Preliminary investigation of key factors in pedestrian bridge health monitoring using cost-effective IoT platform

Prof. Hong Guan[1], Huiyue Qiao[1], A/Prof. Yong Zhu[1], Dr. Shoja Jamali[2]

[1.] *School of Engineering and Building Environment, Griffith University*

[2.] *KBR, Inc.*

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Outline

- Footbridges
- IoT-based SHM
- Proposed research plan
- Key factors
- Summary

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Footbridges

- Designed for pedestrians, may involve cyclist; lighter than vehicular bridges; more vulnerable to vibrations
- Span ranges: small (< 20m); medium (20-50m); long (> 50m)

Beam

Webb Bridge, Melbourne, VIC

Truss

Dension Bridge, Bathurst, NSW

Arch

Bondi Beach Bridge, Bondi, NSW

Tied-arch

Matagarup Bridge, Perth, WA

Benefits

- Landmarks
- Connect different communities
- Ensure safe crossing over water, traffic, railroads, etc
- Provide easier access for anyone who is disabled

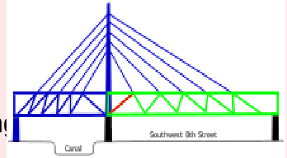
Suspension

Northam Pedestrian Bridge, Northam, WA

Cable-stayed

Jack Pesch Bridge, Brisbane, QLD

Collapse events of footbridges

Footbridge	Causes of failure	Casualties	Figures
Morbi bridge, Gujarat (2022)	• Overloading • Rusted cables • Overweight replaced flooring • Reopen early after repairs without required certificate • Large swinging **Overload**	135 killed	
CST bridge, Mumbai (2018)	• Irresponsible and negligent structural audit: failed to point out an impending failure **During construction**	6 killed, 35 injured	
Florida International University – Sweetwater UniversityCity bridge, Florida (2018)	• Failure of recognising danger of collapsing during inspection • Notable structural cracks on concrete truss • Design deficiencies	6 killed, 10 injured, 8 crushed vehicles underneath	Green: collapsed parts Blue: not installed Red: truss underwent post-tension rod tensioning 
Troja footbridge, Prague (2017)	• Cable corrosion • Unreliable inspection • Impact of 2002 flood **Corrosion**	4 injured	
Navvies bridge, Cumbia (2009)	**Extreme weather** • Intense rainfall produced extreme river loads that overwhelmed the bridges	1 killed	
Bhagalpur pedestrian bridge, Bhagalpur (2006)	**Traffic underneath, truck collision, etc** • 150-year-old pedestrian bridge (being dismantled) collapsed onto a railway train as it was passing underneath	33 killed	

Serviceability for footbridges

Millennium Bridge, London
"Wobbly Bridge"

- Unexpected lateral vibrational mode due to resonant structural response
- Energy exerted on the bridge from unsteady pedestrians to keep balance → more wobbly bridge
- Synchronous lateral excitation

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Serviceability for footbridges - *Human comfortability*

Resonant vibration effects:
Bridge fundamental frequencies approach pedestrian walking load frequency

Sensitivity of human on vibration displacement amplitude: 0.001mm*

Dynamic response of the bridge:
Human-induced vibration + Equation of motion (MDOF)

$$\mathbf{M}\ddot{\mathbf{x}}(t) + \mathbf{C}\dot{\mathbf{x}}(t) + \mathbf{K}\mathbf{x}(t) = \mathbf{f}(t)$$

Vibration:
- Mass
- Damping
- Stiffness
- External force

Serviceability limit state (SLS) in Australian Bridge Code (AS5100:2017):
5 Hz & 1/600 span (vertical)

* A.J. Pretlove, J.H. Rainer, Human response to vibrations, in: *Vibration Problems in Structures: Practical Guidelines*, Birkhäuser, Basel, 1995, Appendix I.

