



Output-only Modal Testing & Monitoring (MT&M) of Civil Engineering Structures: Instrumentation & Test Management

A. Nguyen, T.H.T. Chan, D.P. Thambiratnam, K.T.L Kodikara, N.T. Le, S. Jamali

Presenter: A. Nguyen, BEng, MEng, PhD

Research fellow in Civil/Structural Engineering, QUT

Outline of presentation

1. Introduction of Output-only MT&M
2. Typical test structures for illustration
3. Instrumentation aspects (transducer & placement-mounting, DAQ system, DAQ software, module and synchronization)
4. Some test/system management aspects (excitation issues, long-term system status, transient event detection)
5. Conclusions

Introduction

Definition: Output-only MT&M => The use of

- **Appropriate modal transducers**
- **DAQ hardware and software**
- **Modal analysis techniques**

To obtain appropriately conditioned **vibration response of a structure** under its ambient or operating loading conditions & subsequently **modal parameters** that may enable further useful engineering applications for the structure (St-Id, damage detection, performance monitoring, etc.)



Introduction

Advantage of output-only MT&M

- Can be done **when structure is under normal service** → Virtually no economic loss
- Measured data reflecting closely **actual working conditions of structure**

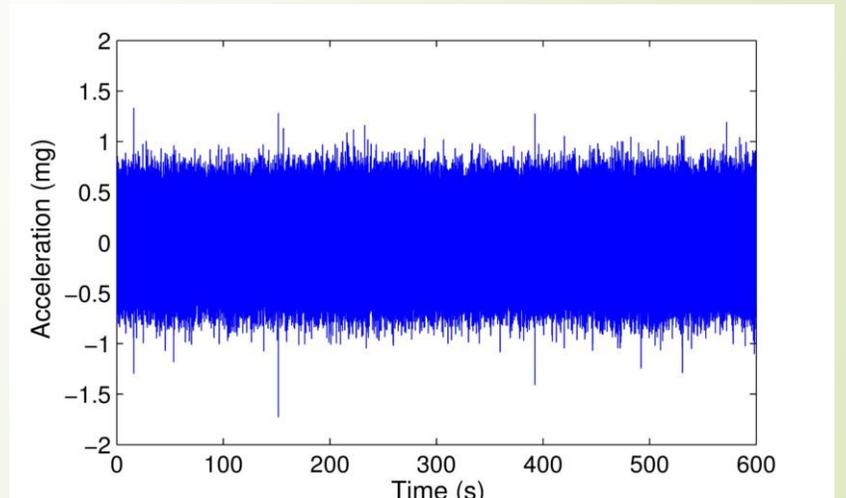
→ Considered as a convenient & effective tool for SHM & life-cycle management of civil engineering structures



Introduction

Challenges in output-only MT&M

- Requiring knowledge & skills of
 - Sensor & measurement,
 - DAQ & signal processing
(besides structural dynamics)
- Practical difficulties
 - Low-amplitude/ noisy signal
 - Lengthy duration of acquisition
 - Different structures have different characteristics and scales, etc.

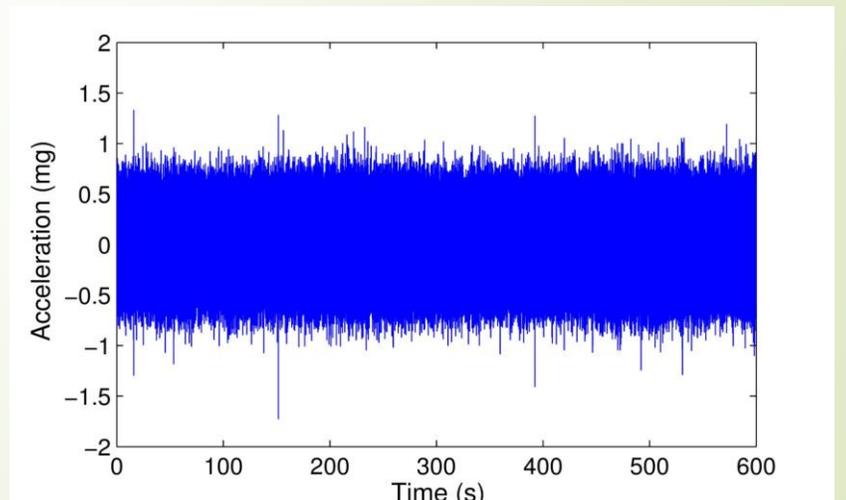


Introduction

Purpose of the presentation

- To provide some in-depth discussion in two of the most confusing aspects
 - Instrumentation
 - Test management (long-term)

With illustrations with two typical cases of test structure



Typical test structures

Case I: QUT's P block building (under long-term monitoring)

