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Smart Sensing Technology for Earthquake Hazard Mitigation and Maintenance of Infrastructures

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Research & Development

- Background
  - Architectural & Structural Engineering
  - Earthquake Engineering
- Research & Development
  - Structural Control Systems for Earthquake Hazard Mitigation
  - Ubiquitous Monitoring of Buildings
    - Earthquake Monitoring and Structural Monitoring by Sensor Networks
    - Risk Information Delivery System
    - Energy Monitoring
    - Environmental Monitoring
  - Application of Sensor Networks to Smart Buildings and Bridges

Recent Research Topics
－Technologies towards Smart Architecture and City

Design

3Dスキャンデータ処理

VRによる建築設計

BIMとセンシング連携

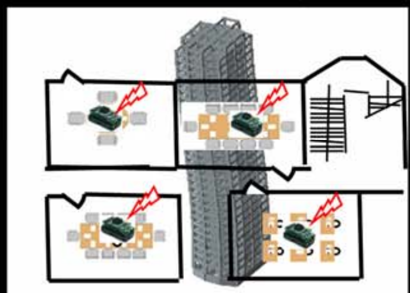
Measure

IoT センサ

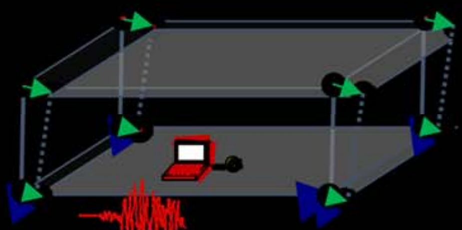
映像センサ

自律型電源システム

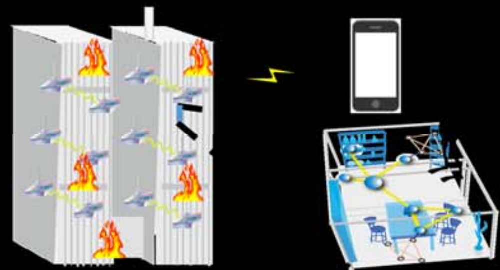
Communicate



無線センサネットワーク

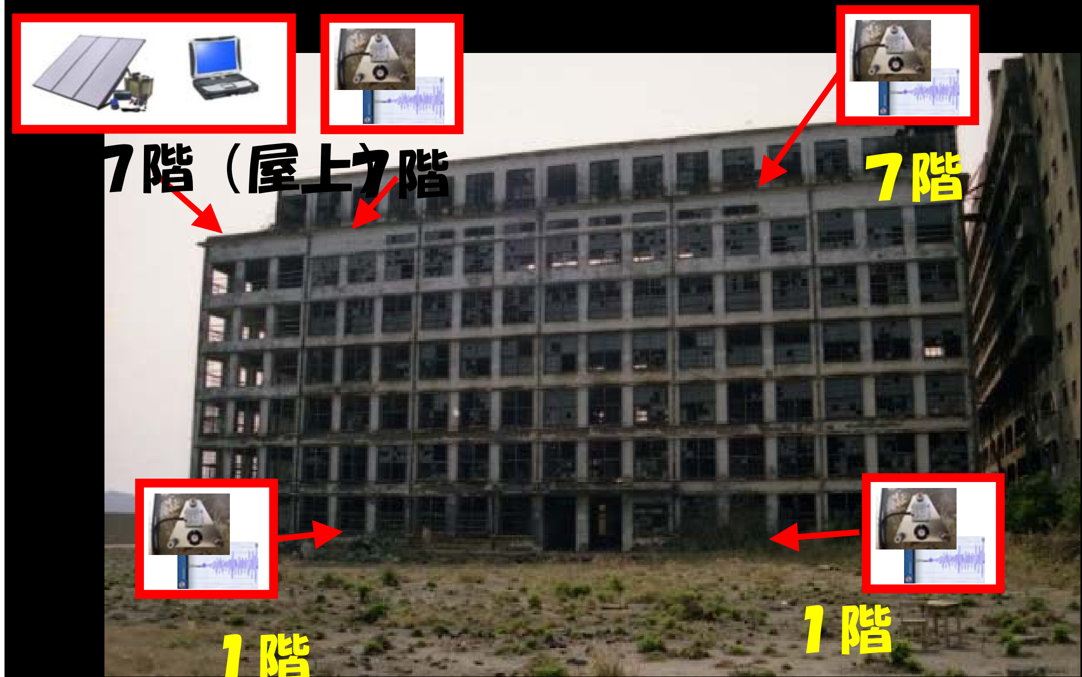


地震時損傷の自動通知



リアルタイム災害情報伝達

Recent Research Topics
－Maintenance of World Heritage Structures
－Gunkan-jima and Angkor Wat



World Cultural Heritage sites






「明治産業革命」世界遺産

軍艦島など23施設

19件目、ユネスコ決定

高層建物が密集した独特の外観から「軍艦島」と呼ばれている端島炭坑＝4月25日、長崎市

【ボン＝宮下日出男】ドイツ西部ボンで開催中の国連教育科学文化機関（ユネスコ）の世界遺産委員会は5日、日本が推薦した「明治日本の産業革命遺産」（福岡など8県23施設）を世界文化遺産に登録することを決定した。登録は「富士山」（山梨、静岡）、「富岡製糸場と絹産業遺産群」（群馬）に続いて3年連続で、日本の世界遺産は文化15件、自然4件の計19件となった。

産業革命遺産は19世紀半ばから20世紀初頭にかけ、日本の近代化を牽引した重工業分野の施設で構成。「軍艦島」の通称で知られる端島炭坑（長崎市）などのほか、官営八幡製鉄所の修繕工場（北九州市）、三菱長崎造船所のクレーン（長崎市）といった100年以上経過した現在も稼働中の施設も含まれる。

