SIM-MWG-14

Metrology for Digital Transformation
SIM-MWG-14

Introduction to the FORUM-MD Discussion Group on Sensor Networks (FORUM-MD-DG-SN)

Wan-Ho Cho

Metrology for Digital Transformation
15th M4DT DAY 2025

KRISS

Overview

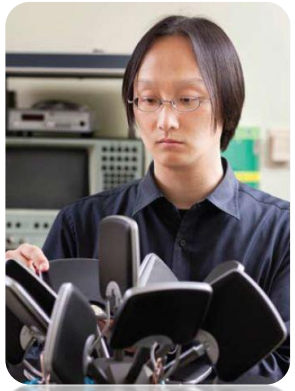
Organization of FORUM-MD-DG-SN (2025~)

- **Terms of Reference**
  - to advise the FORUM-MD on matters relating to metrology for sensor networks;
  - to facilitate knowledge transfer relating to the field;
  - to harmonize the terms and definitions related to the field.

- **Co-Chairs**

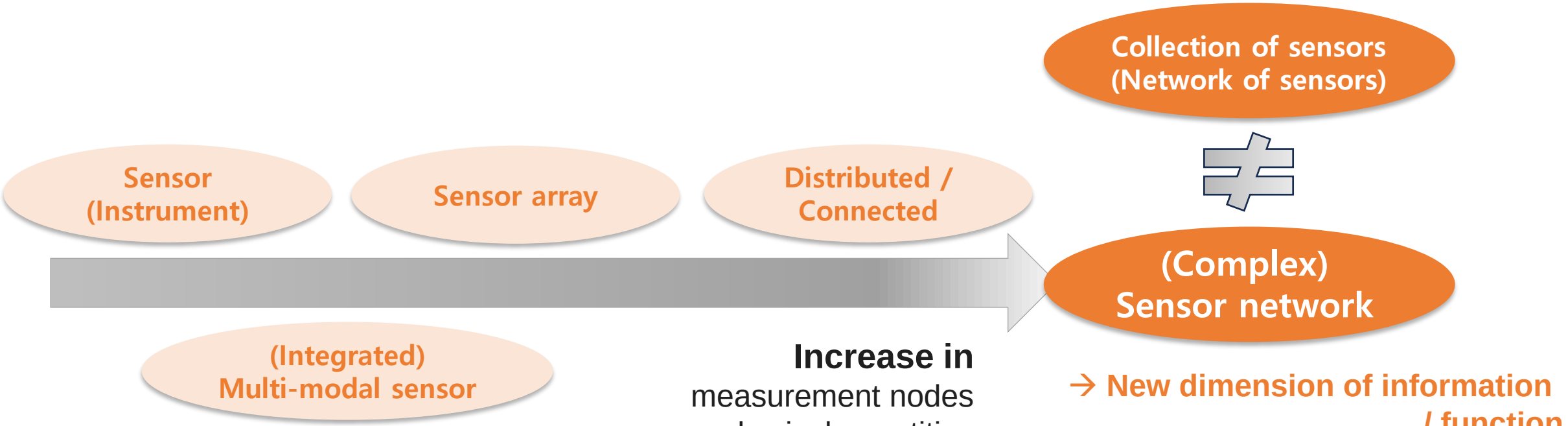
- Dr. Shan Cui
National Metrology Centre
Agency for Science, Technology and Research Singapore

- Dr. Wan-Ho Cho
Korea Research Institute of Standards and Science



Conceptualization

Sensor/Array/Network



Increase in
measurement nodes
physical quantities
exchange of info.
Etc…

→ New dimension of information / function

Key points:
Connected
Communicate

Initiation

1st FORUM-MD Meeting (2024)

- **Discussion to organize TG/WG @ breakout session**
  - Traceability, DCCs and DCRMs, Services and Applications
    Chaired by Ms. G. Macdonald, NRC/Director, NCSLI/President
  - Interoperability and quality of data
    Chaired by Dr. R. Hanisch, NIST/Office director
  - RMOs, Capacity Building and interaction between CCs and the BIPM
    Chaired by Dr H. Laiz, INTI
  - Future Technologies
    Chaired by Prof. C. Denz, PTB/President