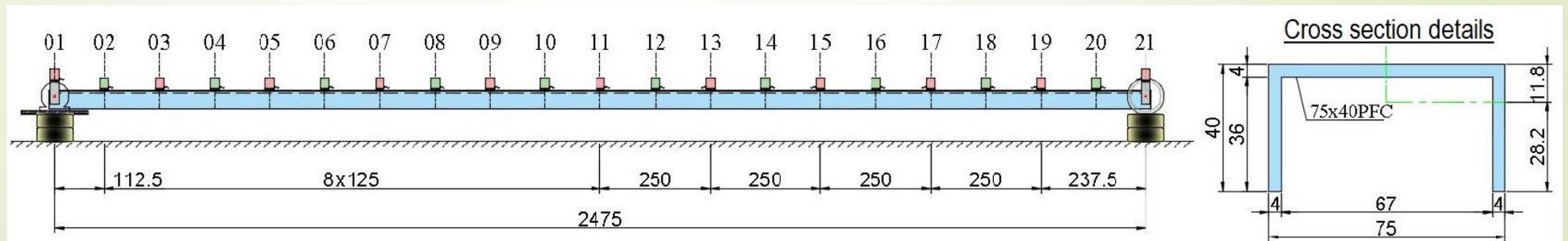
- ▶ Large scale
 - ▶ 4 semi-undergrounds (75mx65m)
 - ▶ 6 upper levels (65mx45m)
 - ▶ >40m high
- ▶ Rather low fundamental frequency & low measurable frequency range
 - ▶ 0.99 Hz predicted by detailed FEM
 - ▶ No more than 50 Hz for frequencies of first 8 modes
- ▶ Possible low amplitude
 - ▶ Under ambient excitation
(but insignificant wind excitation)



Typical test structures

Case II: Beam structure representing small- to medium-scale structures

- Small scale (obviously!)
- Much larger frequency range
 - First 8 modes ranging from approx. 16 –700 Hz



Instrumentation aspects

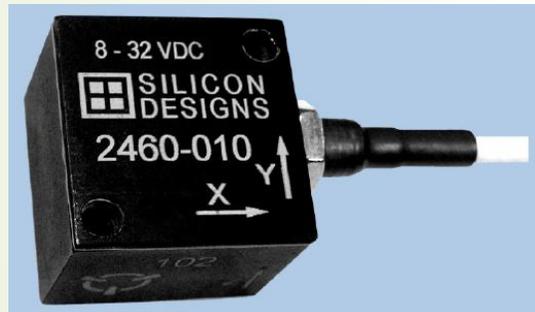
Modal transducers



- Main specs
 - Sensor type: **AC-response** (piezoelectric) vs. **DC-response** (piezoresistive, capacitive & force balance)
 - Sensitivity & Measurement range: **Inverse relationship**; depending structure (stiff/flex.) & excitation level
 - Dynamic range: depending on frequency range of interest

Instrumentation aspects

Modal transducer – Case 1_P block



- SDI models 2460 (tri-axial) & 2210 (single-axis)
 - **DC-response** (capacitive) type for low freq. measurement
 - Good sensitivity (2V/g) for coping with low-amplitude vibration
 - Reasonable measurement range (+/- 2g)
 - Dynamic range (0-300/400 Hz): quite easy to meet in this case!

Instrumentation aspects

Modal transducer – Case 2_Beam

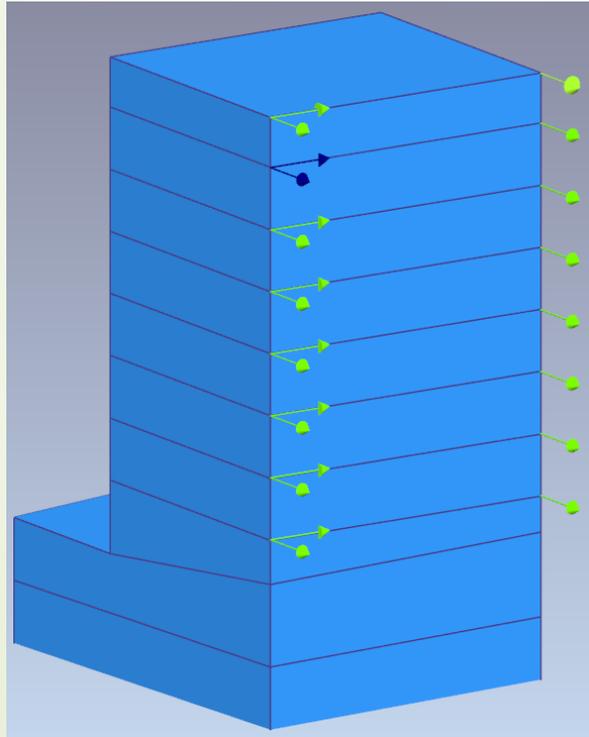
- **Kistler model 8630B5**



- AC-response (piezoelectric)
- Reasonable sensitivity (1V/g) & reasonable measurement range (+/- 5g)
- **Broad dynamic range** (0.5-2000 Hz): Important feature in this case!

