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Bridge Monitoring & Bridge Management Systems

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ARC Linkage, Infrastructure, Equipment and Facilities (LE140100053, 2014)

National Facility for Non-destructive Testing of Concrete Infrastructure N-DETECT

Australian Government
Australian Research Council

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The University of Sydney
Swinburne University of Technology
RMIT University
Curtin University
Victoria University
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THE UNIVERSITY OF MELBOURNE | Modern Non-Destructive Testing Technologies

Interferometric Radar (IBIS-S)

- Use microwave interferometry for remote static and dynamic monitoring of structures.
- Operate remotely to measure structural displacement up to an accuracy of 0.01mm at a distance of up to 1km.
- Measure dynamic displacements by comparing the phase shifts of reflected radar waves collected at the same time intervals.

(ARC -LE140100053)

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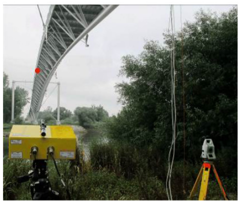

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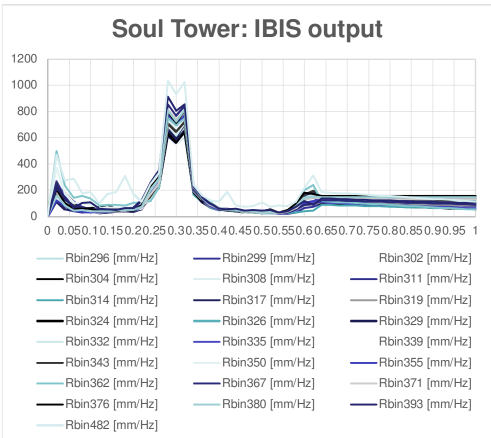
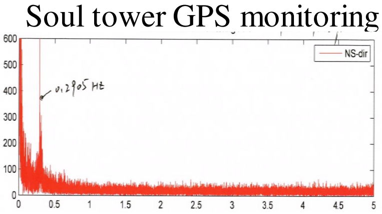
THE UNIVERSITY OF MELBOURNE | **Monitor Vibration of Tall Buildings**



Soul tower GPS monitoring



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Applications – Bridge Monitoring

NDT test — Selected NDT tools for RC

IBIS-FS

Hi-Bright

MIRA

- Each NDT method has its advantages and limitations for certain assignments
- The integrated strategy by using combination several NDT techniques will provide better prediction (Alani et. al. 2014)
- Three NDT tools have been tested: **(1) IBIS-FS (2) GPR (3) MIRA**

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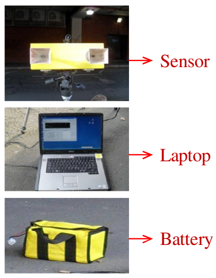
Applications – Bridge Monitoring

NDT test — IBIS-FS Interferometric Technique

An instrument which capable of remotely measuring displacements of structures

Advantages:

- Accuracy up to 0.01 mm
- Distance measurements up to 1 km
- Sampling frequencies up to 200 Hz
- No interruption of traffic on bridge
- Real-time simultaneous mapping of deformations
- Fast installation and operation
- Static and dynamic monitoring
- Operates day-night, in all weather conditions
- Provides direct displacements, not derived quantities



IBIS system

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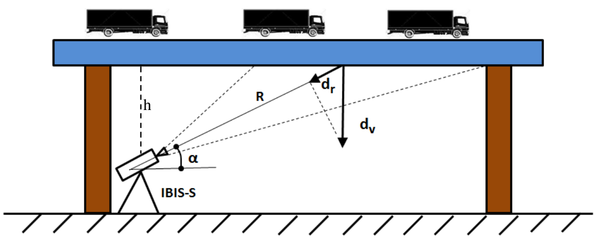
Monitor Vibration of Bridges

NDT test | IBIS-FS Basic Principle



$d_r = d_v \sin\alpha$

$h = R \sin\alpha$

$d_v = d_r \frac{R}{h}$

- IBIS-FS measures displacement in the direction of the line of sight of the system (d_r)
- Knowledge of the acquisition geometry is used to calculate the real vertical displacement (d_v)
- The calculation necessarily assumes that the horizontal displacement is zero.

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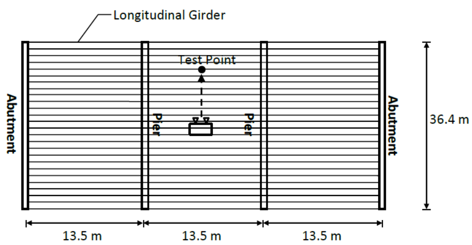
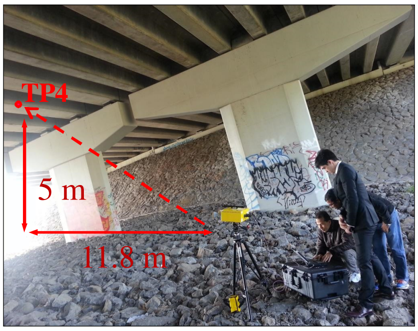
Application of IBIS for Bridge Monitoring

Results | IBIS-FS test at Merlynston Creek Bridge

- IBIS survey : 8 July 2015.
- weather : sunny
- temperature : 11° C
- sampling freq. : 167.2 Hz
- survey duration : 5 minutes





IBIS SET UP

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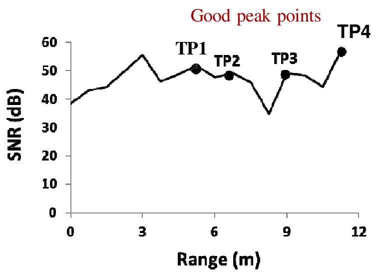
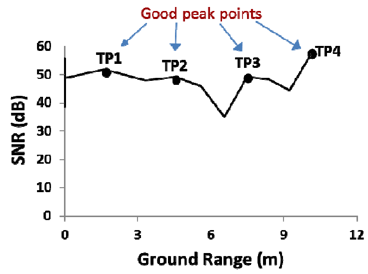
Application of IBIS for Bridge Monitoring

Results Range Profile of the Bridge



(a) Typical Range Profile



(b) Ground Range Profile

TP4 is a selected target point.