- **Discussed topics in 'Future Technologies' session**
  - Blockchains as distributed technology: importance of smart contracts
  - Digital twins: physics-informed virtual simulations
  - Artificial intelligence: Metrology for AI, AI methods for NMI tasks
  - Smart sensor networks: Metrology of emerging features

Initiation

1st FORUM-MD Meeting (2024)

- **Task Groups proposed from 'Future Technologies' session**

- Proposed TG 1: Secure and trustworthy AI

√ Identification of uniform quality metrics for AI & workflows for AI
√ Quality of data: accuracy & uncertainties representativeness
√ Quality of algorithms: transparency, explainability, robustness

→ Accepted:

FORUM-MD-TG-AI

- Proposed TG 2: Complex sensor networks

√ Harmonize metrics for networks of many & heterogenous sensors
√ Defining measures of networks of (smart) sensors as a whole
√ Uncertainty, traceability, calibrations, … control methods

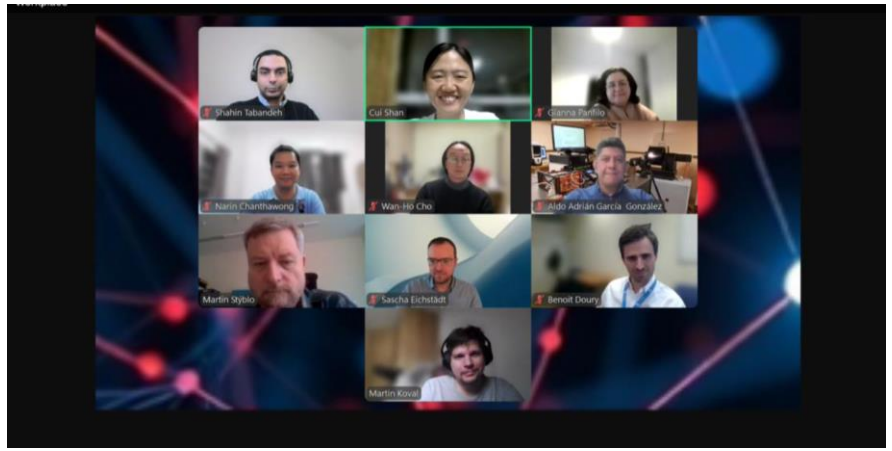
→ Recommended that a decision be made after further discussion through **Workshops**, etc.

Preliminary event

FORUM-MD Workshop on Metrology for Complex Sensor Networks

- **Overview**

- Date: February 11-12, 2025
- Fully online supported by BIPM's Zoom webinar service
- Theme: Sensor network metrology, regional examples of (heterogeneous) sensor networks, seismic sensors, sensors in cities of the future, energy networks, …
- Orgarnising committee:
  - Aldo Adrián García González, CENAM
  - Cui Shan, NMC
  - Martin Koval, CMI
  - Narin Chanthawong, NMIT
  - Sascha Eichstädt, PTB
  - Wan-Ho Cho, KRISS
- More info:
  https://www.bipm.org/en/committees/fo/forum-md/wg/forum-md-ws/2025-02-11



195 registrations

Actual attendance: 138

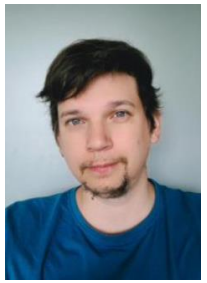
Including speakers and panellists: 11

Preliminary event

FORUM-MD Workshop on Metrology for Complex Sensor Networks

- **Program (Day 1)**

Title	Presenter
Challenges and Opportunities in Sensor Network Metrology (EURAMET TC-IM 1551)	Dr. Martin Koval Czech Metrology Institute (CMI)
EPM-FunSNM: from Generic Tools to Real-World Applications	Dr. Shahin Tabandeh Valtion Teknillinen Tutkimuskeskus, Mittatekniikan Keskus (VTT MIKES)
Metrology for Sensor Networks in Asia Pacific Metrology Programme's Focus Group on Digital Transformation	Dr. Shan Cui National Metrology Centre, Agency for Science, Technology and Research (NMC, A*STAR)
Pilot Metrology Cloud with IOT Sensor Network THB for SIM Region	M.Sc. Aldo Adrián García González Centro Nacional de Metrología (CENAM)