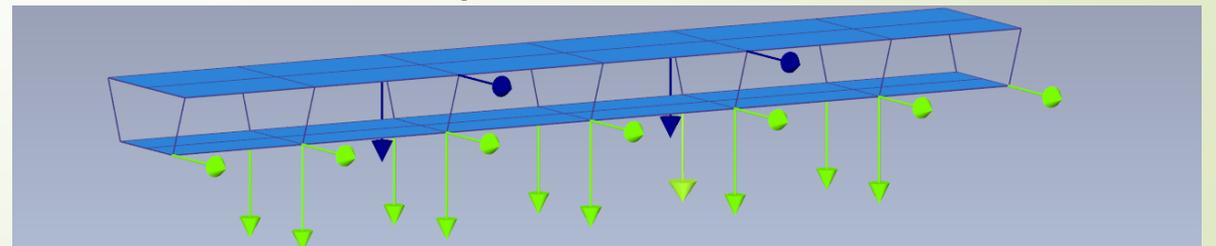
Instrumentation aspects

Transducer placement



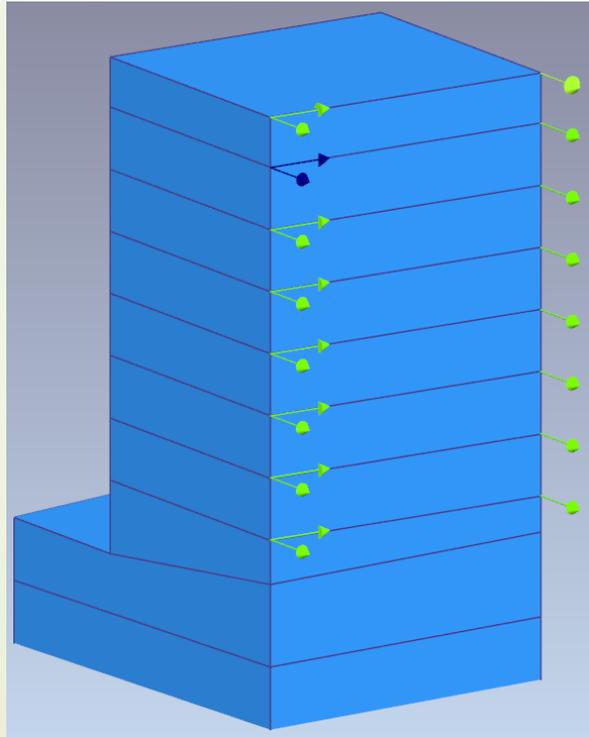
Source; HTC building model in ARTeMIS

- Position on boundary points (corners) to capture overall shape & maximise no. of modes detected
- Measure 1D (e.g. vertical), 2D, 3D? Prediction from FEM?
- Avoid sitting on nodal points within the modes of interest (especially the first few ones)



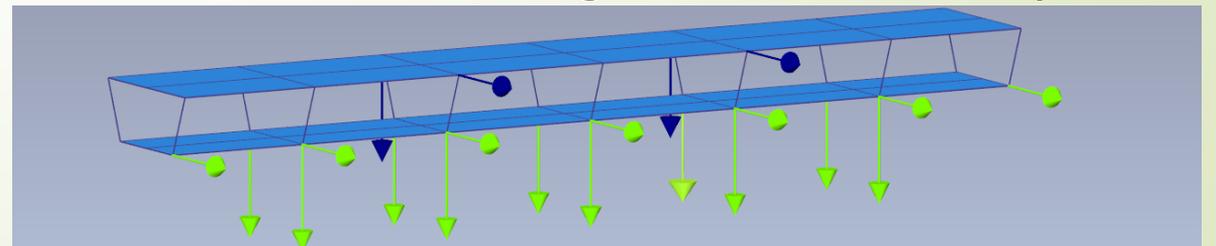
Instrumentation aspects

Transducer placement



Source; HTC building model in ARTeMIS

- Large range transducers for positions with large modal displacements
- Cross section considered as a rigid body - Sensor saving!
- Number of DOFs \gg number of sensors \rightarrow using multi-setups of sensors (reference transducers should produce good S/N data)



