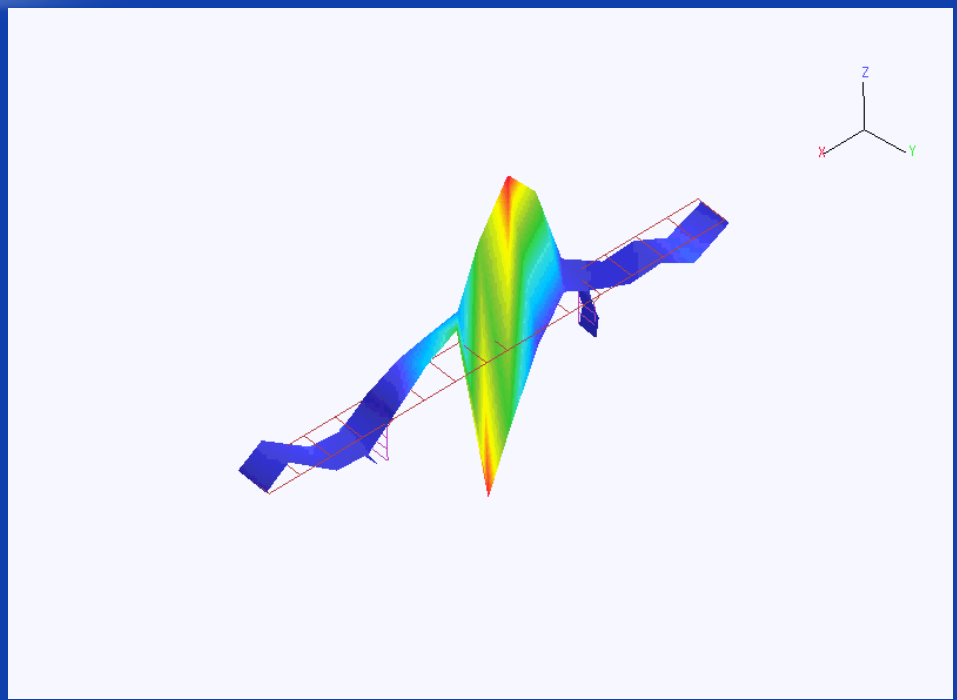


Mode 2

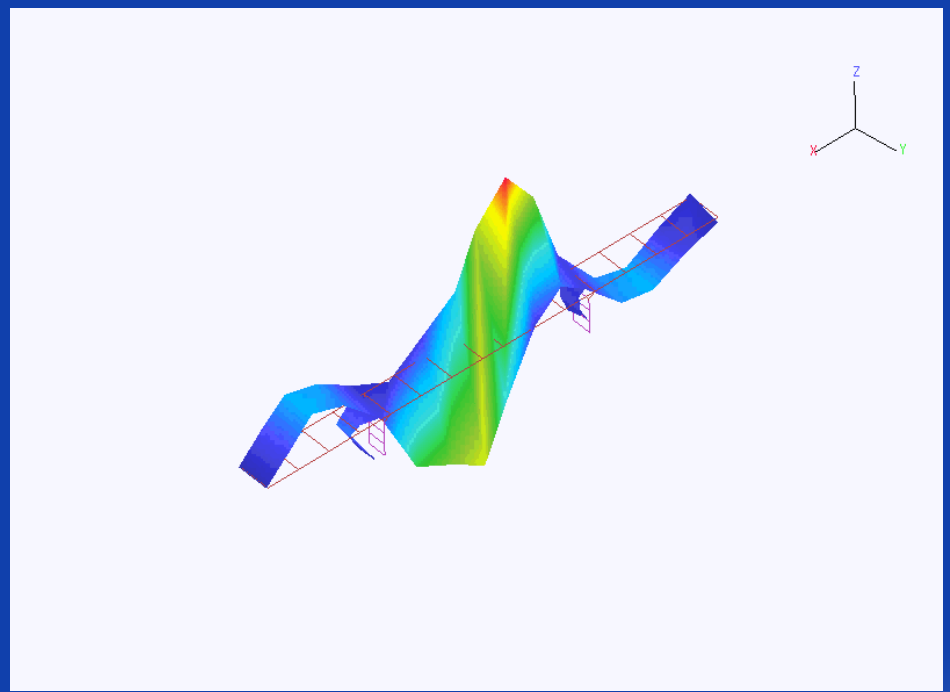


Z24-Bridge
Mode 3

PolyMAX

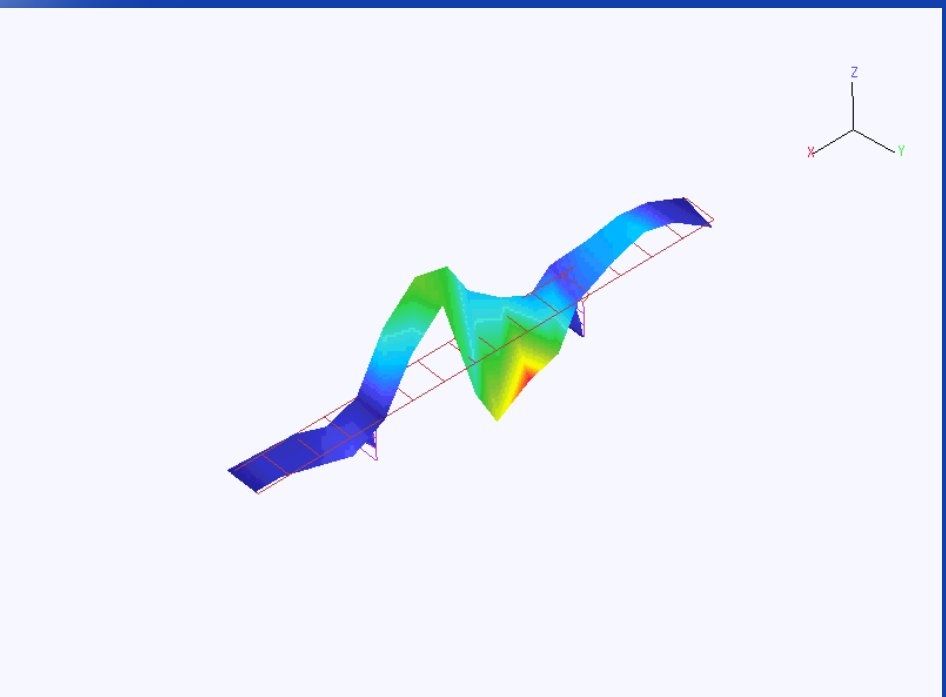


SSI

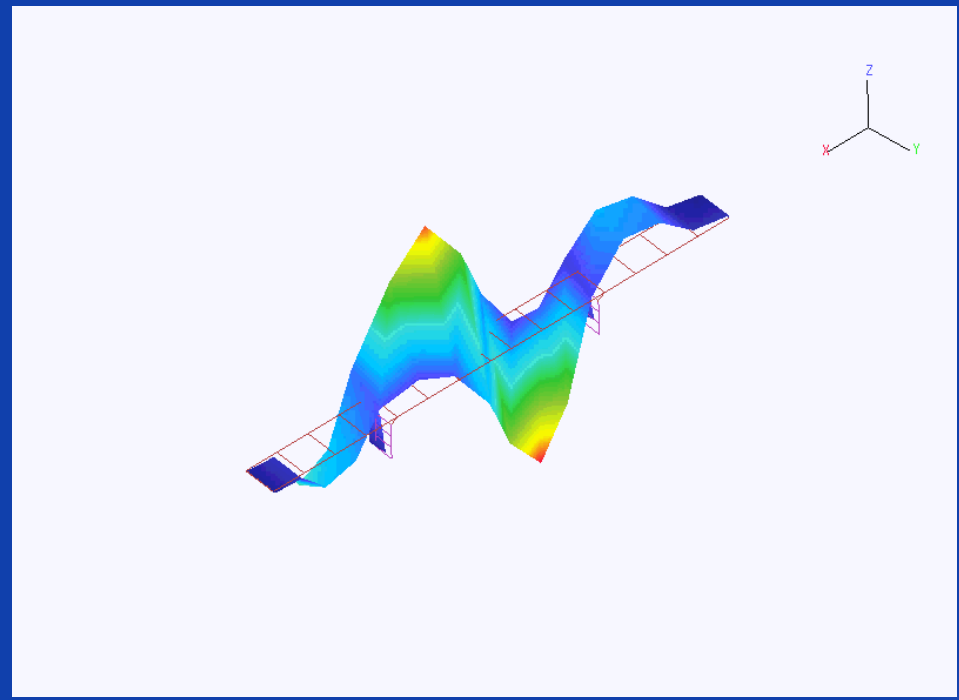


Z24-Bridge
Mode 4

PolyMAX



SSI



Challenges for structural monitoring and damage identification: conclusions

- Systems research on the level of
  - Smart sensors, heterogeneous sensors
  - Sensor networks, topologies, interfaces, buses
  - Wireless transmission & synchronization
  - Power consumption
- Analysis methods research:
  - Various detection and localization methods (Test & FE)
  - Polymax method seen as key technology for automation of OMA and hence for monitoring
  - Methods for environmental effect discrimination
  - Methods for decision
  - Local/global processing (reduction & autonomy)
- Leverage horizontal research results: Relevant input from Medical and AeroSpace research (IMEC, CSL, INRIA, LMS...)


Thank you !