Preliminary event

FORUM-MD Workshop on Metrology for Complex Sensor Networks

- **Program (Day 2)**

Title	Presenter
Innovative Metrology for Complex Sensor Networks: Insights from the CTBTO IMS Stations	Mr. Benoit Doury Comprehensive nuclear Test Ban Treaty Organization (CTBTO)
Sensor Networks in Future Cities	Dr. Barbara Jung Physikalisch-Technische Bundesanstalt (PTB)
Computational Reconstruction of Calorific Value on Gas Distribution Networks	Mr. Martin Stýblo SIMONE Research Group
Panel Discussion Moderator: Dr. Sascha Eichstaedt, PTB	Panellists: Mr. Benoit Doury, CTBTO Mr. Martin Stýblo SIMONE Dr. Shahin Tabandeh, VTT

Preliminary event

FORUM-MD Workshop on Metrology for Complex Sensor Networks

- **Outcomes**

- Potential topics identified panel discussion
  - √ To answer what calibrating a sensor network really means
  - √ To consolidate knowledge gained and to facilitate knowledge transfer
  - √ To develop guidelines on
    - Calibrations; vocabularies; interface to digital twins
    - Collecting high quality big data using sensor networks
    - Data communication from sensor networks
      e.g. recommendation to IEEE community on meta data to address metrology information

- Proposal to establish an official group for collaboration
  - √ Task Group/Sub-Task Group/Interest Group in the future on Sensor Network Metrology

Establishment

Change of FORUM-MD organization in 2025

- **FORUM-MD-TG-AI**
  - FORUM-MD ad hoc Task Group on Secure and Trustworthy AI
  - Chair: Dr. Louise Wright (NPL)
- **FORUM-MD-TG-DQ&FPM**
  - FORUM-MD Task Group on Data Quality and Fair Practice in Metrology
  - Chair: Dr. Robert Hanisch (NIST)
    Dr. Daniel Hutzschenreuter
- **FORUM-MD-TG-MS**
  - FORUM-MD ad hoc Task Group on Metrological Semantics
  - Chair: Dr. Tyan White (NRC)
- **FORUM-MD-TG-H-DCC/DRMC**
  - FORUM-MD ad hoc Task Group on Harmonizing DCC and DRMC
  - Chair: Dr. Martin Koval (CMI)
- **FORUM-MD-TG-SIDF**
  - FORUM-MD ad hoc Task Group on SI-digital Framework
  - Chair: Dr. Anna Cypionka (BIPM)

- **FORUM-MD-WG-S**
  - FORUM-MD Working Group on Strategy
  - Chair: Prof. Dr. Cornelia Denz (PTB)
- **FORUM-MD-WG-CC**
  - FORUM-MD Working Group on coordination between CC
  - Chair: Dr. Peter Blattner (METAS)
- **FORUM-MD-WG-RMO**
  - FORUM-MD Working Group on coordination between RMO
  - Chair: Mr. Nikita Zviagin (Mendeleyev Institute for Metrology)

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- **FORUM-MD-DG-SN**
  - FORUM-MD Discussion Group on Sensor Networks
  - Chair: Dr. Shan Cui (NMC A*Star)
    Dr. Wan-Ho Cho (KRISS))

Challenges

Potential candidates of topics to be discussed

Definition & ranges

- Definition of terminology (including 'Sensor Networks')
- Decision of sub-topics to be covered by DG

Method for quality assurance

- Efficient & practical calibration method for sensor network system/elements
- Traceability & communication protocol
- Application of Digital Calibration Certificate

Harmonization

- Harmonization with traditional metrology standards
- Harmonization with existing smart sensor standards
  (e.g. IEEE 1451 transducer electronic data sheet (TEDS))

→ **IEEE is not signed the Joint Statement of Intent on the digital transformation**