Instrumentation aspects

Transducer mounting



- Main options

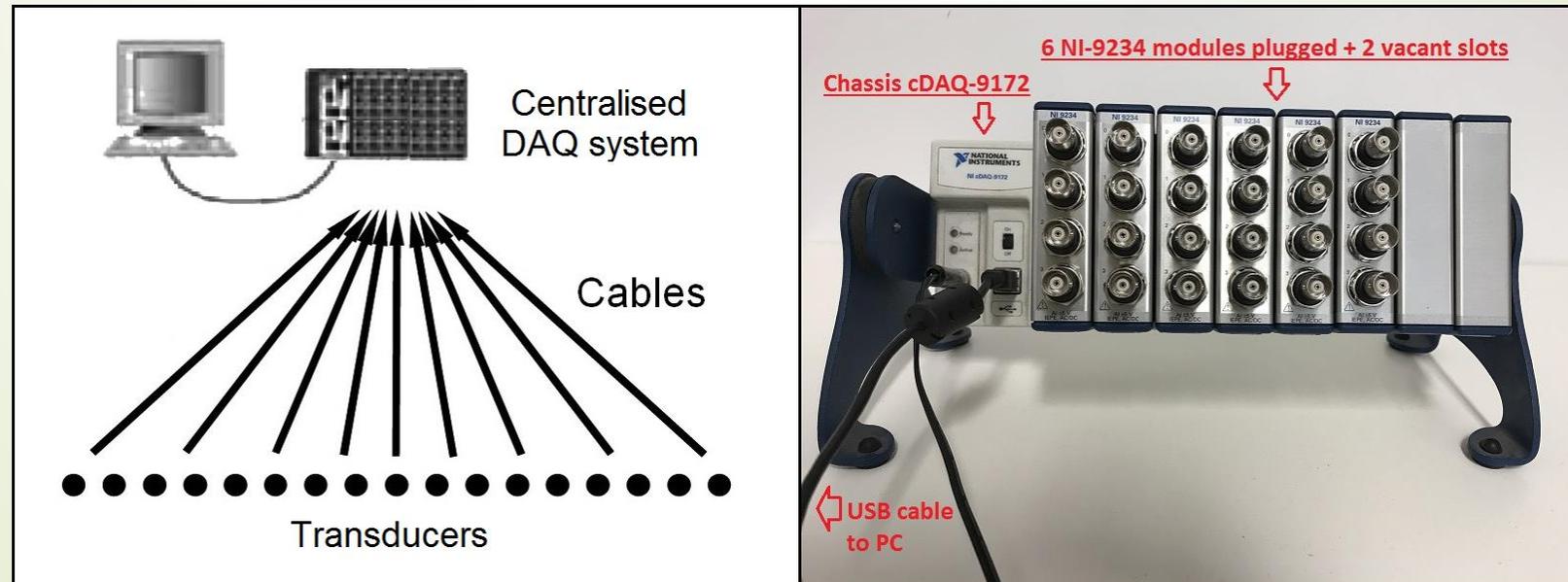
- Using stud/ mounting block (P block case)
- Using magnets i.e. for Ferromagnetic materials (Beam case)
- Using adhesives



Instrumentation aspects

DAQ system architecture – Beam case

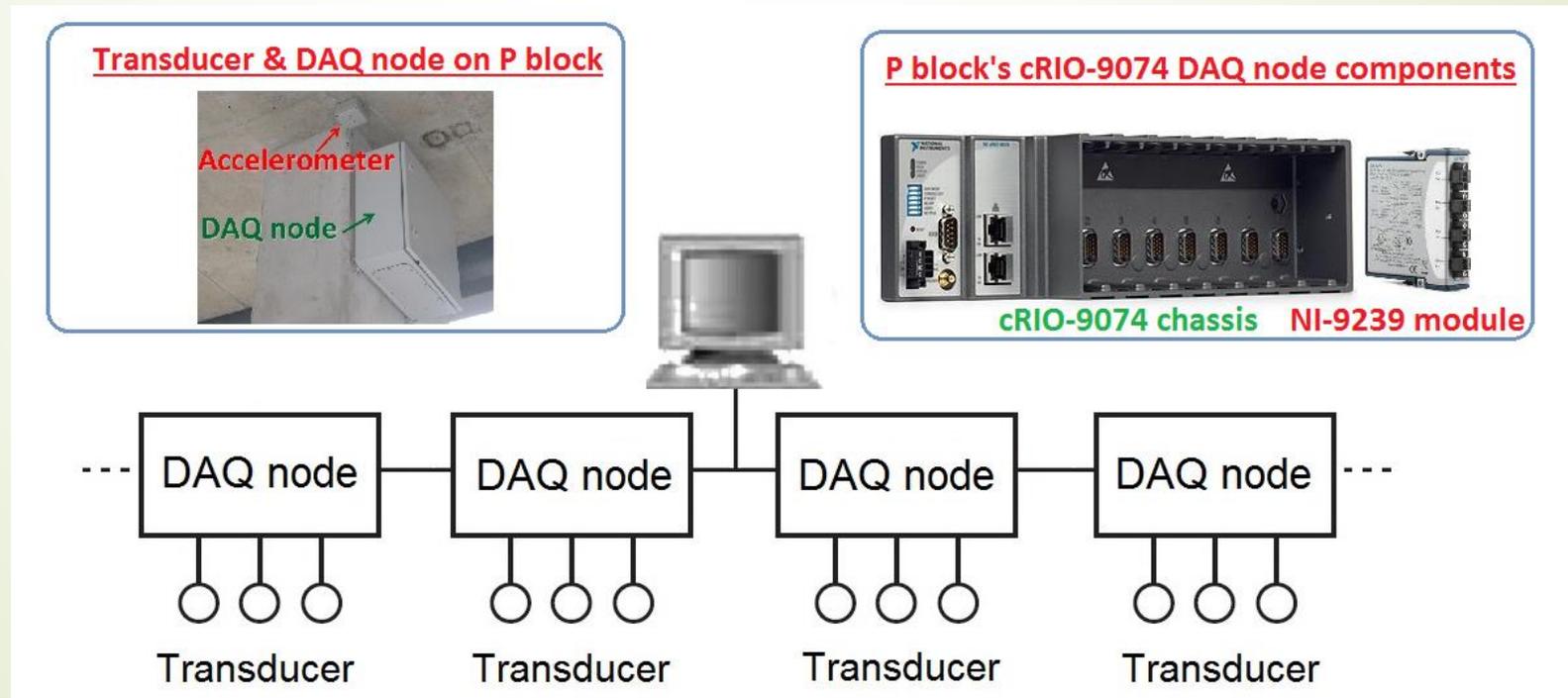
- ❑ Centralised system: Single chassis housing all modules, analogue signal routed from transducers to modules
- ❑ Cables should not be long - suits small- to medium-scale structures