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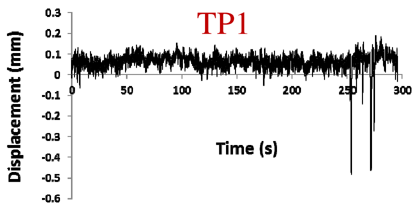
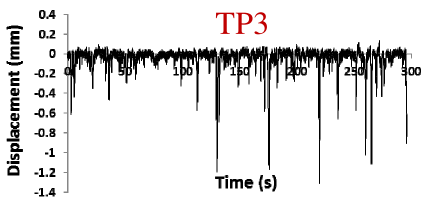
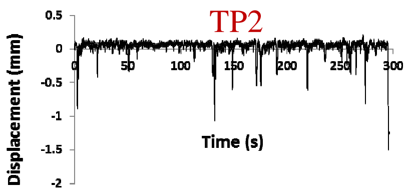
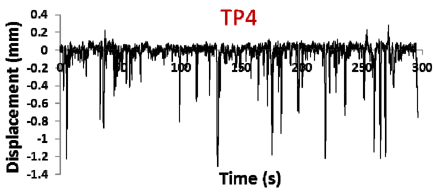
Results Time-history displacement









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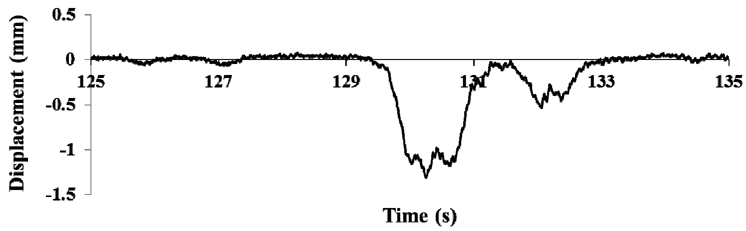
Results Maximum displacement at TP4



Maximum displacement around 1.3 mm

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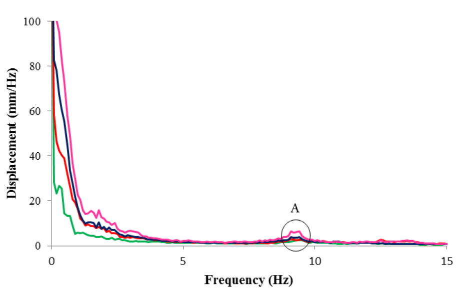
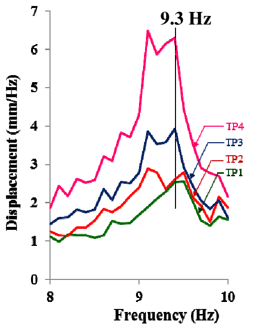
Results Resonant frequency



Displacement Vs Frequency



Plot Displacement Vs Frequency at point A

- Local resonant frequencies to be in the range 9-9.5 Hz.
- This result is consistent with other studies which suggested that the natural frequency of the similar bridges is between 8-12Hz (Menn, C, 1978)