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

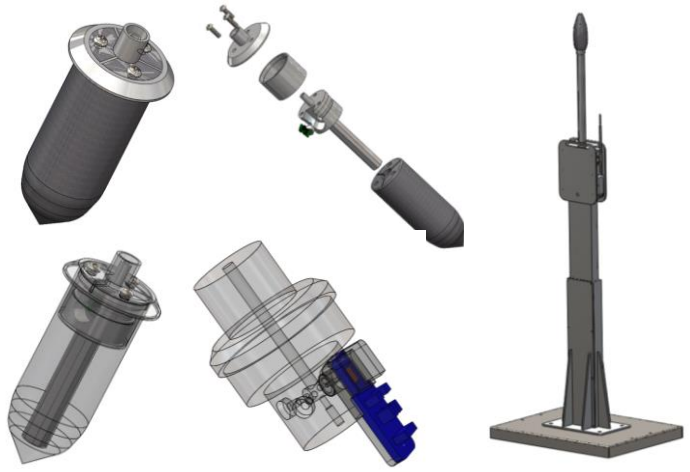
- **Change of measurement process**

	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)

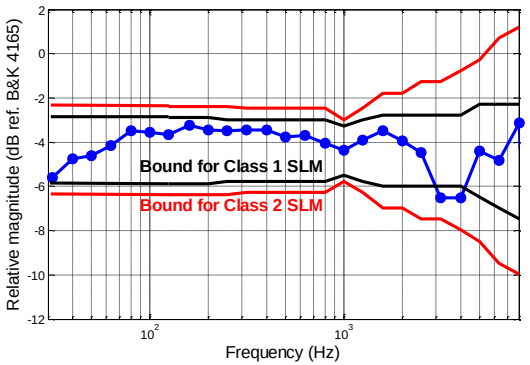
Application of sensor network in acoustics

Research works on single node – Single sensor

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



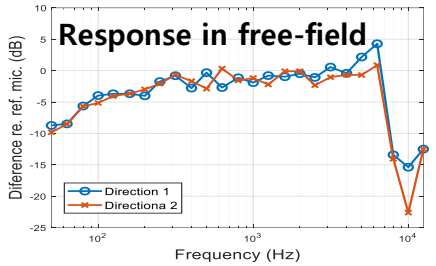
Outdoor noise monitoring system



Calibration of system

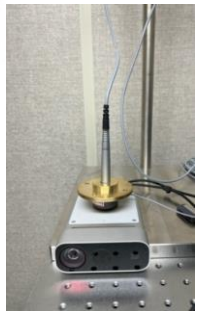
Development of reliable sensor

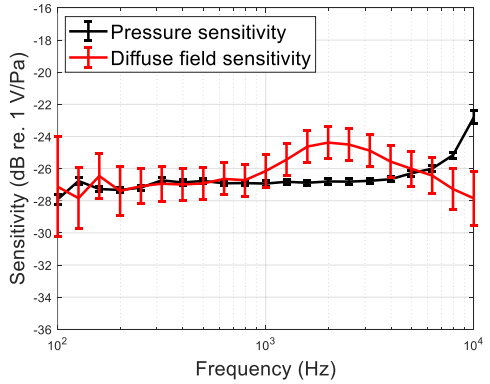
- **Quality infrastructure for non-standardized devices**
  - Low-cost sensor / Smart device application



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

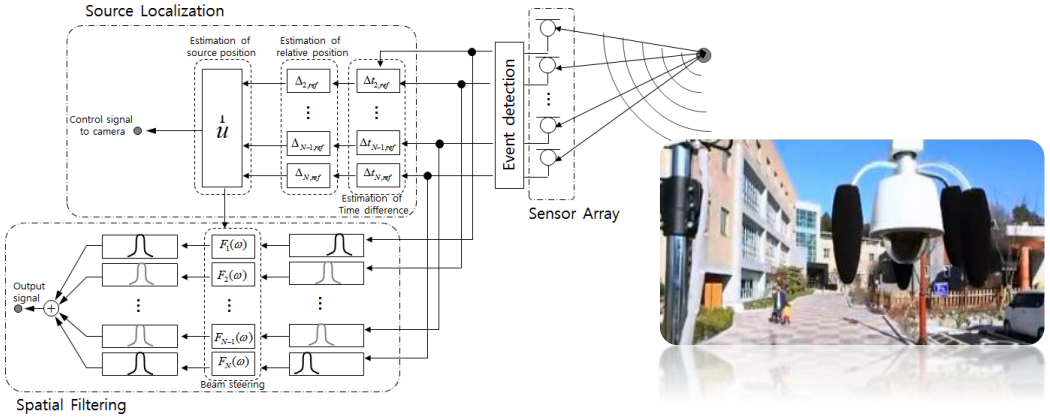
DCC compatibility can be applied as a type approval requirement