Instrumentation aspects

DAQ system architecture – P block case

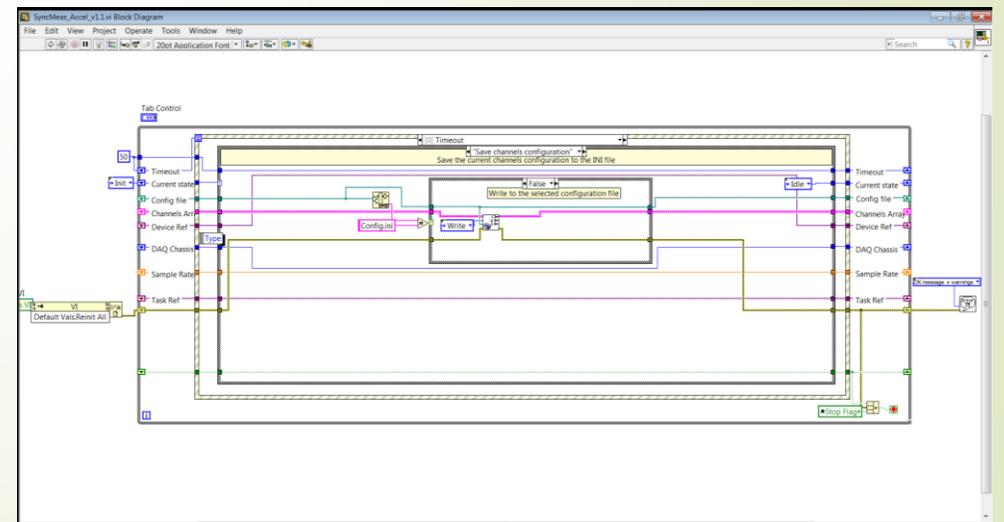
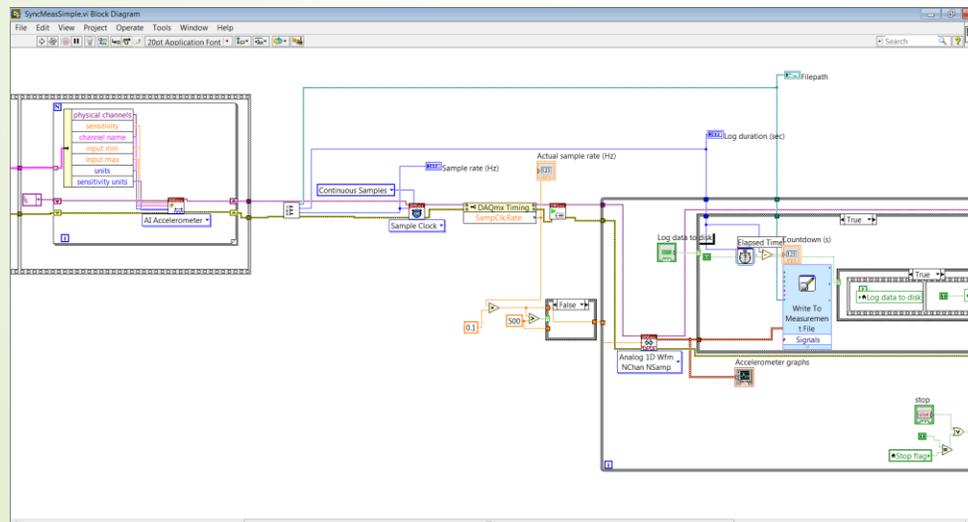
- ❑ Distributed system: multiple chassis forming a network
- ❑ Suits large-scale structures