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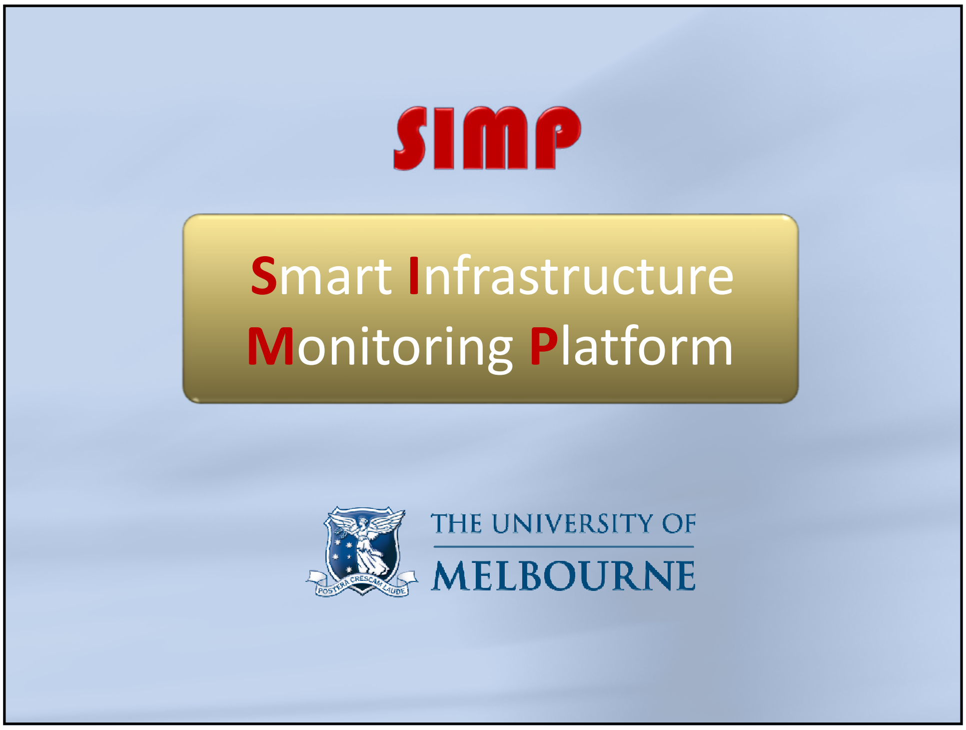
SIMP
Smart Infrastructure
Monitoring Platform
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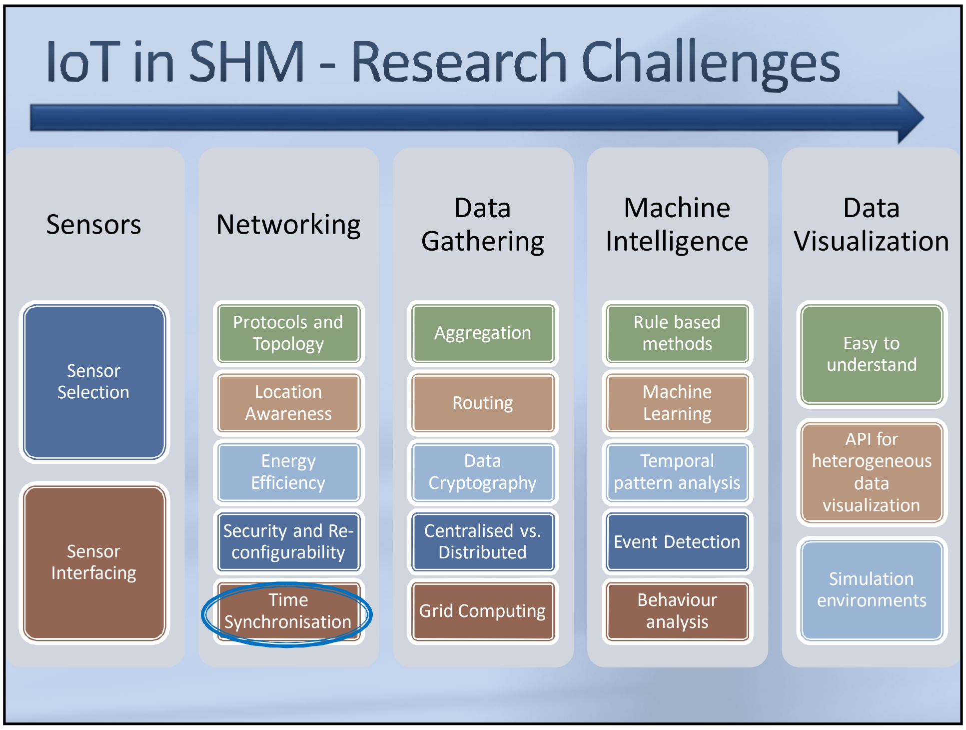
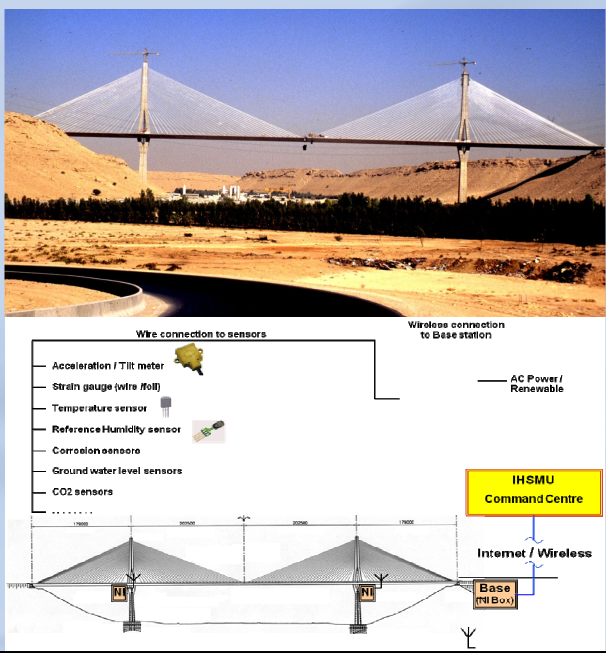
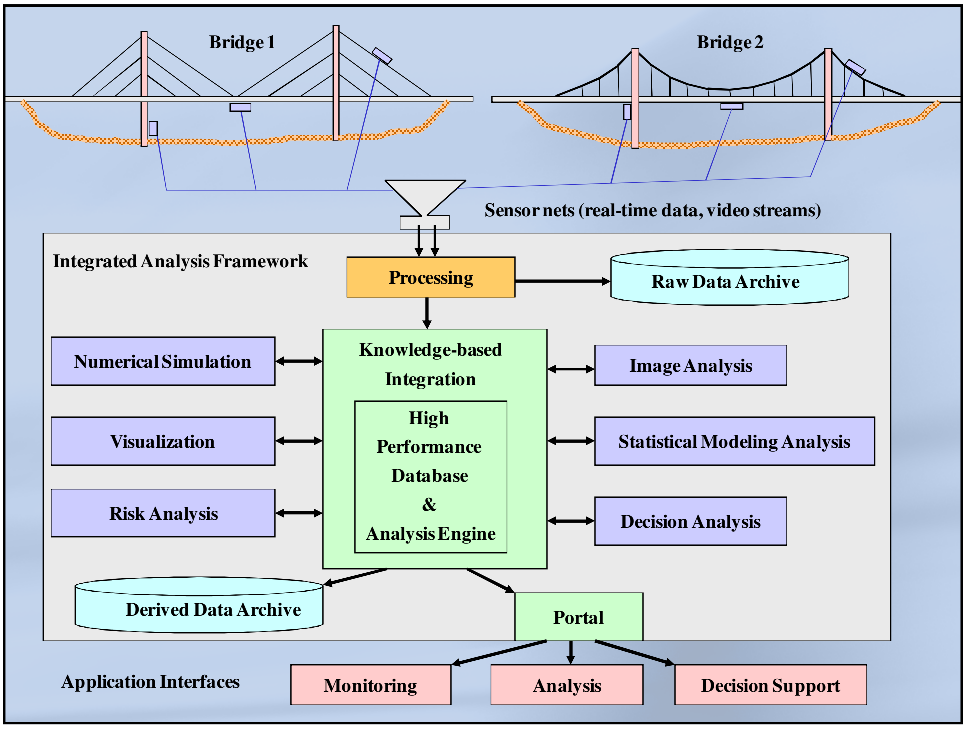

IoT in SHM - Research Challenges
Sensors
Networking
Data Gathering
Machine Intelligence
Data Visualization
Sensor Selection
Sensor Interfacing
Protocols and Topology
Location Awareness
Energy Efficiency
Security and Re-configurability
Time Synchronisation
Aggregation
Routing
Data Cryptography
Centralised vs. Distributed
Grid Computing
Rule based methods
Machine Learning
Temporal pattern analysis
Event Detection
Behaviour analysis
Easy to understand
API for heterogeneous data visualization
Simulation environments

Wadi Leban Bridge – Saudi Arabia

Wadi Leban Bridge – Wireless Sensor Network



Wadi Leban Bridge – Wireless Sensor Network



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Time Synchronization - Problem

