Metrology for Sensor Networks in Asia Pacific Metrology Programme’s Focus Group on Digital Transformation

Digital Transformation
in Metrology
APMP-DXFG

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APMP-DXFG

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About APMP-DXFG

- Established since Nov 2021
  - In response to an APMP Executive Call for a DXFG in June 2021
  - Founding Chair: Dr Blair Hall, MSL (Nov 2021 – Nov 2024)
  - Current Chair: Dr Cui Shan, NMC (Nov 2024 – Nov 2027)
  - 54 members from 19 economies, including 3 RMO liaisons (EURAMET, GULFMET, COOMET)
- Objectives of APMP-DXFG:
  - To acquire the latest information on DX;
  - To identify the challenges for APMP;
  - Awareness raising, knowledge transfer and stakeholder liaison;
  - Stakeholder engagement, including industry and QI bodies;
  - Maintain alignment with the BIPM and other RMOs;
  - To help developing economy members narrow the gap.
- Some members have work related to sensor networks
  - No specific task group or collaboration project in DXFG

Related work in MSL

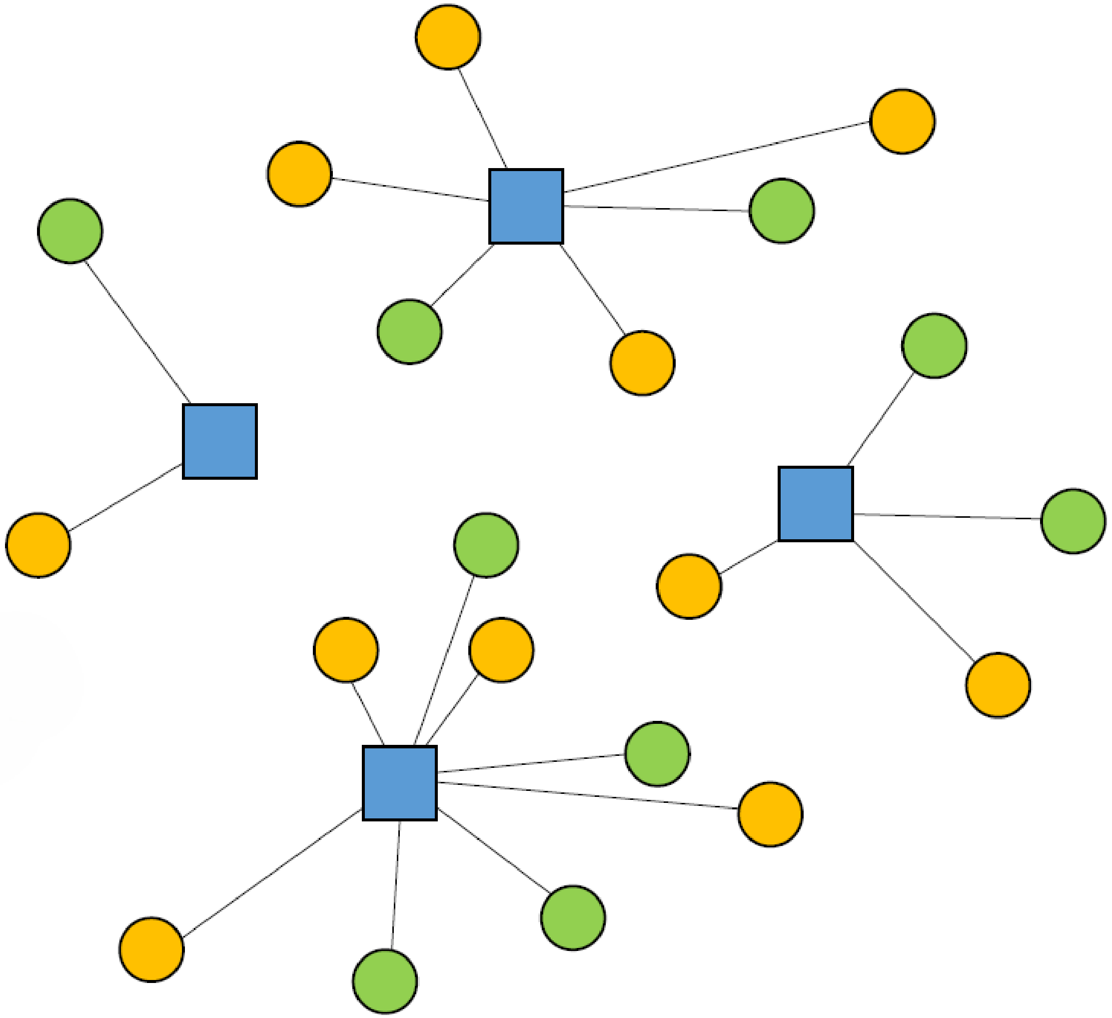
Modelling to enhance sensor networks

Dr. Blair Hall

Measurement Standards Laboratory of New Zealand

Modelling to enhance sensor networks

Measurement Standards Laboratory of New Zealand



Sensor networks are a multitude of tiny measuring systems

Can sensor data be made traceable?

How can raw sensor data be transformed into traceable measured values?