審査は当初、4日午後に予定されていたが、審査の場での韓国側の発言内容をめぐる日韓の調整が難航したため、最終日の5日に先送りされた。

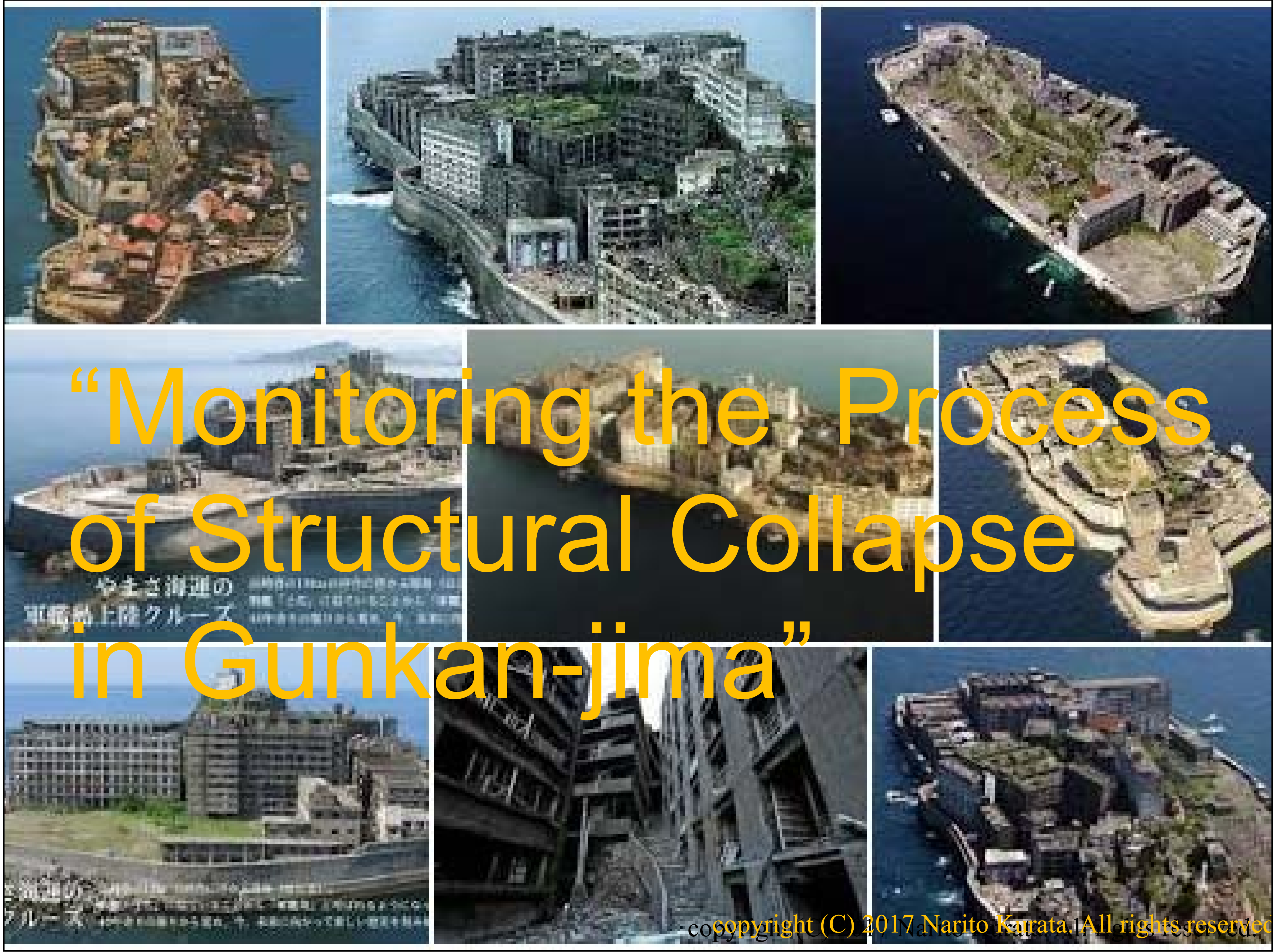
委員会開催に先立ち、韓国は八幡製鉄所など7施設で「戦時中に朝鮮人労働者が強制徴用されていた」と主張して反対活動を展開、6月の日韓外相会談で両国が双方の推薦案件が登録されるよう協力することで一致した。