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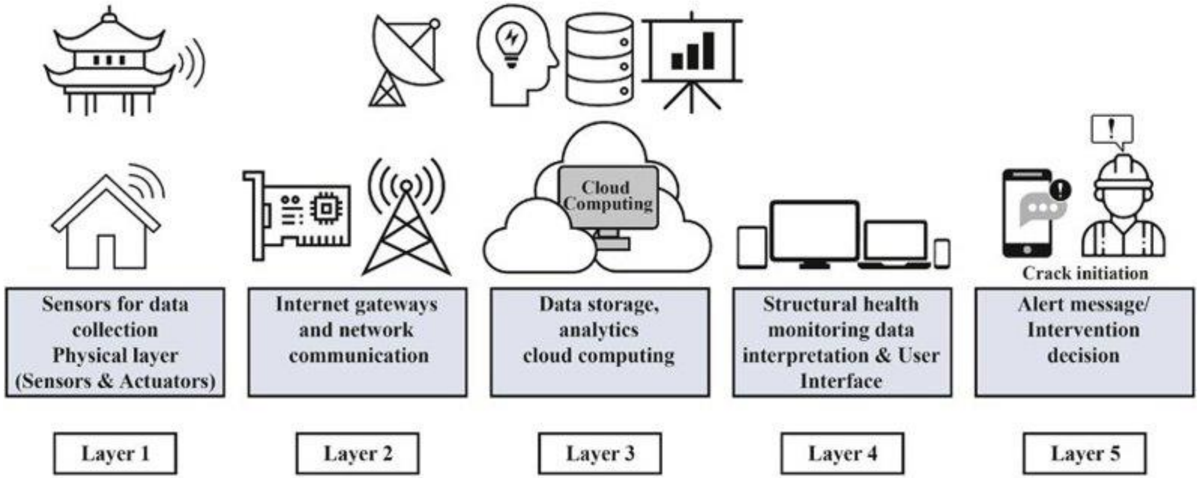
Introduction to IoT - Cyber network of physical objects

Benefits

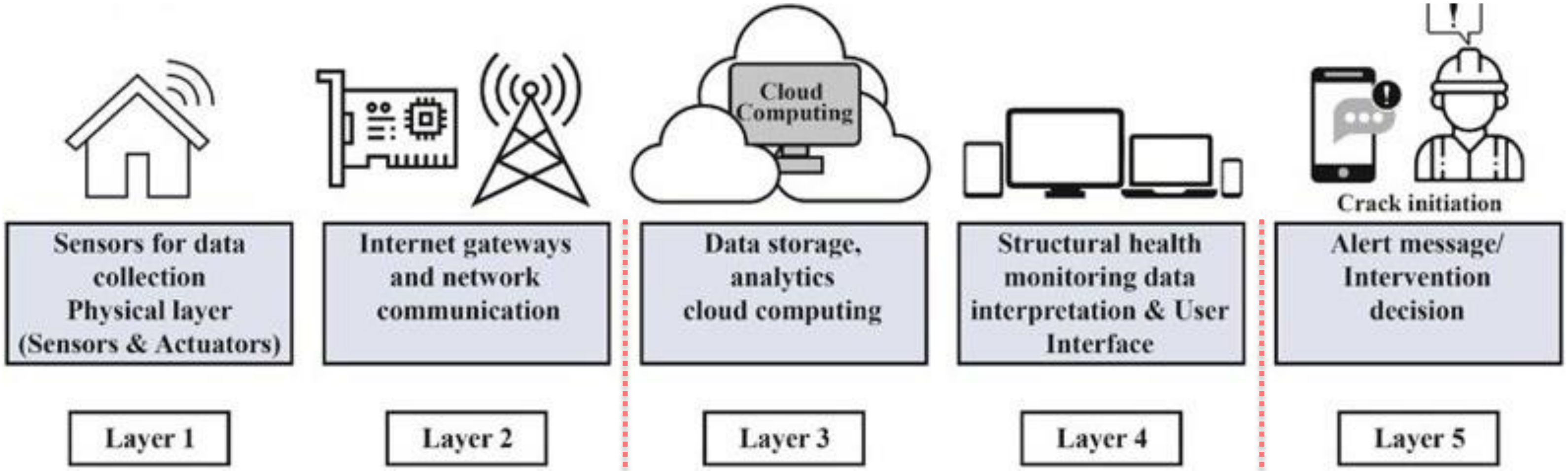
- Real-time test data
- Cloud-based data storage systems
- Remote data access
- Cohesive device connectivity
- Improve efficiency of existing SHM systems

IoT architecture for SHM applications



From "Structural health monitoring of civil engineering structures by using the internet of things: A review," by Mishra, M., Lourenco. P.B., & Ramana. G.V. (2022), *Journal of Building Engineering(48)*,103954.