When sensors are manufactured, batch properties can be characterised

Mean offset, gain, etc., and sample variability (systematic effects)

Reading variability (repeatability)

Also, sensor types can be modelled to explain imperfect behaviour

$$x_i^{\text{sensor}} = Y + O_{\text{batch-mean}} + O_{\text{batch-variation}}^{\text{sensor}} + E_{\text{rep-}i}^{\text{sensor}}$$

So, batch parameters can be attributed to individual sensors, which are modelled

Unique digital IDs avoid ambiguities

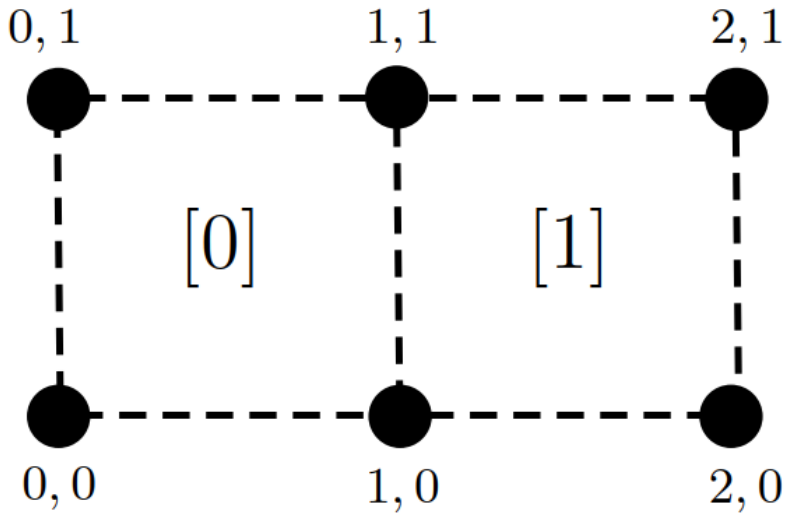
Data processing can fuse raw data from multiple sensors

Batch characteristics tend to correlate sensor data, but this can be accounted for and used to enhance accuracy of certain measurements

For example, a lattice of temperature sensors

Each sensor measures temperature at its location.

Can we interpolate to get the temperature at other locations, or measure a temperature gradient?



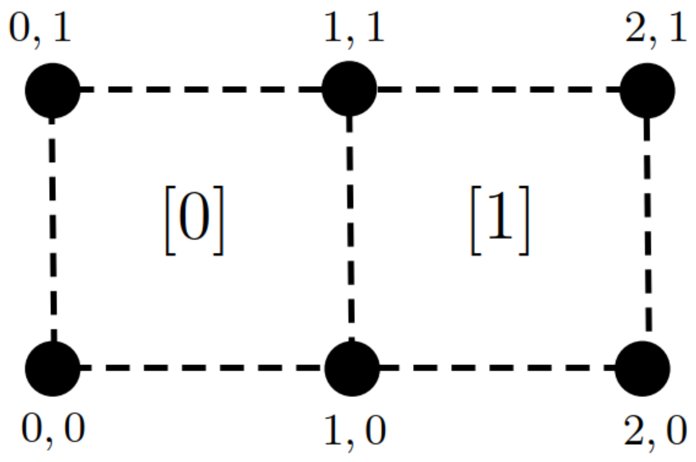
$$T[0] \approx \frac{T_{00} + T_{01} + T_{10} + T_{11}}{4}$$

$$\frac{dT[0]}{dx} \approx \frac{(T_{10} - T_{00}) + (T_{11} - T_{01})}{2}$$

Consider four different models for the sensors in the grid

In the different model cases, a sensor reading has:

1. a random error
2. a systematic error (common to all sensors)
3. a random error and a (common) systematic error
4. a random error and a characterised systematic error



case	$u(t[0])/°C$	$u(\frac{dt[0]}{dx})/°C$	$r(t[0], t[1])$	$r(\frac{dt[0]}{dx}, \frac{dt[1]}{dx})$
1	0.50	1.00	0.50	−0.50
2	1.00	0.00	1.00	0.00
3	0.79	0.71	0.90	−0.50
4	0.06	0.09	0.75	−0.50

Sensor modelling and associated data processing

- Common (systematic) and individual sensor behaviour can be represented
- Common influences produce correlated measurements: modelling captures this
- Heterogenous networks can be supported (plug-and-play)
- Light-weight digital processing in sensors (distributed processing)
- Modelling and data processing can support traceability (GUM-compliant)

Further information:

B. D. Hall, “An opportunity to enhance the value of metrological traceability in digital systems”, in: proceedings of the 2019 Workshop on Metrology for Industry 4.0 and IoT (MetroInd4.0 & IoT), DOI: 10.1109/METROI4.2019.8792841.

Software: https://github.com/MSLNZ/GTC

Related work in KRISS

Application of sensor network in acoustics

Dr. Wan-Ho Cho

Korea Research Institute of Standards and Science

Application of sensor network in acoustics

Introduction

- **Type of acoustic sensor configurations**

	Single node – limited range	Multi node – wide range
Non synchronized - **Magnitude**	Sound information only Platform: Sound level meter, Etc… - Monitoring at single sampled position	Spatial distribution of sound Platform: Outdoor measurement system, Etc… - Monitoring at various sampled positions
Synchronized - **Magnitude + Phase**	Sound & Spatial information – direction Platform: Array system - Sound localization - Spatial filtering of signal	Sound & Spatial information – 3D + α Platform: Connected sensor network - Wide range surveillance - Acoustic scene analysis

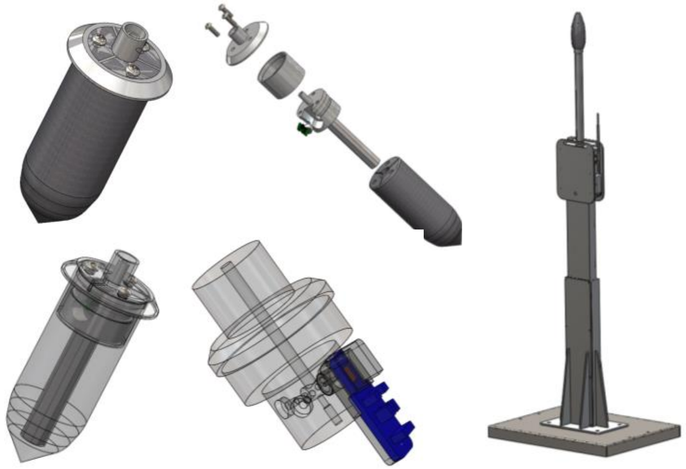
- **Change of measurement process**

	Traditional	Recent / Future
Performer/Operator	Self measurement or provided by known operator → Detailed measurement condition also known	Contribution by unknown operator & devices → Cloud of measurement data
Scalability	Limited	
Accessibility	Accessible to every step of measurement data & instruments	Not accessible to every step (even any)