- Hardware clocks drift with time due to ageing, low-cost quartz crystal properties
- WSNs and IoT subnets use low-cost quartz crystal oscillators on each sensor nodes
- The frequency, offset, skew and drift are different for each crystals
- Hence, communicated time and sampling intervals varies from node to node
- Energy consumption is also affected by incorrect clocks – because of scheduled sleep and awake times

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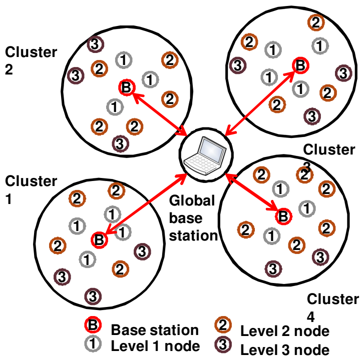
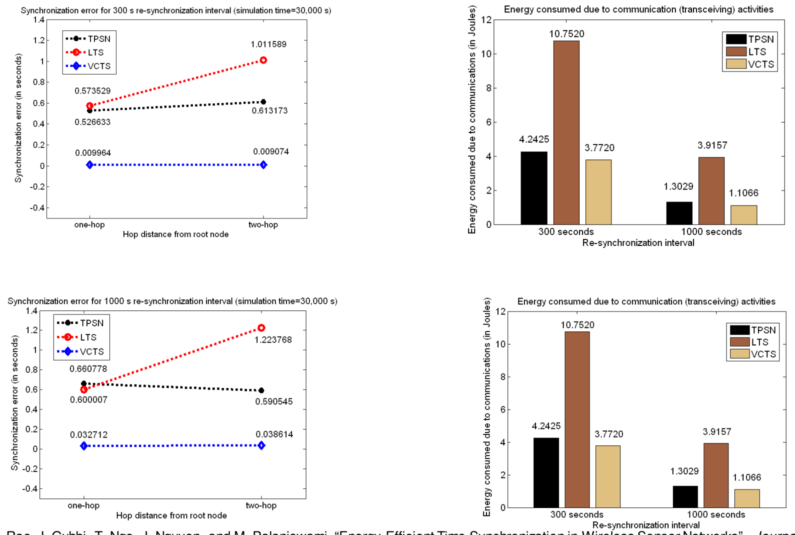
Proposed - Virtual Clock Time Synchronization

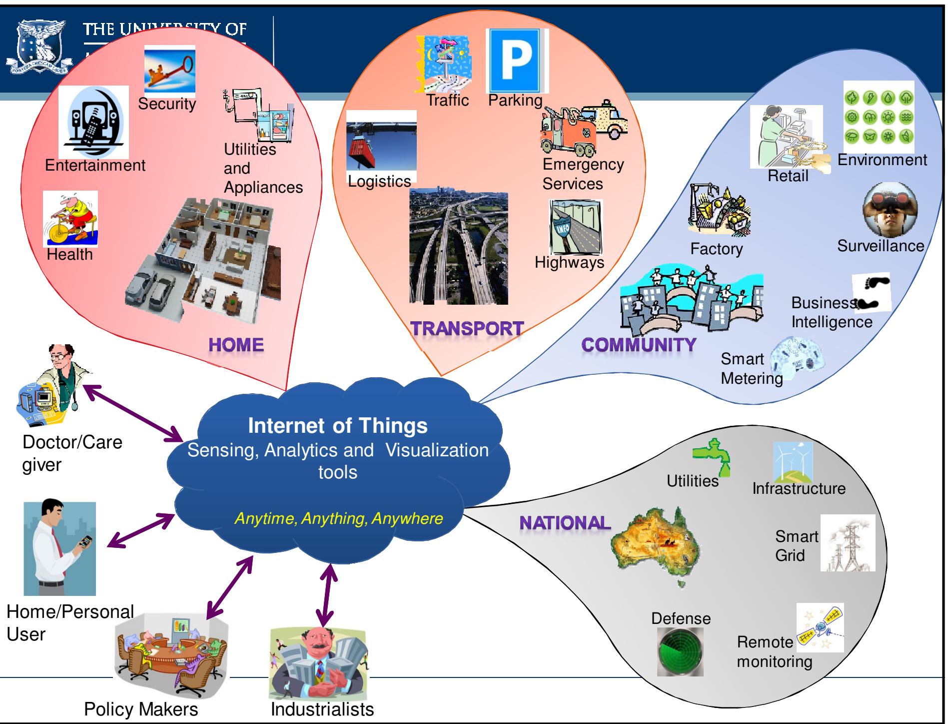
- Hierarchical tree is built using dynamic network creation
- Parent node maintains a virtual clock of for each of the child nodes by measuring relative offset
- The message from child to the root node is compensated by parent nodes across the tree
- A new parent is created in case of failure of the parent node



1. S. Rao, J. Gubbi, T. Ngo, J. Nguyen, and M. Palaniswami, "Energy Efficient Time Synchronization in WSN for Critical Infrastructure Monitoring", *Trends in Network and Communications*. vol. 197, D. C. Wyld, M. Wozniak, N. Chaki, N. Meghanathan, and D. Nagamalai, Eds., ed: Springer-Verlag Berlin Heidelberg, 2011, pp. 314-323.



A. S. Rao, J. Gubbi, T. Ngo, J. Nguyen, and M. Palaniswami, "Energy-Efficient Time Synchronization in Wireless Sensor Networks", *Journal of Communications Engineering and Networks*.