韓国側は「強制徴用」の歴史を施設の説明に反映させるよう求めていたが、日本は韓国の主張を踏まえ、歴史的な事実関係の範囲内で明示するとの立場を示していた。

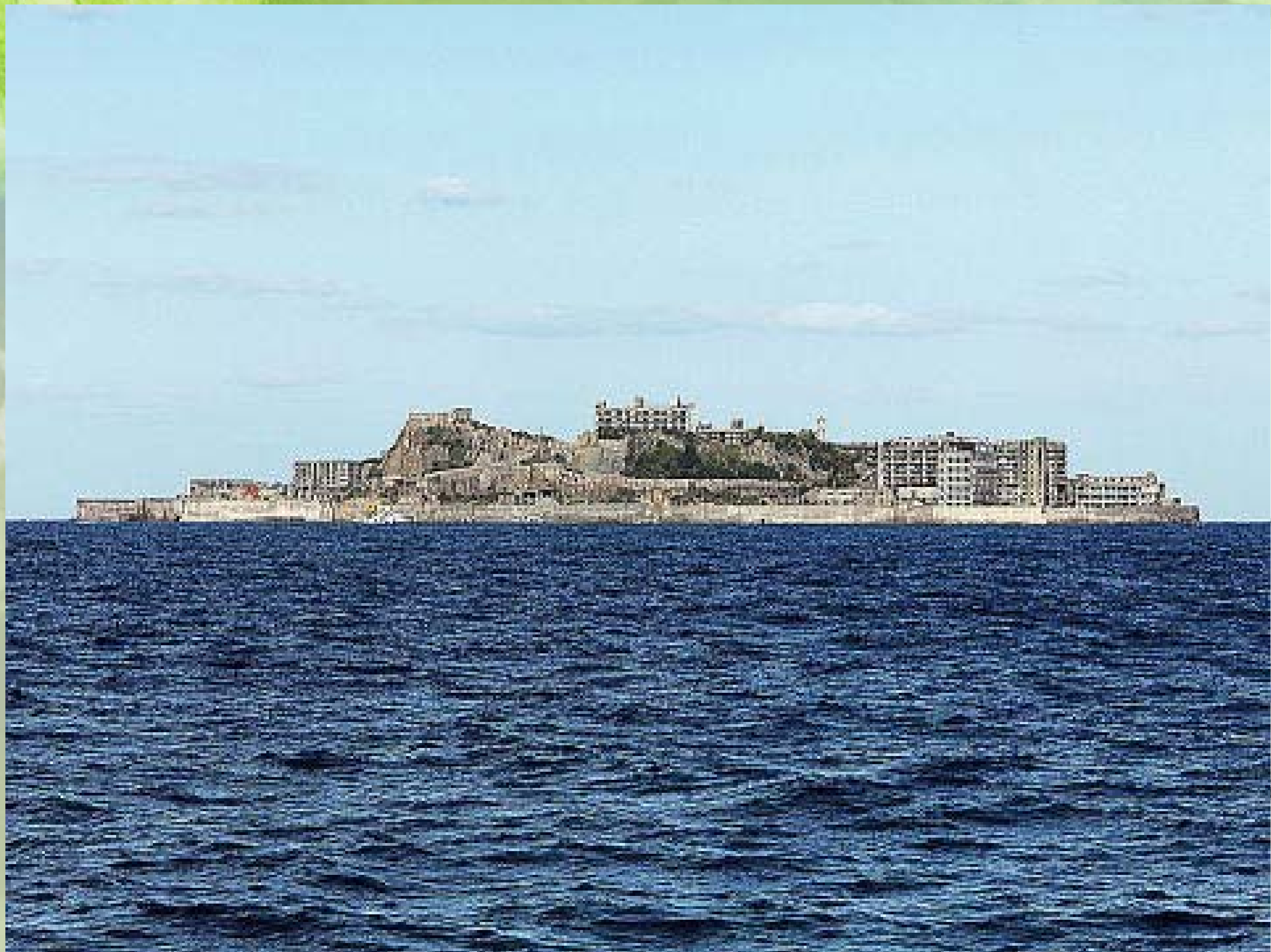
日本政府は来年、「長崎の教会群とキリスト教関連遺産」（長崎、熊本）の世界文化遺産登録も目指している。