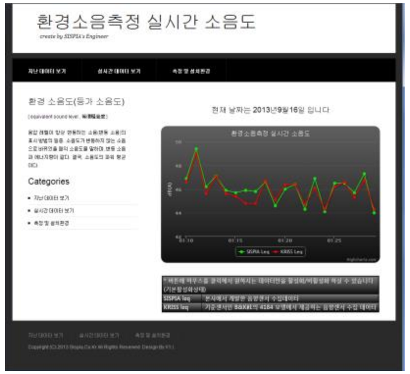
Application of sensor network in acoustics

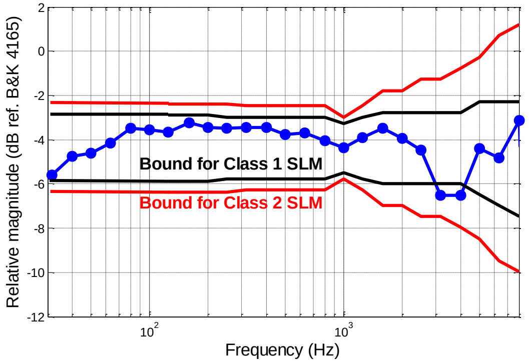
Research works on single node – Single sensor

- **Sensor development/validation/management**
  - Development of outdoor microphone



Outdoor noise monitoring system

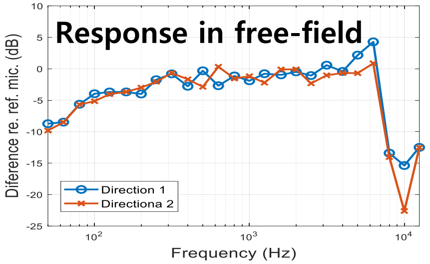




Calibration of system

Development of reliable sensor

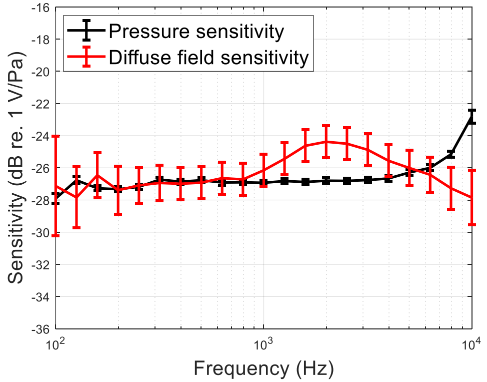
- **Quality infrastructure for non-standardized devices**
  - Low-cost sensor / Smart device application



Pt.	Overall SPL (Diffuse field, dBA)	
	WS2	Smart watch
1	90.26	90
2	90.44	90
3	90.26	90
4	90.07	90
5	90.09	90

Example of smart watch evaluation

Efficient calibration of MEMS microhpone



Validation & qualification of sensor

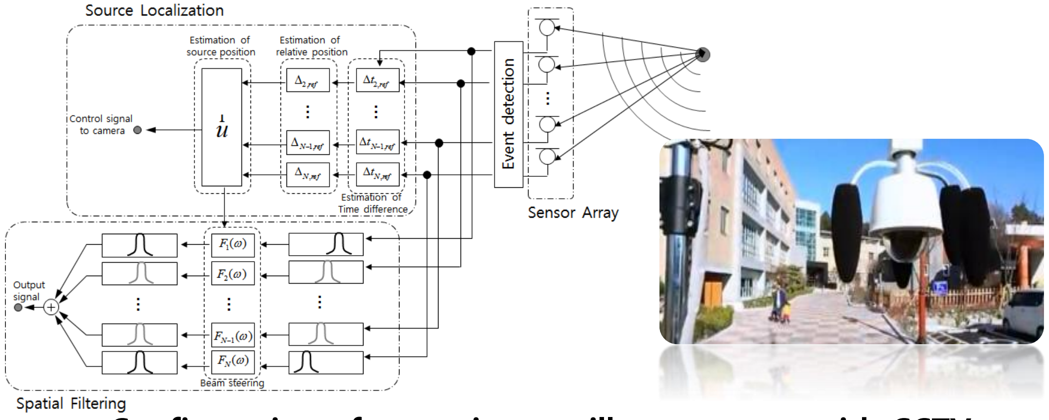
DCC compatibility can be applied as a type approval requirement

Application of sensor network in acoustics

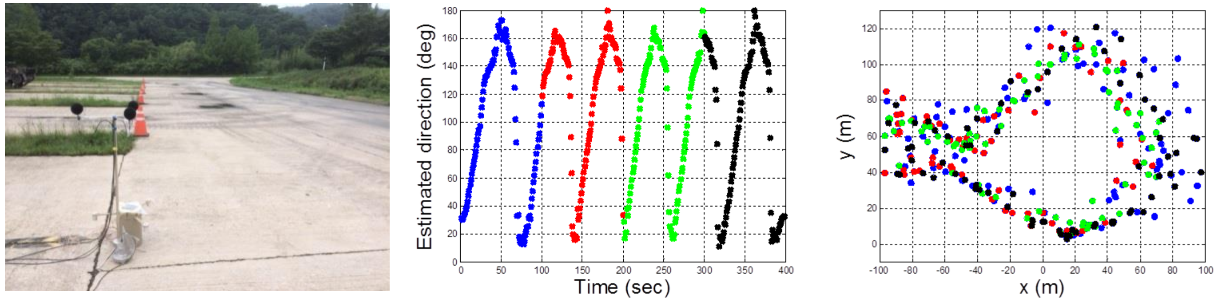
Research works on single node – Array system