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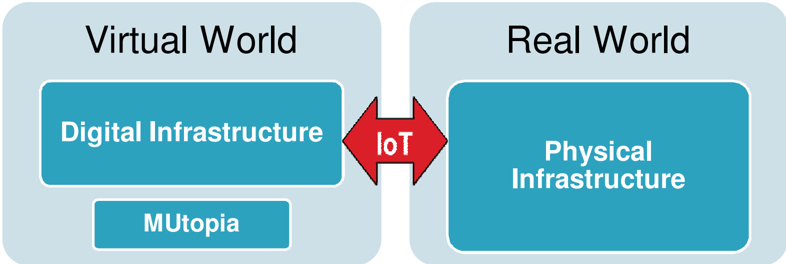
Internet of Things – General issues

- Lack of a Shared Infrastructure
- Lack of Common Standards
- Battery Life
- Data Control
- Data Sharing



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IoT: Case Studies

- **Video based**
  - Pedestrian detection on bridges (Crowd monitoring in MCG)
  - Hazard detection on bridges (left baggage detection)
  - Vehicle categorisation
- **Automated vehicle diagnostics – Networked vehicles**
- **Load estimation using low cost sensors**

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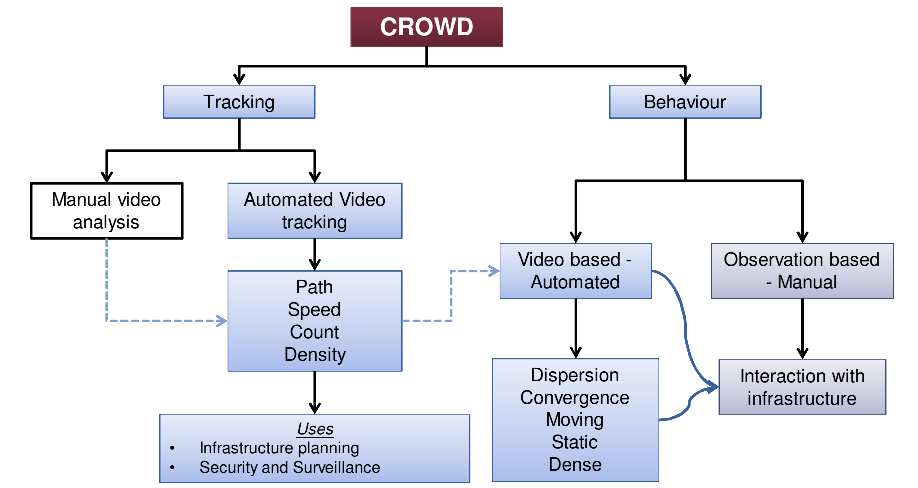
Crowd Monitoring using visual sensors



Research question: Can we use automated video analysis techniques for understanding human behaviour? Particularly, we are interested in user interaction with infrastructure.

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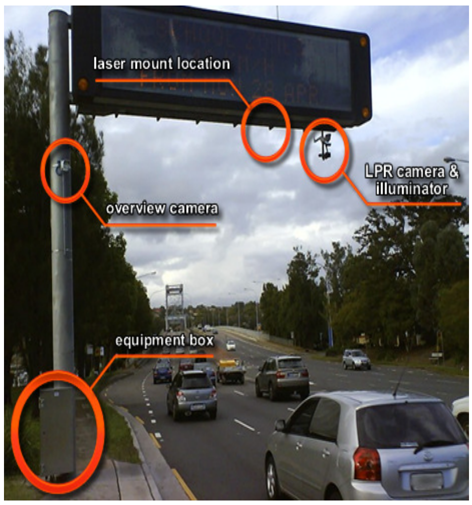
Vehicle Categorisation

Vehicle Classification System

(in NSW in collaboration with SenSen Networks)
(currently under deployment in Singapore and Dubai)

- **Provides the system with a comprehensive information about vehicle that passes under it**
- **Includes**
  - Speed
  - Height
  - Width
  - Length
  - Classification
- **The database provides**
  - Storage
  - Data interpretation
  - System user interface
  - End-user interface via web services



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IoT: Case Studies

- **Continuous monitoring**
  - Aquatic monitoring
  - Urban Noise Monitoring
- **Video based**
  - Pedestrian detection on bridges (Crowd monitoring in MCG)
  - Hazard detection on bridges (left baggage detection)
  - Vehicle categorisation
- **Automated vehicle diagnostics – Networked vehicles**
- **Load estimation using low cost sensors**

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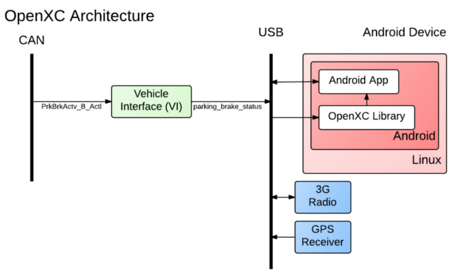
Automated vehicle diagnostics – Networked vehicles



- **Sensed data:**
  - Primary: Engine Speed, Vehicle speed, Odometer, Fuel, Door, GPS, etc.
  - Secondary: Steering wheel angle, Accelerator pedal position, Brake pedal position, Transmission gear position, etc.
- **Potential uses**
  - Locate vehicle
  - Behaviour Analysis feedback on driving test qualifications
  - Crowdsourcing – stuck in a traffic or an accident, how much time is required (how many vehicles are in front of me, how long the queue is?)

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Bridge monitoring using low cost sensors

- **Common sensor measurements along the road/bridge**
  - Temperature
  - Wind direction and speed
  - Stress and strain
  - Stiffening truss vibration
  - Pressure and Force sensors
  - Weigh-in-motion sensors
- **Useful in ongoing monitoring of**
  - Structural health of the bridges
  - Hanger tension measurement
  - Load measurement
  - Any other specific use case

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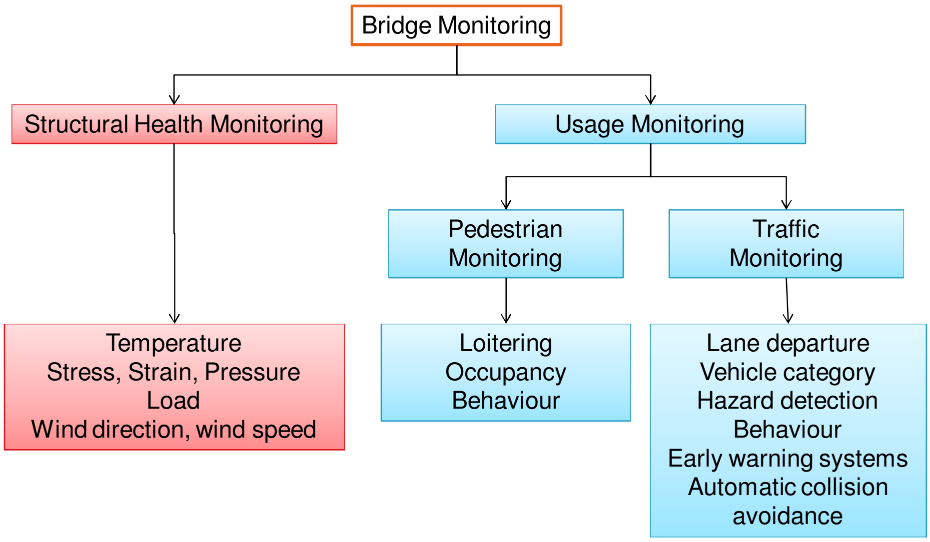
IoT: Bridge Monitoring Summary