Application of sensor network in acoustics

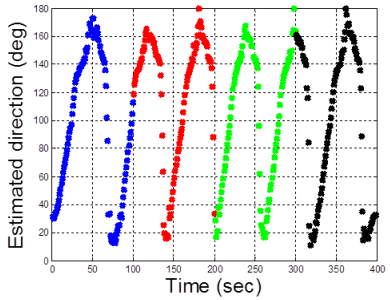
Research works on single node – Array system

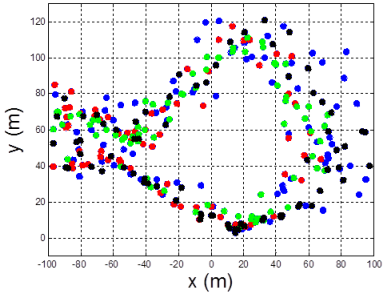
- **Conventional application**
  - Sound source localization
  - Signal enhancement

by TDoA, Beamforming, Etc…



Configuration of acoustic surveillance system with CCTV

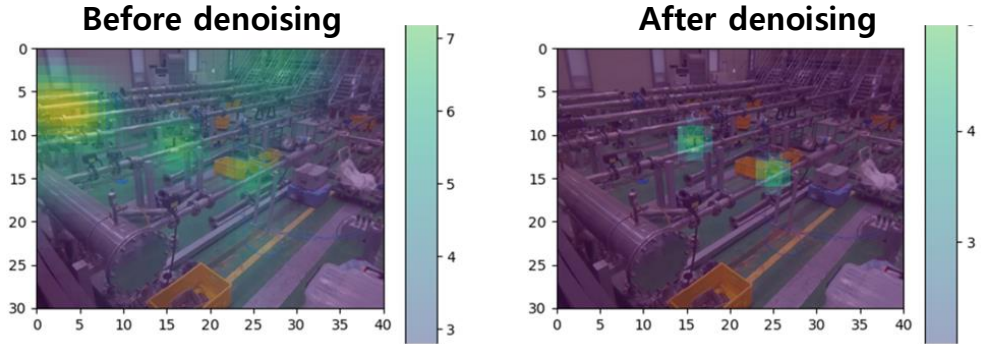




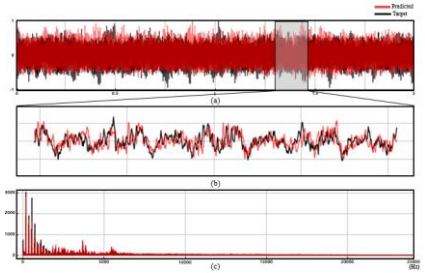
Localization & tracking of moving vehecle