- **Conventional application**
  - Sound source localization
  - Signal enhancement

by TDoA, Beamforming, Etc…



Configuration of acoustic surveillance system with CCTV

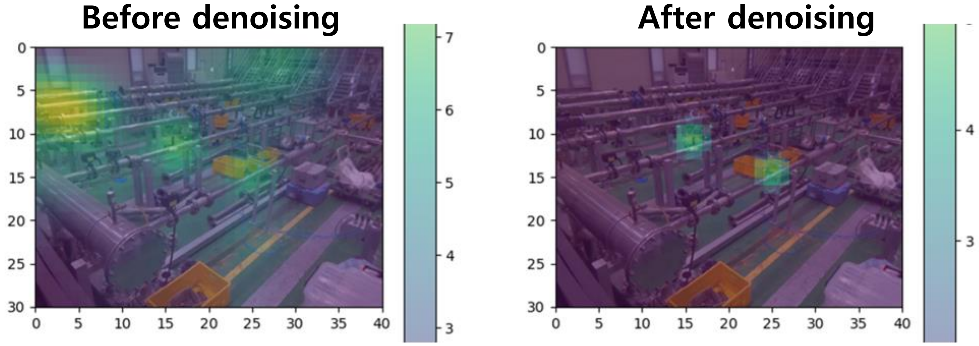


Localization & tracking of moving vehecle

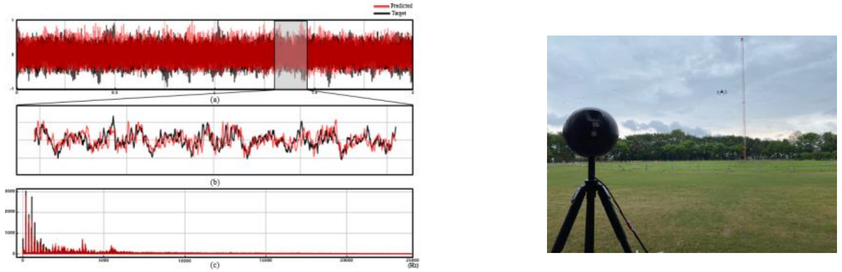
- **Expansion of application**
  - Expansion of frequency range: Ultra- & Infrasound range
  - With AI & ML techniques: Low S/N ratio condition

→ **Diagnosis & Inspection (e.g.) partial discharge, leakage, …**

Wide range monitoring (e.g.) anti-drone, …



Inspection & localization of gas leakage in noisy condition



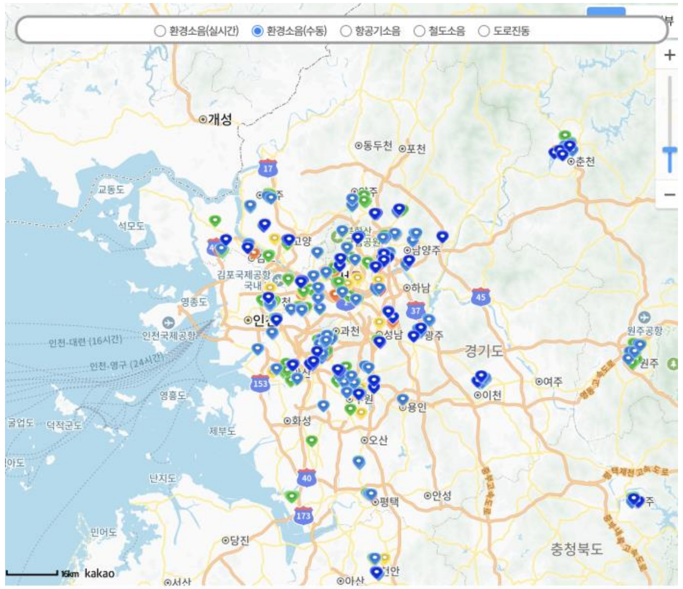
Reconstruction of drone noise

Application of sensor network in acoustics

Research works on multi node application

- **Conventional monitoring network**
  - Environmental noise monitoring
    Sampled information (Time & position)

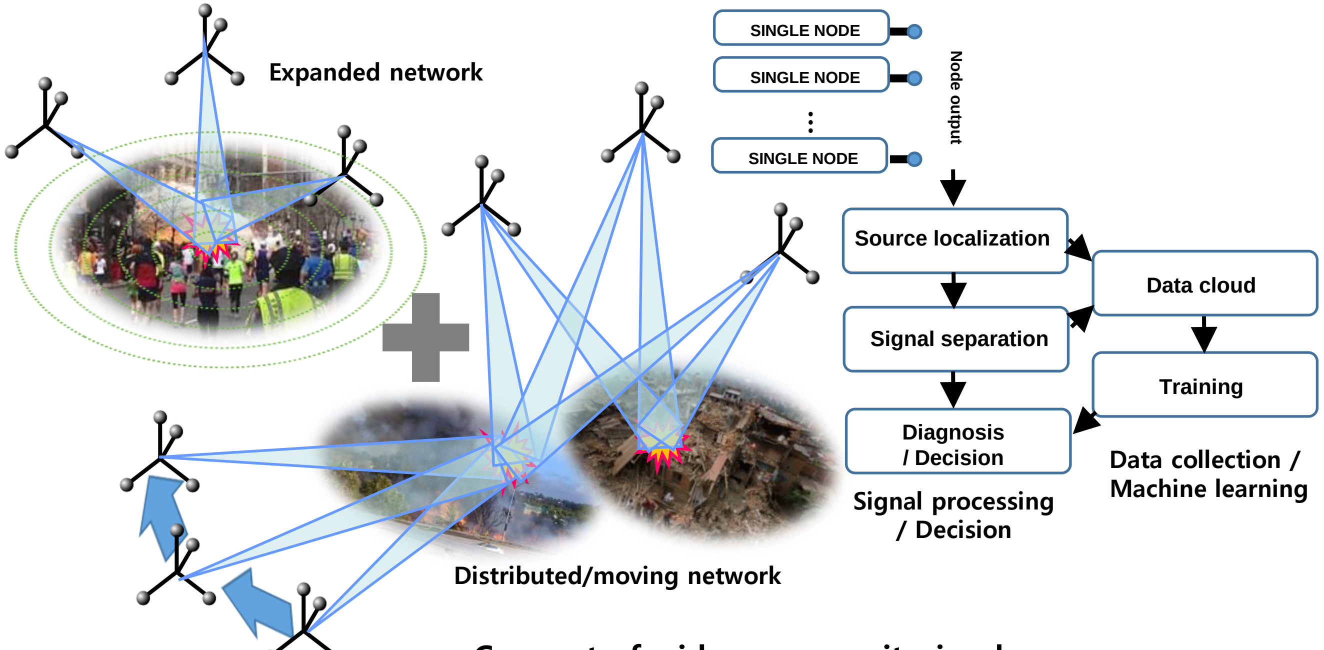
  → Real time & constant monitoring
  with high density locations