Challenges in IoT based SHM



Data Acquisition
- Large quantity of data
- High energy consumption
- Poor reliability/robustness of sensor
- Limited signal transmission range
- Compromised quality of data

Data Processing & Analysis
- Difficulty in choosing the appropriate Machine Learning technique for particular application
- Inefficient use of cloud computing in SHM due to lack of meaningful insights about data
- Insufficient training for civil engineers for integration of IoT and SHM

Decision Making
- Uncertainties in the empirical formulas cause errors for the estimation of SHM indicators
- Lack of provisions in building codes for the adoption of the IoT in SHM

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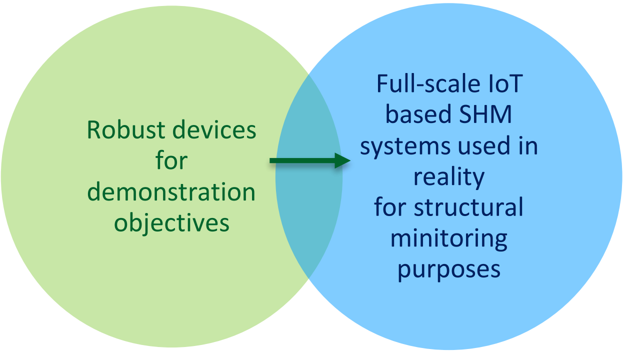
Current research gaps in IoT based SHM

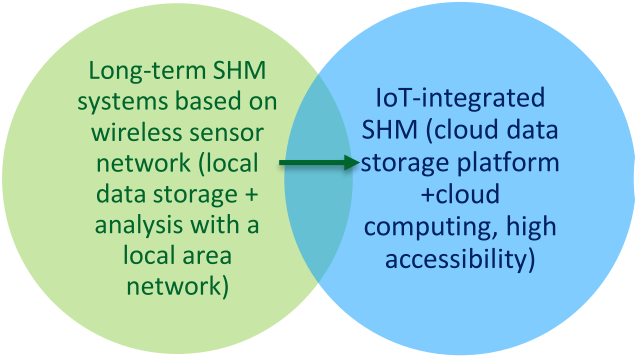
IoT-based SHM platform



Potential difficulties in field

- sensor deployment
- ambient implications on data acquisition
- network stability, etc

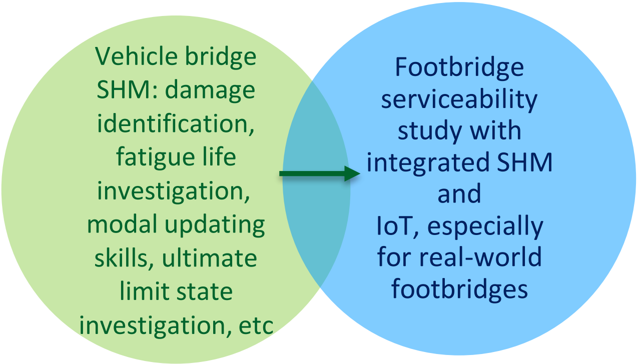
Integration of IoT and SHM



IoT technique application

- choice for appropriate machine learning algorithms in cloud computing
- meaningful insights about data, etc

SHM for footbridges (serviceability)



More improvement for research on this field, especially for slender and light footbridges built recently with more dynamic movement

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Case study - GU cable-stayed footbridge

- Built in January 2007;
- Connect the northern campus with the student accommodation center and the GELI building on the southern side over Smith St Motorway;
- 96m long span (63m main + 33m back span), 4m wide deck (steel plate box);
- Single 1:10 sloped tower, 40m high (box section), 5 sets of anchors, 60mm & 75mm VSL MT600 bars for stays;
- Back stay anchors installed on the southern abutment to control deflections of the tower.

Issues:

- Noticeable vibration
- Bolt corrosion
- Partial anchor bolt missing in abutment