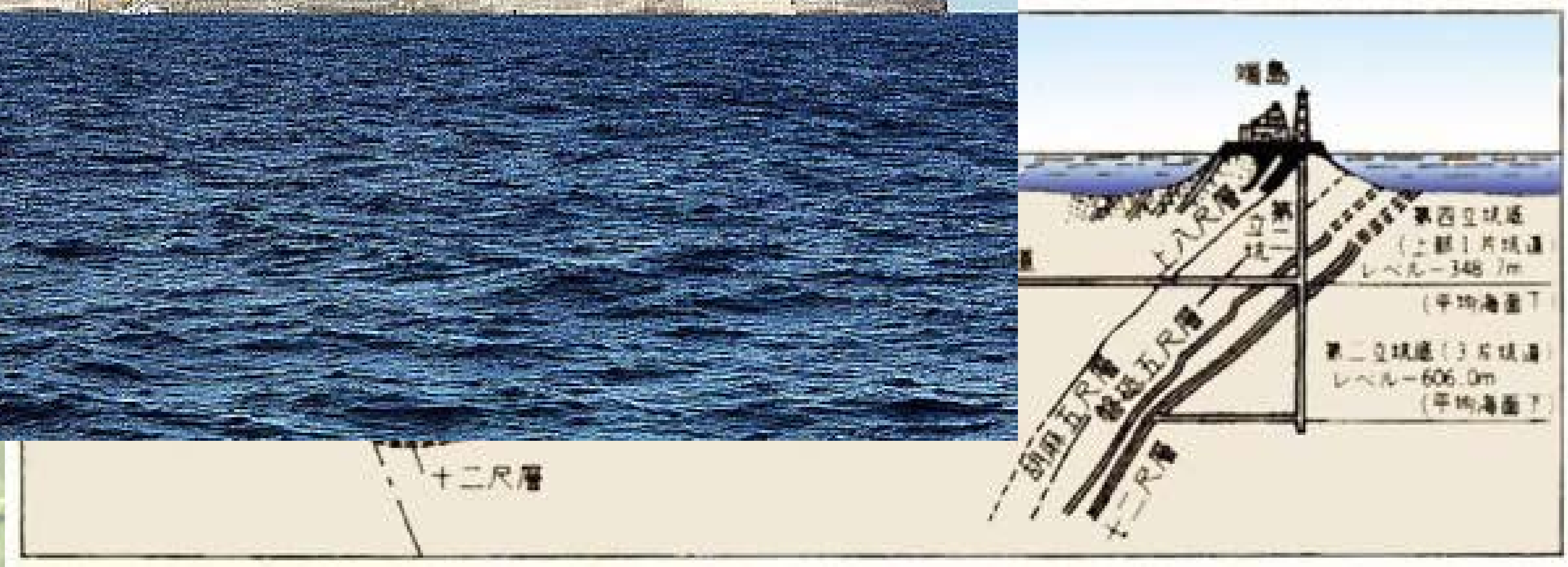
7月5日　産経新聞

“Monitoring the Process of Structural Collapse in Gunkan-jima”



Gunkan-jima (Battleship Island)






Gunkan-jima (Battleship Island)
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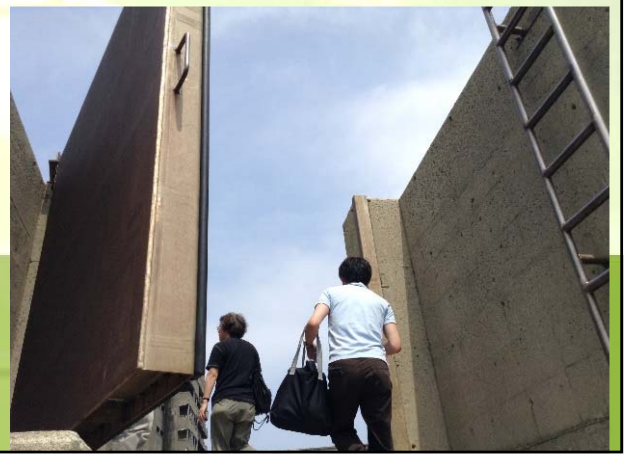
Location of Gunkan-jima

Gunkan-jima

We can go anywhere under special permission

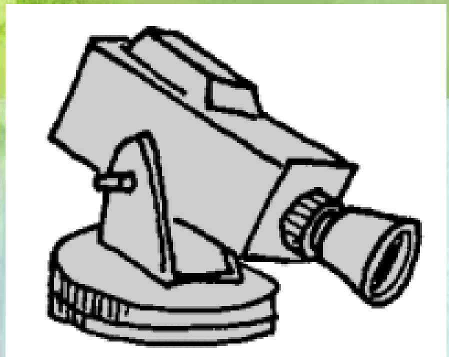


Building with the foundations exposed

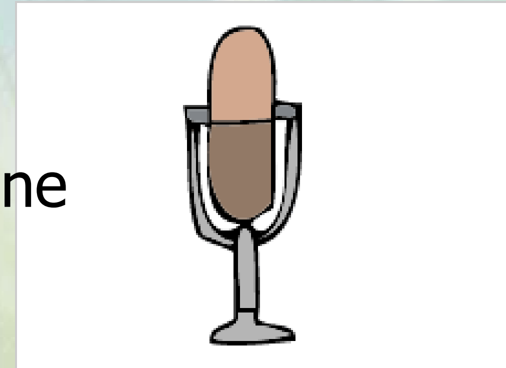
First Multi-family Housing Building of Reinforced Concrete, Built 100 Years Ago