National noise information system
(https://www.noiseinfo.or.kr)

- **Wide-area monitoring by distributed/dynamic network**
  - Data collection by scalable sensor network
  - Application of acoustic scene analysis

  → Real-time monitoring & decision for various situations

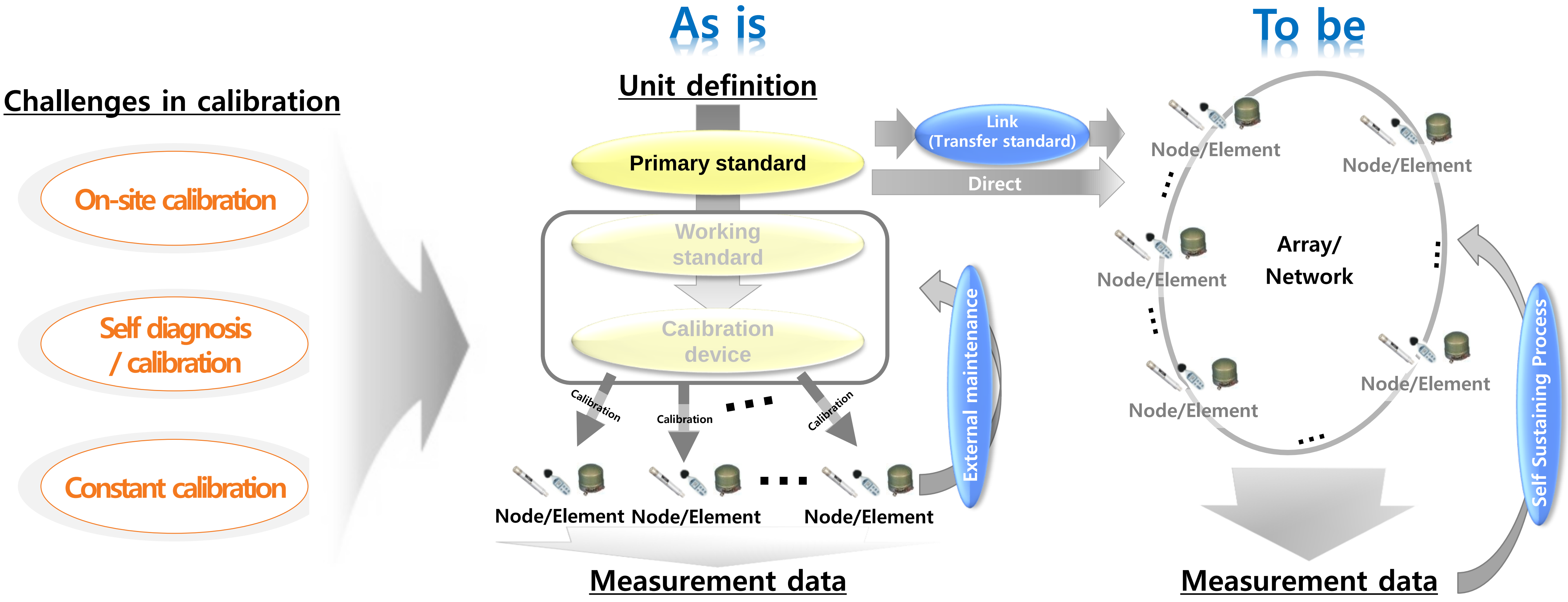


Concept of wide-area monitoring by
distributed/dynamic acoustic sensor network

Application of sensor network in acoustics

Future scan – Vision

- Sustainable sensor network



Related work in NMC

Data-driven metrology for sensor networks

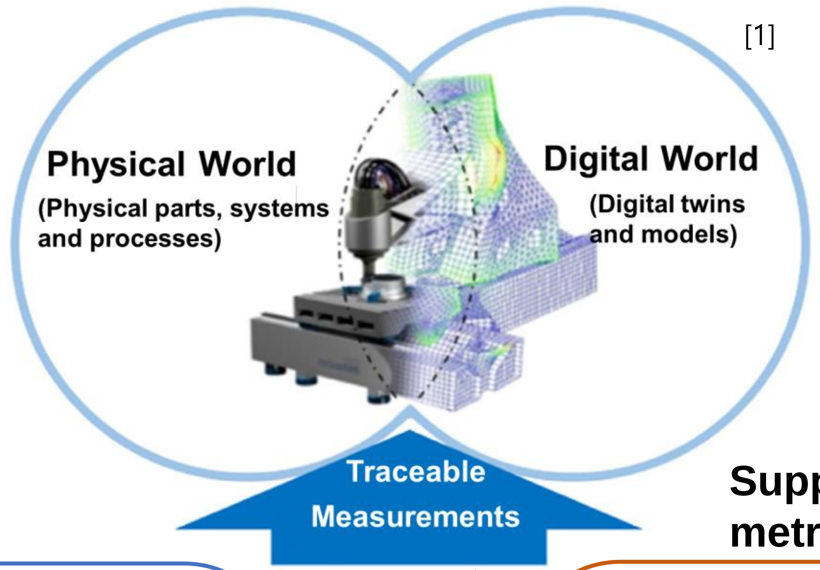
Dr. Shan Cui

National
Metrology Centre
NMC

Digitalisation of Metrology

Today's Metrology
Physical World

- Physical reference standards
- Calibrations in labs
- Paper calibration certificates