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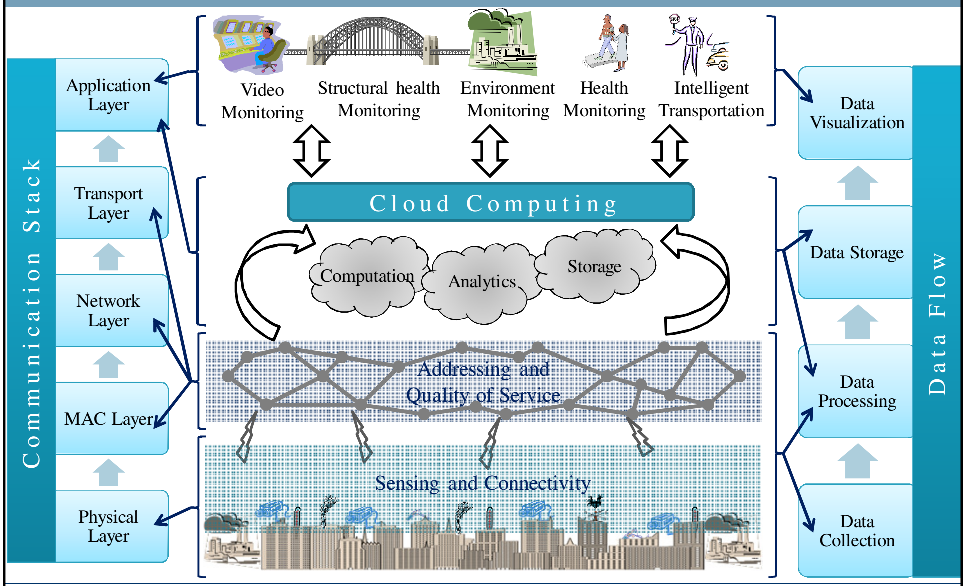
IoT Infrastructure for Smart Cities



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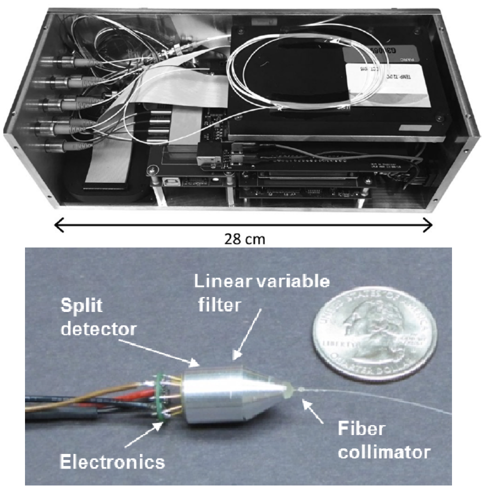
PARC: High resolution Fibre-Optic Sensing for Bridge Monitoring

- PARC system: low cost solution for embedded high-fidelity, real-time monitoring based on fibre-optic sensors and optical readout.



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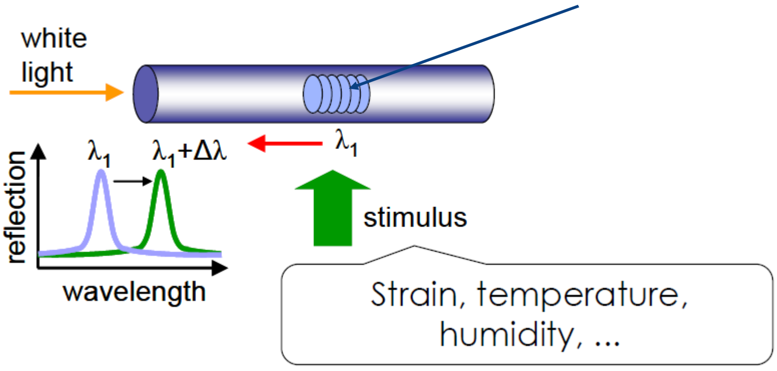
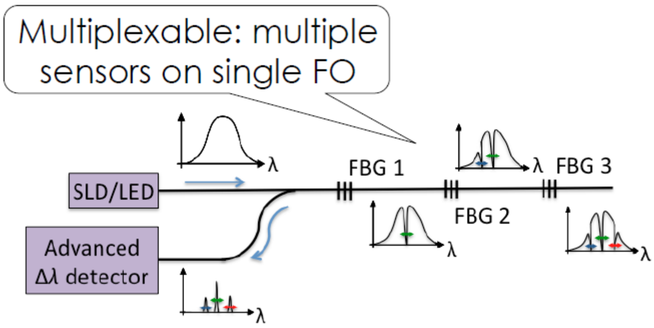
PARC: High resolution Fibre-Optic Sensing for Bridge Monitoring

- Fundamental concept of fibre-optic sensing: **Fibber Bragg Gratings (FBGs)**



PARC: High resolution Fibre-Optic Sensing for Bridge Monitoring

- Benefits of fibre-optic sensing:
  - **Multiplexing sensing**
  - **Compact system**
  - **High accuracy**
  - **Resistance to corrosion and electromagnetic environment**



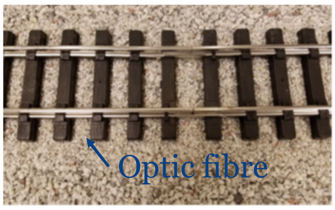
PARC: High resolution Fibre-Optic Sensing for Bridge Monitoring