Monitoring the Collapse Process of Buildings

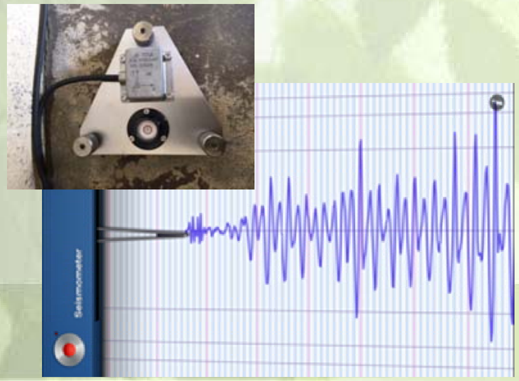
Camera



Microphone



Vibration Sensor



video

+

sounds

+

vibtation

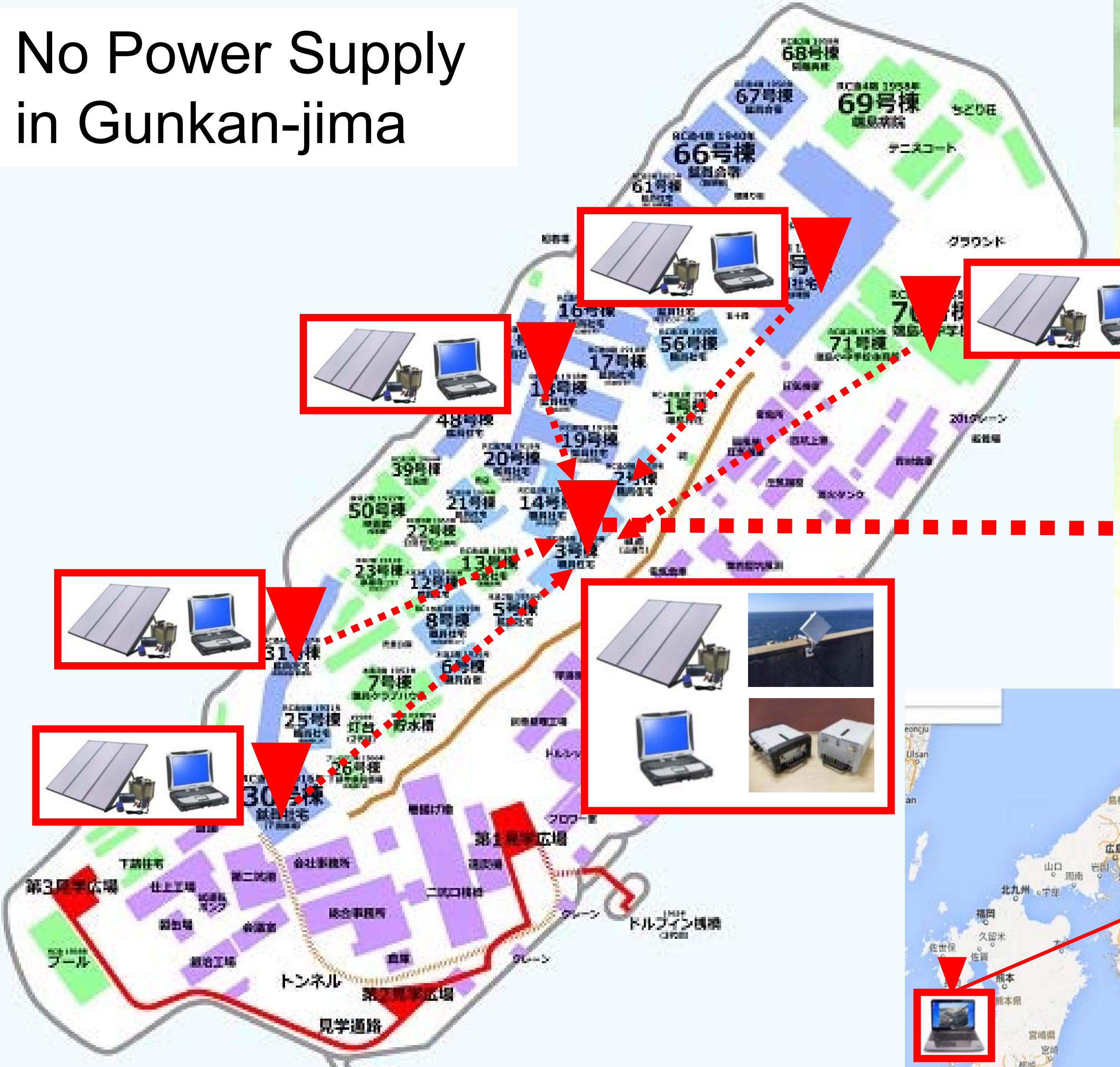