[1]

Tomorrow's Metrology
Digitalization

- Digitalised reference standards
- ***Remote/data-driven calibrations***
- Digital calibration certificates

Support digital ecosystem with digitalised metrology system & services

Physical National & Ref. Standards

Paper calibration certificate

Physical calibration

[2]

Physical Transfer

Remote / data-driven calibration

Digital calibration certificate

Metrology Cloud

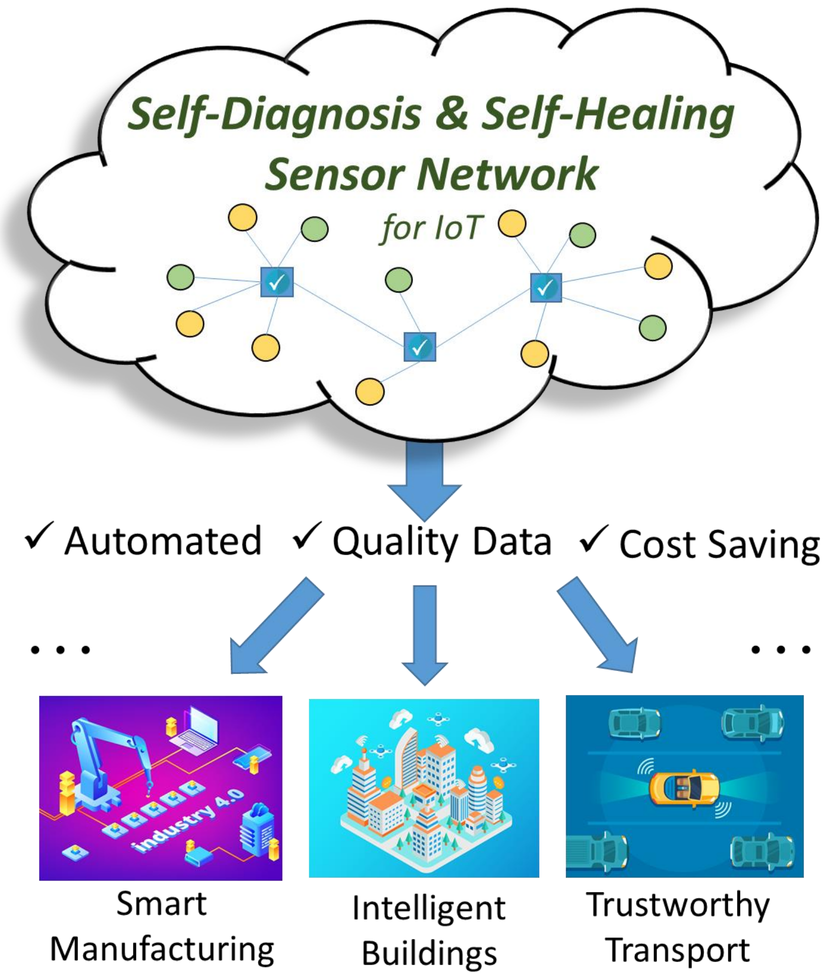
Digitalised National and Ref. Standards

Image credit: [1] Carmignato, S., et al. "Dimensional artefacts to achieve metrological traceability in advanced manufacturing." CIRP annals 69.2 (2020): 693-716.
[2] https://www.nymail.com/index.php/blog/mail-receiving-services

Data-Driven Calibration of Sensor Networks

- **Looking at measurement data point of view in digitalization of economy**
  - How to ensure measurement data is traceable and reliable in IoT without relying on lab-based calibration
    - Smart city/nation, smart factory, smart building, and so on
  - How to ensure sensing data used by data analytics and AI is validated and reliable
    - Especially for applications that need high-reliability and safety, such as autonomous vehicles (cars, planes, trains, ships)

Sensor Data in IoT Reliable?



NMC's on-going efforts in data-driven quality assurance of measurement in IoT

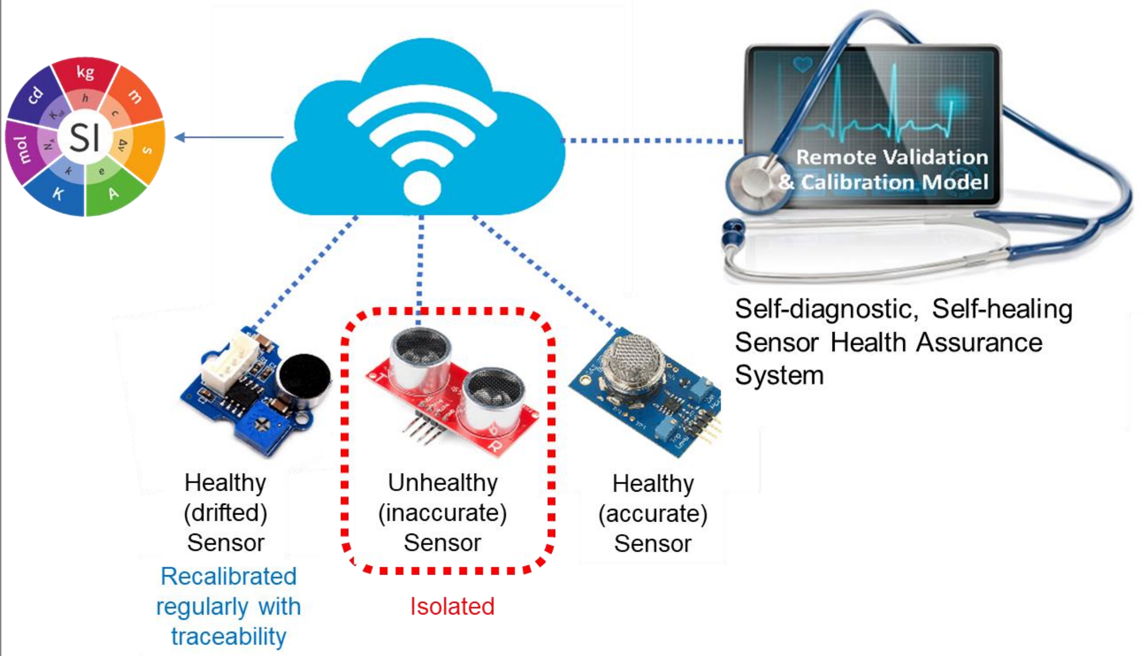
Self-Diagnostic Self-Healing Sensor Health Assurance System