Instrumentation aspects

DAQ application software

- Turnkey (InstantDAQ)
- Configurable (LabVIEW Signal Express)
- Programmable (LabVIEW Professional) – used at QUT



Instrumentation aspects

I/O module (AI module)



- Common desire features for MT&M:
 - high-resolution delta-sigma ADC, high sample rate, low input voltage & low input noise
- Be compatible with the type of transducer
 - Piezoelectric transducers IEPE signal conditioning - constant current to power the amplifier & AC coupling, e.g. NI-9234 for Piezoelectric transducer of Beam case
 - Non IEPE transducer can go with general-purpose voltage input modules, e.g. NI-9239 for capacitive transducer of P block

Instrumentation aspects

Synchronization

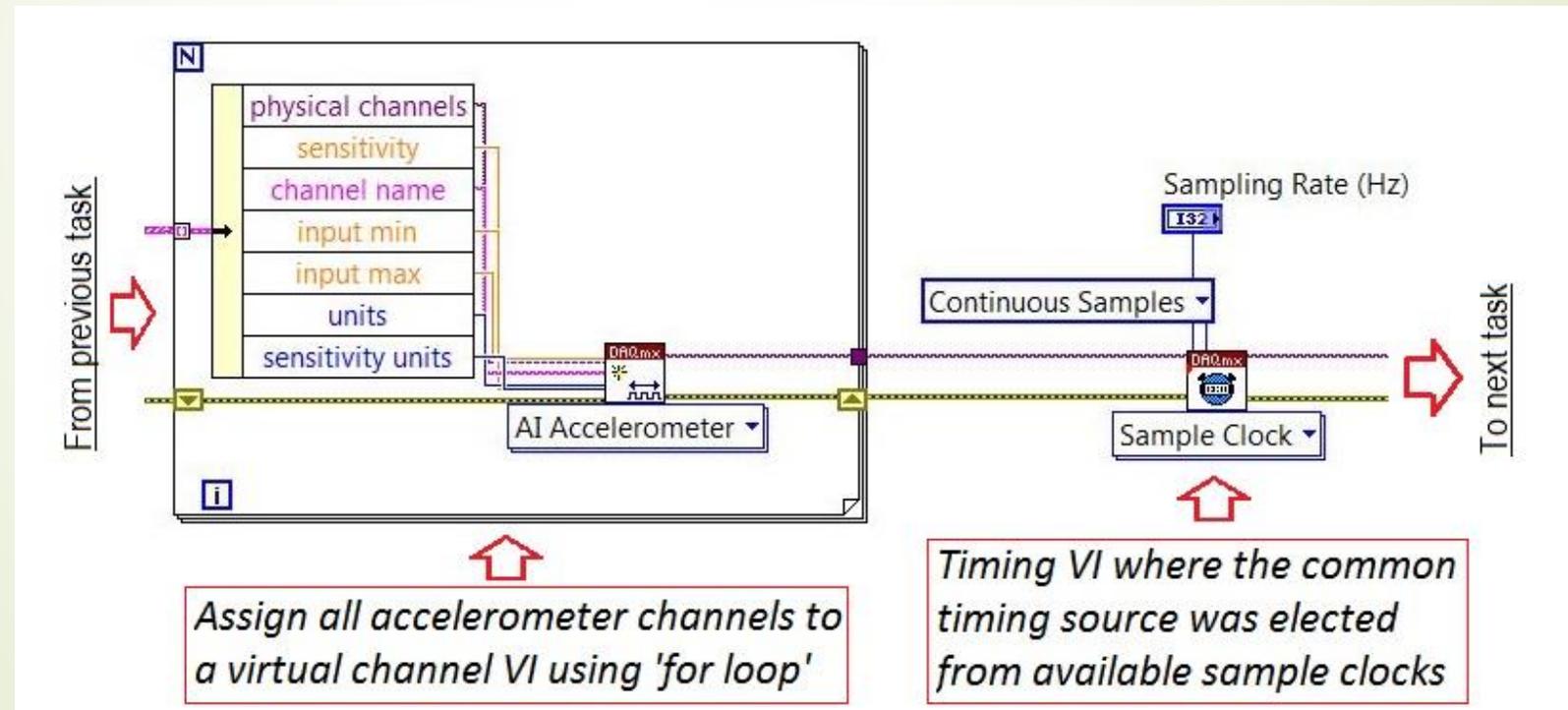


- Important feature in MT&M
- Full sync (across different modules- channels) may not be possible with turnkey and even configurable