- **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 noise condition

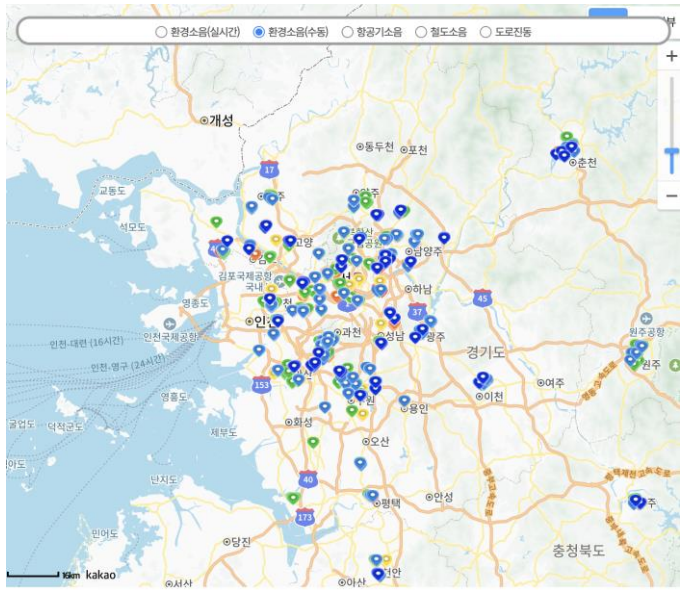


Reconstruction of drone noise

Application of sensor network in acoustics

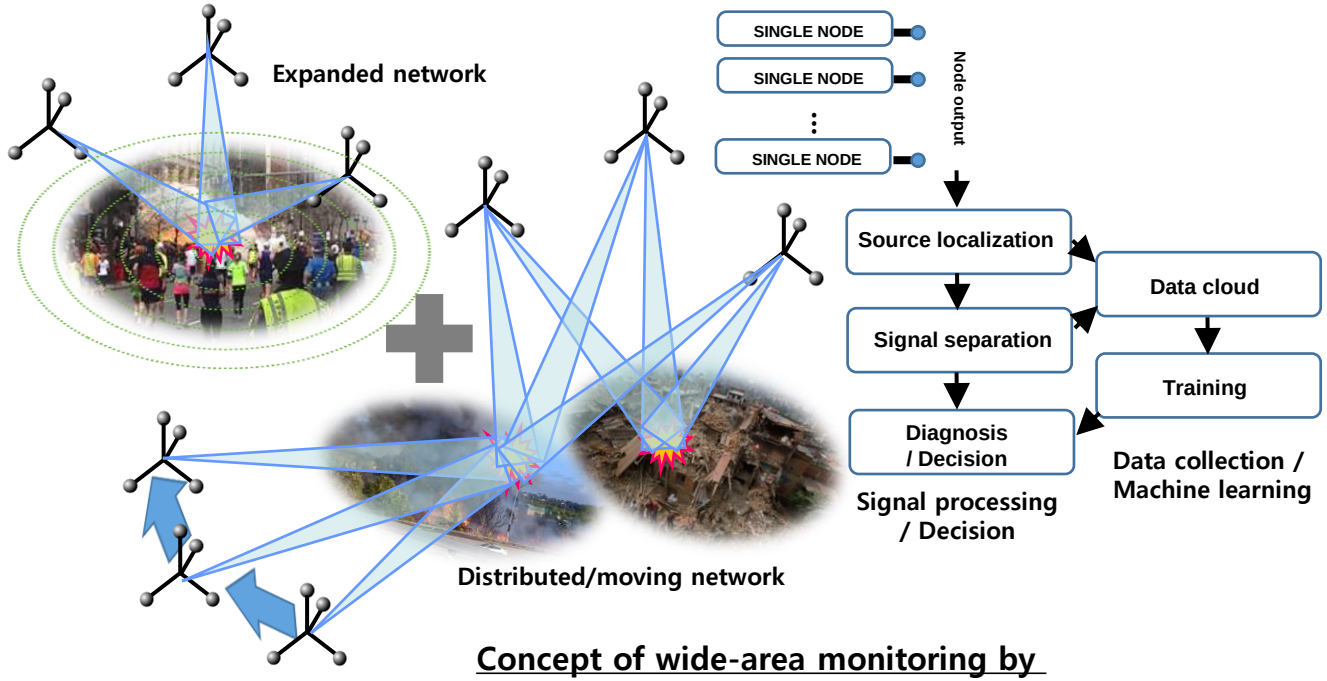
Research works on multi node application

- **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)