Technology Overview

Reliable Sensing Data in IoT/IIoT

- Ensuring sensing data accuracy and reliability of sensor networks
- Using data-driven approach instead of purely relying on lab-based or on-site calibration
- Autonomous diagnosis of sensing error and correction with measurement traceability

Schematic



SDSH to automate measurement quality assurance in sensor network with measurement traceability to the SI units

Impacts

- Deployed in a Green Mark Platinum building for energy efficient ventilation control and good indoor air quality
- Cost reduction in long-term maintenance of sensors by minimizing lab-based calibration
- Reliable sensing data for reliable control
- Reduced downtime
- Wide applications for IoT and IIoT sensing

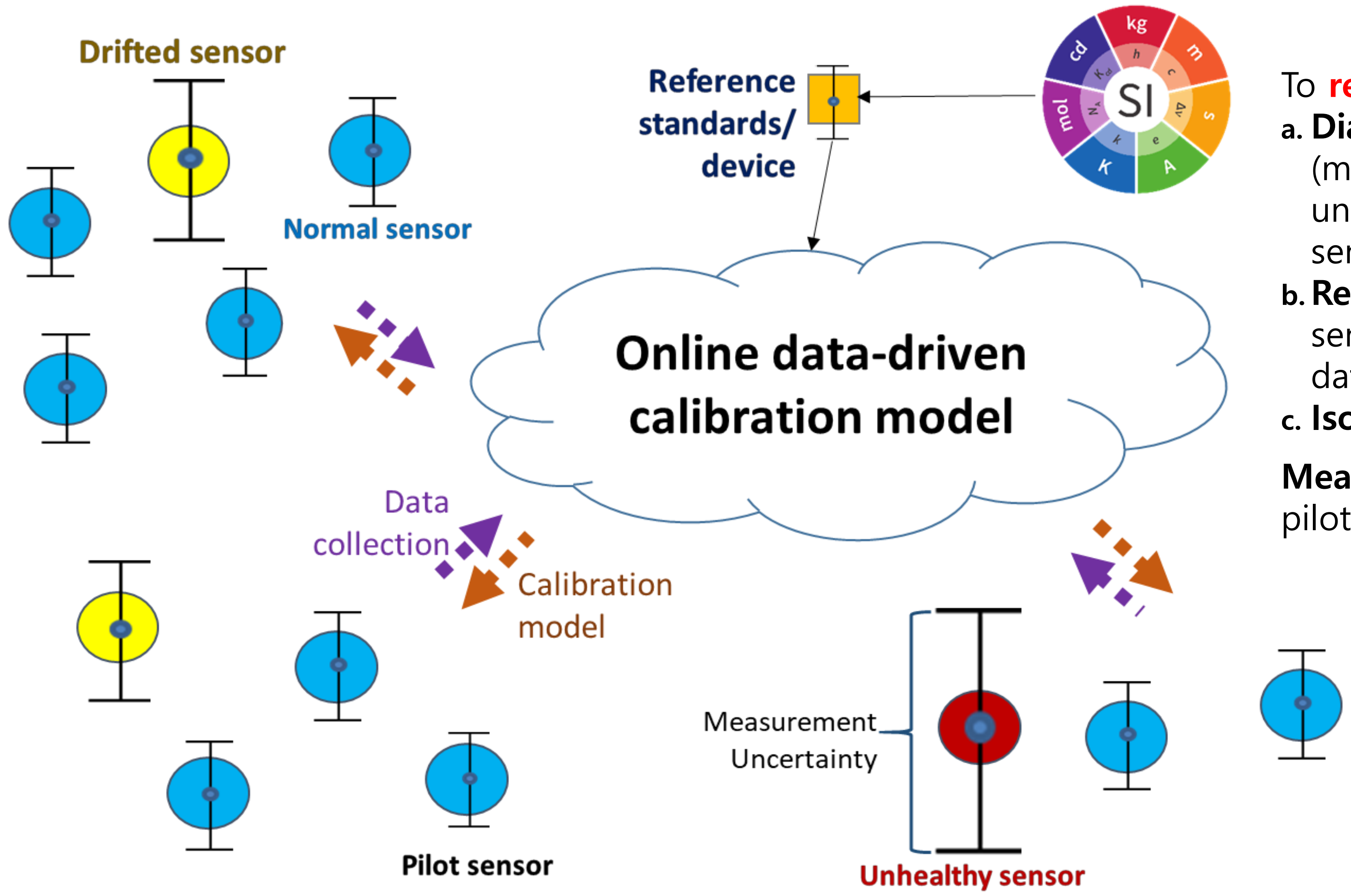
Tech Features

- Autonomous calibration of sensing data assisted by machine learning
- Minimising errors in sensing data with built-in metrology

TRL

- TRL 7

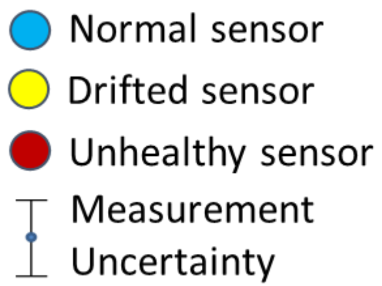
How SDSH Works



To **remotely** and **autonomously**:

a. **Diagnose** the health condition (measurement accuracy & uncertainty) of a network of sensors,
b. **Reinstate** the health condition of sensors, when possible, through data-driven recalibration, and
c. **Isolate** unhealthy sensors.