Instrumentation aspects

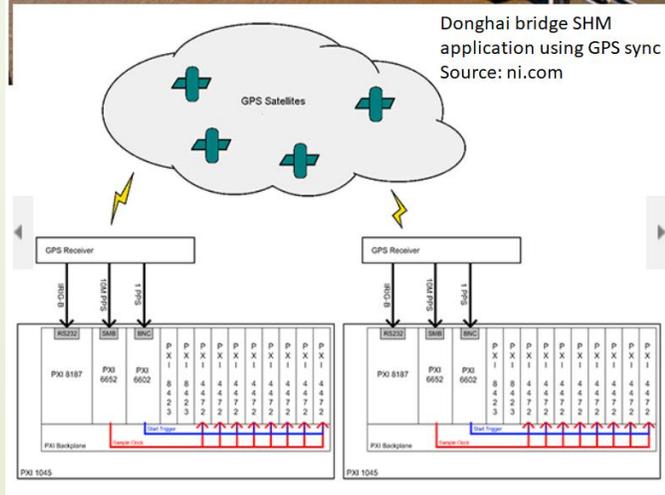
Synchronization

- Full sync is simple via programming for centralised system



Instrumentation aspects

Synchronization – distributed system



- Hardware-based:
 - GPS
 - Synchronisation module + CAT5
- Software-based (semi-complete)
 - Use common trigger to start signal acquisition process before relying on on-module clock to control the acquisition timing – for P block (*)
 - Use FPGA timing correlation

(*) Nguyen et al. 2015. Development of a cost-effective and flexible vibration DAQ system for long-term continuous structural health monitoring. *Mechanical Systems and Signal Processing* 64-65:313-324.

Test management aspects

Excitation issues



- May vary significantly during test time (esp. long term) → good to get to know excitation profile
- Sources of excitations
 - Human-related actions (users of constructed system e.g. traffic, etc.)
 - Non human-related sources: wind, tremor, etc.

Test management aspects

Excitation issues



- Small structures (including beam herein): artificially random excitation by tapping: good to make it random in both time & space
 - 2 or more points of tapping
 - 1 source of moving excitation by 'tap & move'

Test/system management aspects

Excitation issues



- P block: real ambient excitation – main source is human-related excitation, characterised by
 - Checking across datasets during the day
 - Results: most datasets recorded during work hours (9am-5pm) have best S/N

Test/system management aspects

Long-term system status

- Long-term system mostly operated unattendedly
- Good to set up an autonomous report channel to reduce down-time period and data loss
- P block: TCP/IP-based autonomous email system
 - Normal operation: only one report email per day is sent to the management team at a specified time
 - Faulty status: an error email message will be broadcasted immediately to notify the team

From: P-Block Sensor Manager [<mailto:secinst@qut.edu.au>]

Sent: Wednesday, 23 August 2017 2:21 AM

To: [REDACTED]

Cc: [REDACTED]

Subject: PBlockSystemErrors

Errors 230817 0220 lyra: Name or service not known lost connection

From: P-Block Sensor Manager [<mailto:secinst@qut.edu.au>]

Sent: Wednesday, 23 August 2017 8:37 AM

To: [REDACTED]

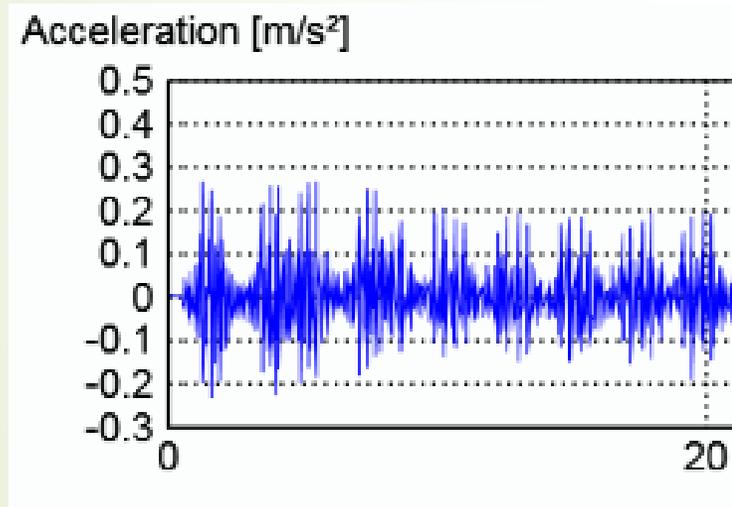
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System live 230817 0836