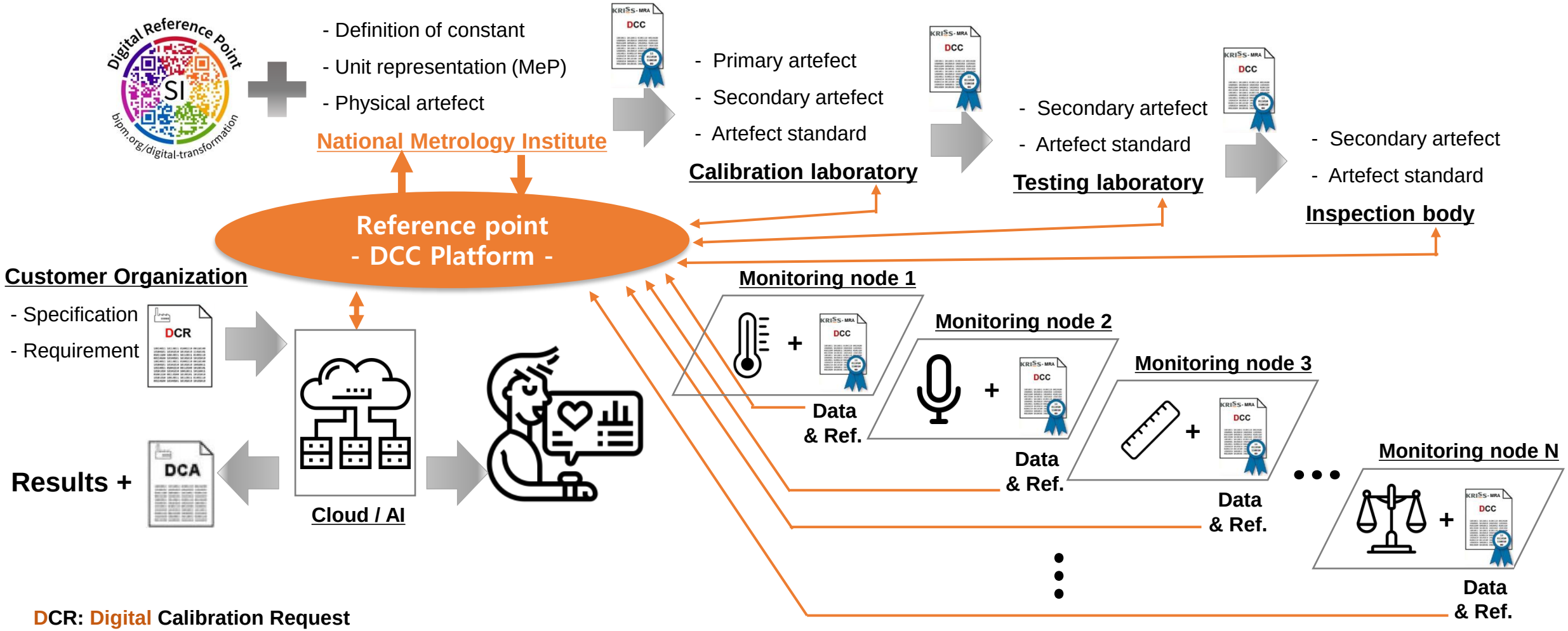
- **Wide-area monitoring by distributed/dynamic network**
  - Data collection by scalable sensor network
  - Application of acoustic scene analysis
  - → Real-time monitoring & decision for various situations