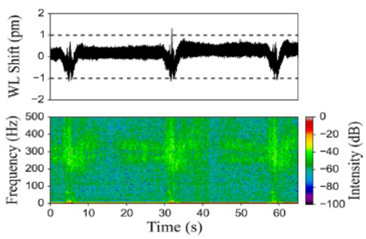
- Challenges of fibre-optic sensing:
  - **Detection multiple wavelength shifts.**
  - **Acquisition at high readout speed.**
  - **Separation of small environmental effect (temperature,…)**

- Advances of PARC system:
  - **A breakthrough wavelength shift detector capable of monitoring over 100 sensors at high resolution.**
  - **High accuracy and high speed**
  - **Significantly smaller and less expensive system Acquisition at high readout speed.**

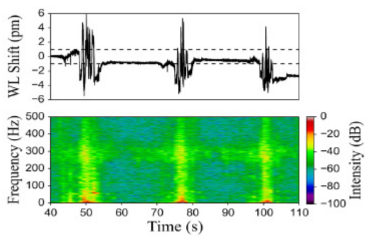
PARC: High resolution Fibre-Optic Sensing for Bridge Monitoring

- Case study of PARC system: Monitoring Track and Rail system





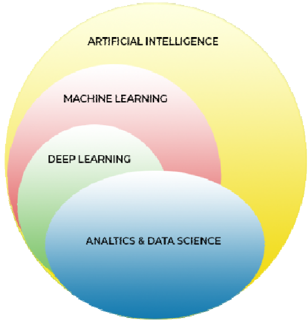
Intact rails



Damaged rails

Deep Learning: Potential in SHM

- Deep Learning: A breakthrough in digital era

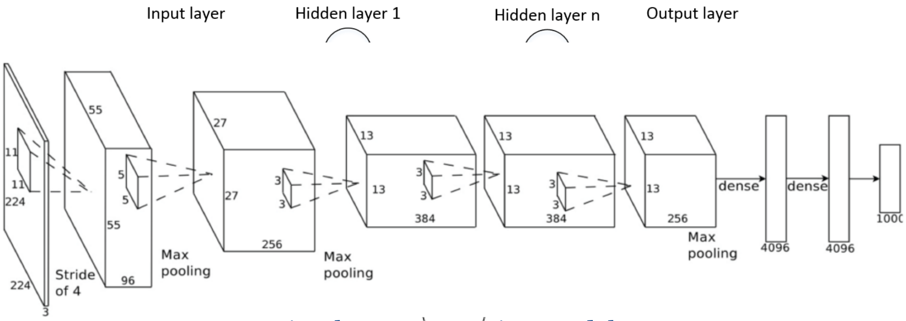


- Why Deep Learning is back with high excitement from researcher and industry:
  - **Big Data.**
  - **Powerful computer resources (GPU, cloud computing).**
  - **High attention from industry and government .**

Deep Learning: Potential in SHM

- Deep Learning is based on Artificial Neural Network

Input layer Hidden layer Output layer



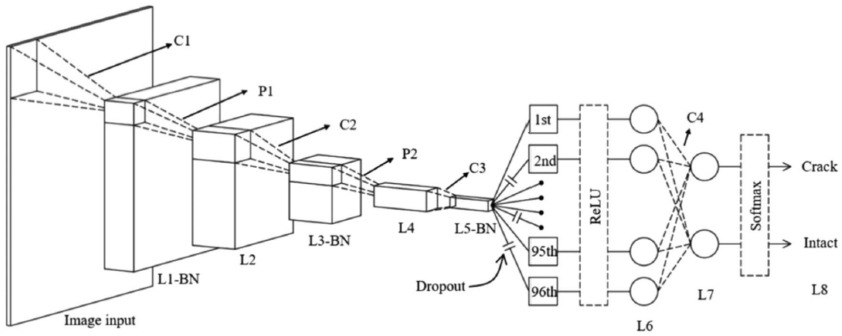
Simple Deep Learning model

Artificial Neural Network

Modern deep convolutional net

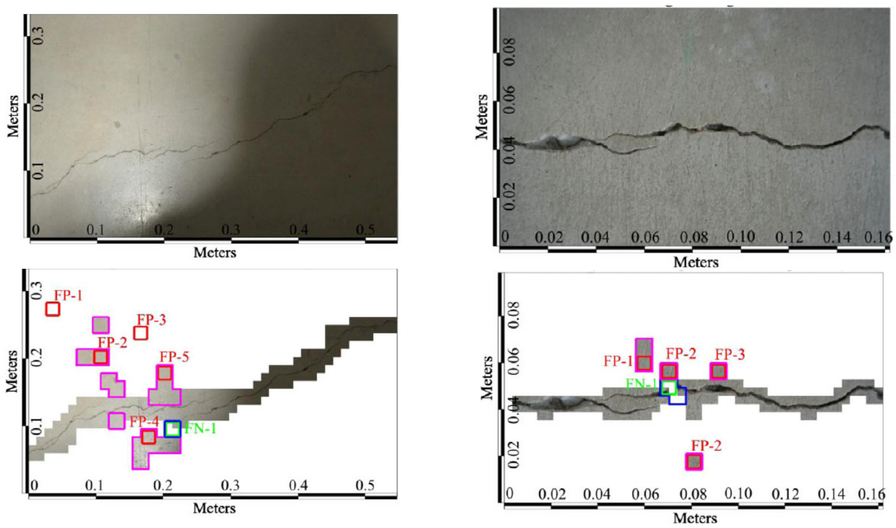
Deep Learning: Potential in SHM

- Potential applications of Deep Learning in SHM:
  - **Analysing measurement data from continuous monitoring**
  - **Developing autoencoder for dimensionality reduction, data compaction**
  - **Recognising patterns for monitored**



Deep Learning: Potential in SHM

- Case study of crack detection using deep learning:



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Thank You

Tuan Ngo (dtngo@unimelb.edu.au)

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Queensland University of Technology
University of Wollongong

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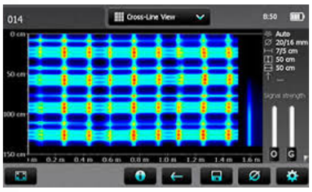
Modern Non-Destructive Testing Technologies

– Profometer (Advanced Concrete Cover Meter)
  - Measure concrete cover and rebar diameters and the detection of rebar locations using the eddy current principle with pulse induction as the measuring method.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Modern Non-Destructive Testing Technologies

– Ground Penetrating Radar System (Hi-Bright)
  - For structures which do not have detailed construction drawings.
  - Assess the conditions of slab and bridge decks.
  - Identify any voids in the structural member.
  - Identify rebar and its condition and cover length, cracks and their extent, settlement, and moisture presence.