Measurement traceability through pilot sensors to physical references

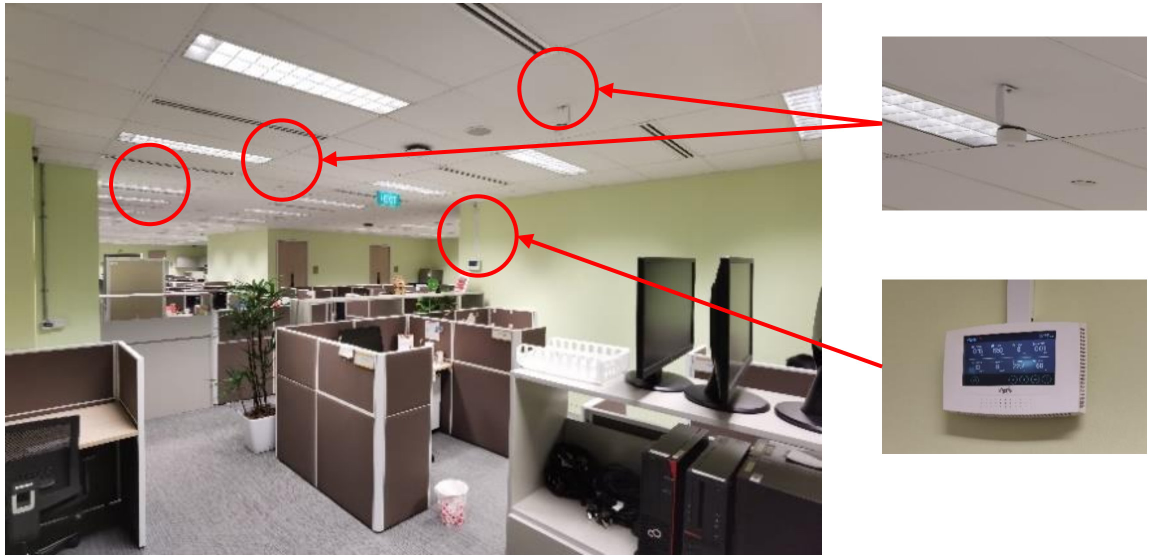


More information: https://www.a-star.edu.sg/nmc/news-articles/news-and-articles/research-spotlight/SDSH

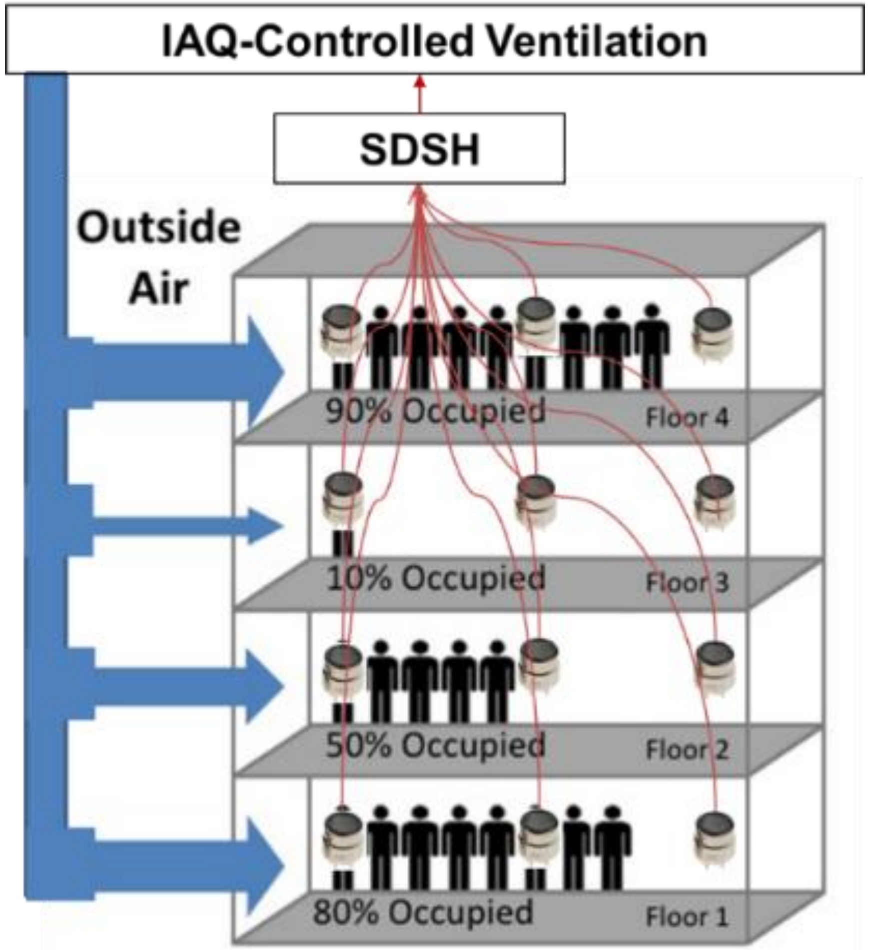
Demonstration in Demand Controlled Ventilation (DCV)

SDSH in indoor air quality (IAQ) sensor network to provide reliable control

✓ Better Energy Efficiency (20% energy saving) & Better IAQ



Location of IAQ sensors



DCV with SDSH

This research is supported by the National Research Foundation, Singapore, and Building and Construction Authority under its Green Buildings Innovation Cluster Programme (BCA 94.23.1.1).

THANK YOU

For more information about APMP-DXFG, visit https://apmp-dxfg.github.io/

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