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

Future Scan

Ex) DCC based quality infrastructure



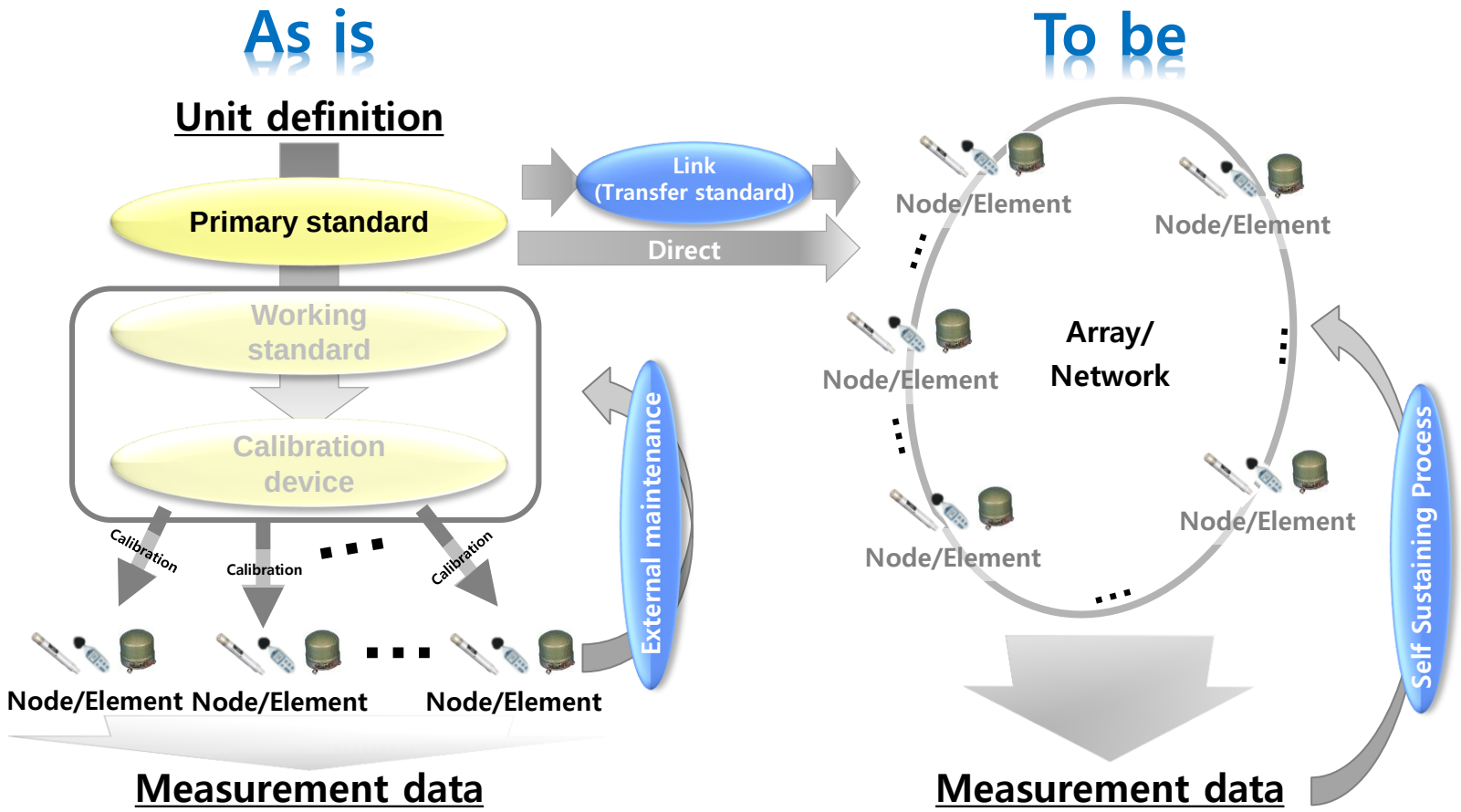
DCR: Digital Calibration Request
DCC: Digital Calibration Certificate
DCA: Digital Calibration Answer

Future Scan

Ex) Sustainable sensor network

Challenges in calibration

- On-site calibration
- Self diagnosis / calibration
- Constant calibration



Future related event

Special session @ M4d conference

- **IMEKO TC-6 International Conference on Metrology and Digital Transformation**
  - September 3-5, 2025, Benevento, Italy
- **Special Session:**
  Advancing Sensor Network Metrology for Industry 4.0 and IoT Applications
- **Organized by**
  - Shan Cui, National Metrology Centre, A*STAR, Singapore
  - Anupam Vedurmudi, Physikalisch-Technische Bundesanstalt, Germany
  - Narin Chanthawong, National Institute of Metrology, Thailand
- **Topics**
  - Metrological principles for digital sensor networks
  - Uncertainty evaluation for time series data in IoT applications
  - Digital representation of metrological information for networked sensors
  - Machine-readable and machine-actionable metrology for automated sensor networks
  - Calibration, co-calibration and data-driven (or virtual) calibration techniques for sensor networks
  - Sensor fault detection and diagnostics
  - Metrology-assisted production and quality control in Industry 4.0

https://www.m4dconf.org/

Thank you for your attention

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