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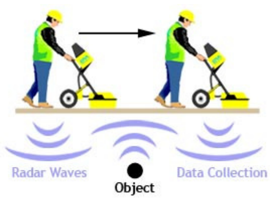

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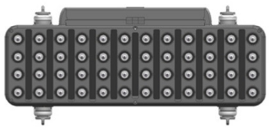
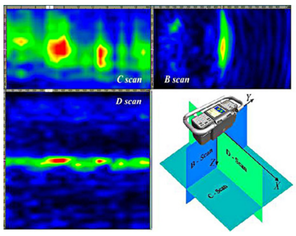
Full imaging system for the interior of concrete (MIRA)

- Capable of void detection for flaws as small as 30 mm at 400 mm depth the MIRA can also measure slab thickness, test tile or panel bond, confirm grouting behind panels or in post tension ducts and is the only system that can measure cover in steel fibre reinforced concrete.





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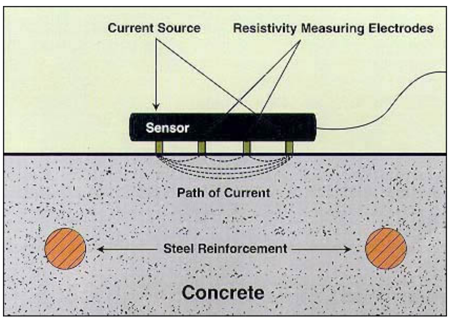
Resipod Resistivity Meter

- Designed to measure the electrical resistivity of concrete in a completely non-destructive test. It is the most accurate instrument available, extremely fast and stable and packaged in a robust, waterproof housing designed to operate in a demanding site environment.



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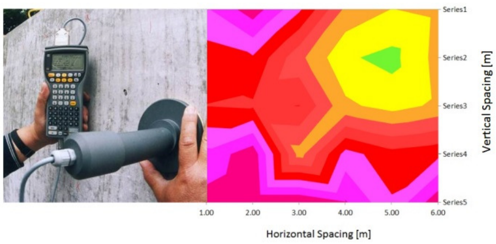
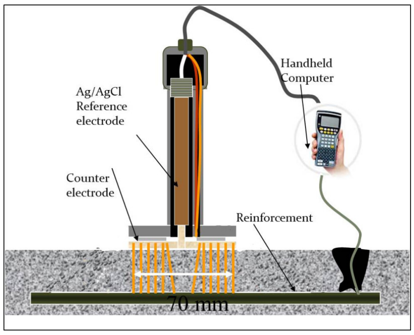
Modern Non-Destructive Testing Technologies

CorroMap

- Use half-cell potential and galvapulse measurement with many user-friendly features.
- Offer reliable evaluation of reinforcement corrosion also in wet, carbonated or inhibitor treated concrete so that the half-cell potential and electrical resistance to the cover layer are give.





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Spectral Analysis of Surface Waves (SASW)

- The SASW method uses the dispersive characteristics of surface (Rayleigh) waves to determine the variation of the shear wave velocity (stiffness) of layered systems with depth.
- SASW is designed for
  - Determination of pavement system profiles including the surface layer, base and subgrade materials
  - Determination of abutment depths of bridges
  - Condition assessment of concrete liners in tunnels, slabs, and other structural concrete members
  - Evaluation of alkali-silica, fire, fire, freeze-thaw and other cracking damage

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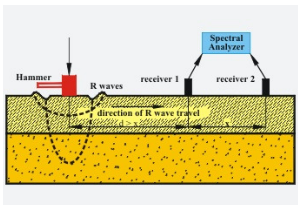

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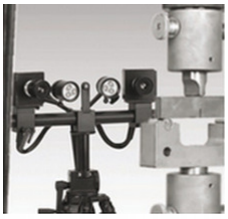
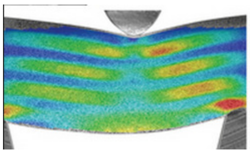
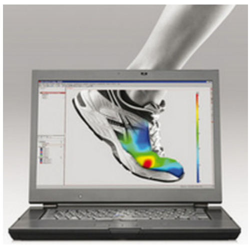
ARAMIS - Optical 3D Deformation Analysis

- A non-contact and material independent measuring system
  - 3D surface coordinates
  - 3D displacements and velocities
  - Surface strain values

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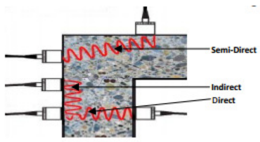
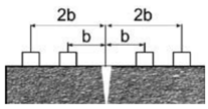
Pundit Lab- Ultrasonic Pulse Velocity Testers

- Ultrasonic testing can be used for
  - The presence of voids, cracks or other internal imperfections or defects
  - Changes in the concrete which may occur with time (i.e. due to the cement hydration) or damage from fire, frost or chemical attack.
  - The strength or modulus of a material.



Methods of Ultrasonic Testing



Crack Depth

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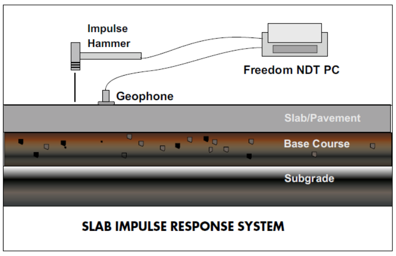
Freedom DATA PC Platform

This multiple system platform can be used for stress-wave based NDT condition evaluation of concrete, masonry, asphalt, wood and other construction materials, as well as seismic testing of soil and rock.



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