Test/system management aspects

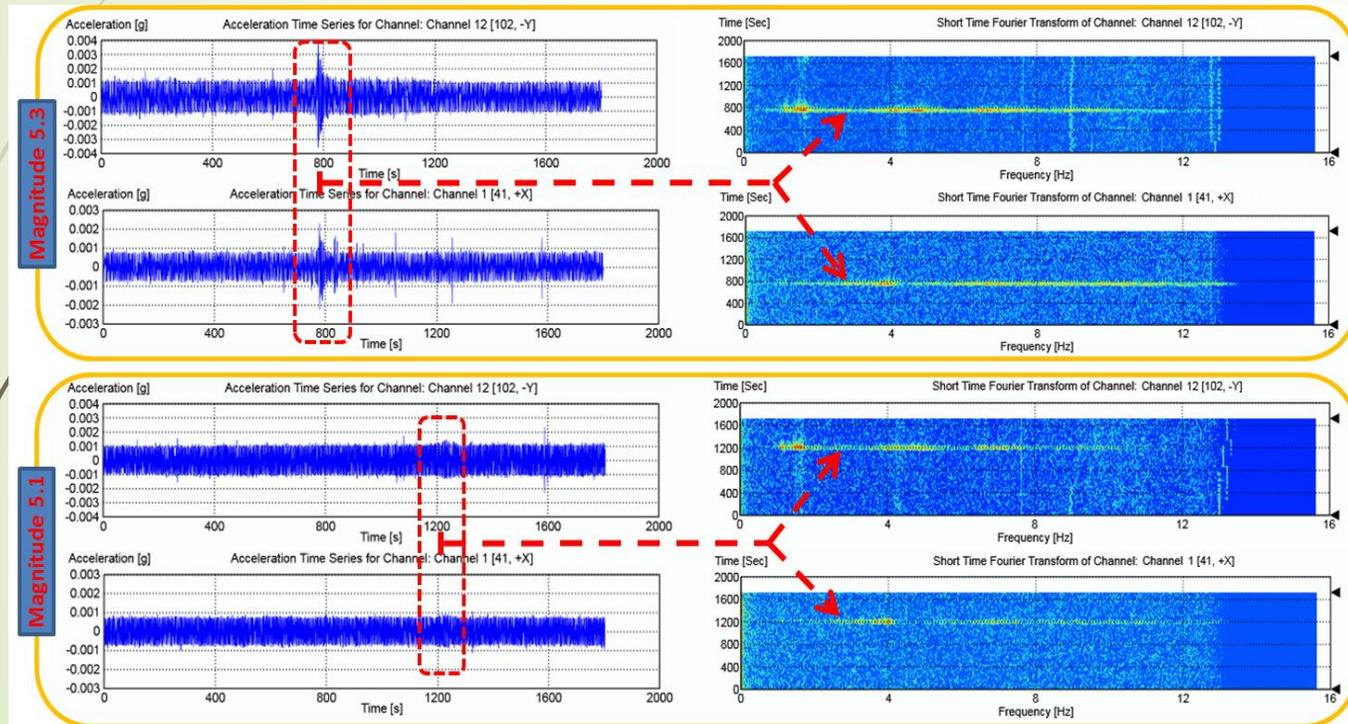
Transient event detection



- Output-only modal analysis: data should be adequately stationary & approximates a Gaussian sequence
- imperative transient events such as earthquakes be correctly detected

Test/system management aspects

Transient event detection



- STFT has been used to detect such events in P block
- Threshold could also be set up to enable more an autonomous safeguarding system

Conclusions

On instrumentation

- Desired type of transducers and DAQ systems dependant on key characteristics of the structure and test application such as structure size/scale, fundamental frequency
- DC-response transducer - structures with low frequency characteristics \gg AC-response - small- to medium-scale structures



Conclusions

On test/system management

- Long-term monitoring requires a lot more effort compared to short-term testing
- Due to paper length limit, only there important issues were covered
 - Non-uniform excitation → choose quality data -> may set up threshold based acquisition for more effective monitoring
 - Autonomous timely system status management is a key to limit system down time and data loss
 - Transient events should be detected to ensure correct datasets can be used for accurate data analysis



From: P-Block Sensor Manager [<mailto:secinst@gut.edu.au>]

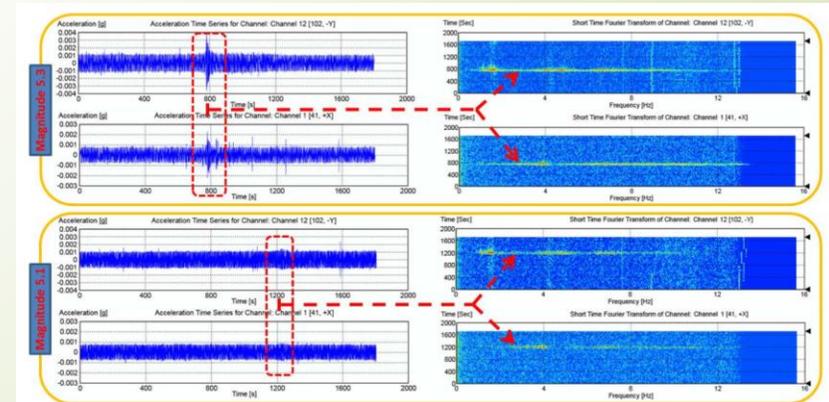
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Thank you!

Q&A