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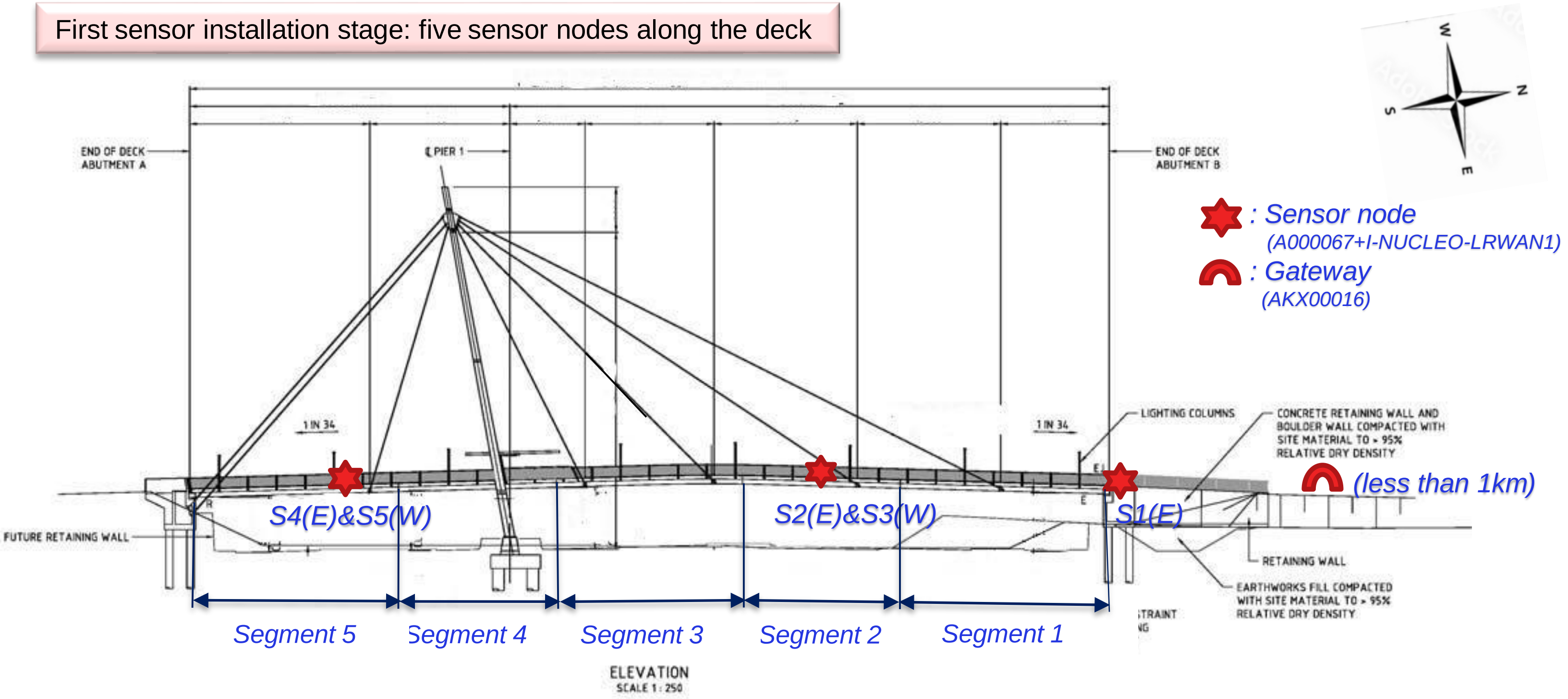
Case study - GU cable-stayed footbridge

- Fabricated in 5 segments; segment splice between adjacent two segments

First sensor installation stage: five sensor nodes along the deck



IoT based SHM for GU footbridges

- Edge computing: filtering + classification
- Energy consumption concern

Further data analysis of key structural parameters: indicators for serviceability assessment

Clients & asset owners

Case study GU cable-stayed footbridge (sensor node deployment) → Gateway → Cloud computing and storage (remote data analysis using ML): improve data quality → Performance indexes based on comfortability and structural health condition

Microcontroller *Sensors*

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Key factors – *Cost-effectiveness*

Sensor:

- Location
  - Based on numerical model
- Calibration
  - Validation test in laboratory (simply-supported beam)
- Energy concern: data acquisition & transmission
  - Solar panel
  - Event-driven: rush hours + extreme weather condition
  - Edge computing: raw data filtering + classification (development board)

Cloud storage and computing:

- Automated damage & unusual dynamic movement detection
  - Machine learning: damage sensitive features—
    - *a. Model-based: numerical analysis (grillage + FE) & Modal Assurance Criterion (MAC), etc.*
    - *b. Data-driven: Artificial Neural Networks (ANNs)*

Data analysis:

- Case study (data from sensors)
- Numerical analysis (grillage + FE)
- Obtain indicators with serviceability consideration with the interaction of the following features: human-induced vibration, ambient vibration (temperature, humidity, wind interaction)

Performance indexes:

- SLS parameters (vibration, deflection, elastic stress, etc.)
- Minimised uncertainty
- Industry guide

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Summary

- Pedestrian bridge health monitoring using cost-effective IoT platform
- Serviceability consideration
- IoT-based SHM for footbridges: machine learning; indicators; performance indexes


THANK YOU
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Any question ?

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