→

collapse process

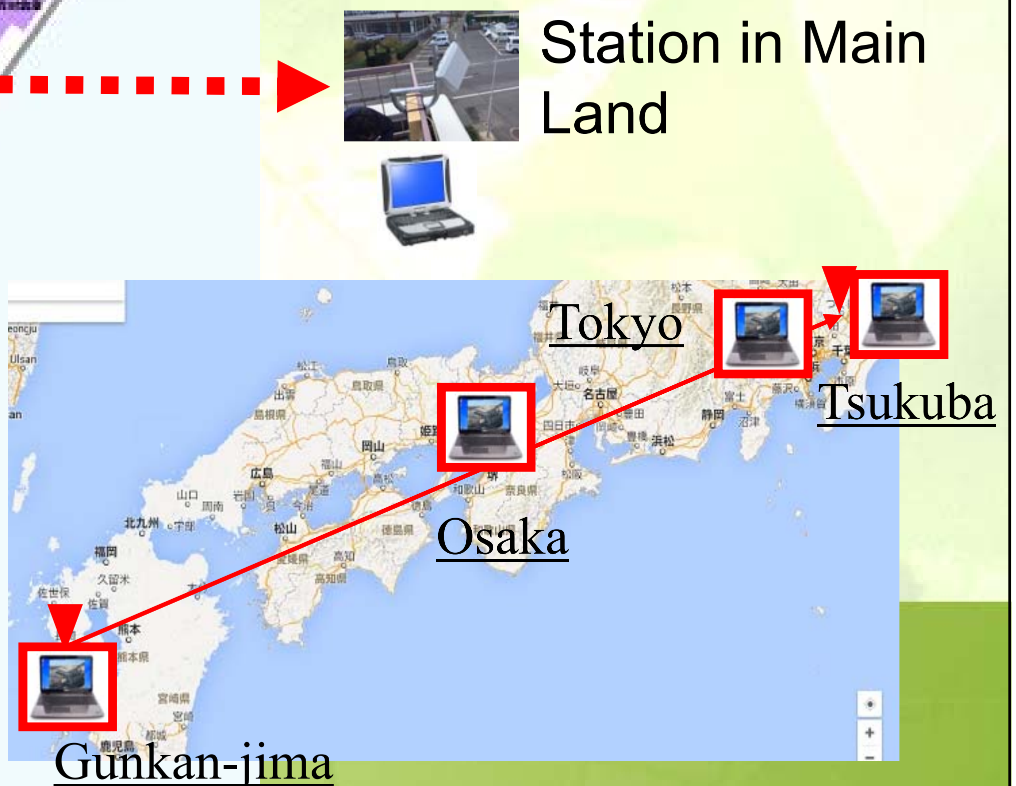
Sensor Network and Data Transmission

No Power Supply in Gunkan-jima

Data can be collected by wireless communication over the ocean

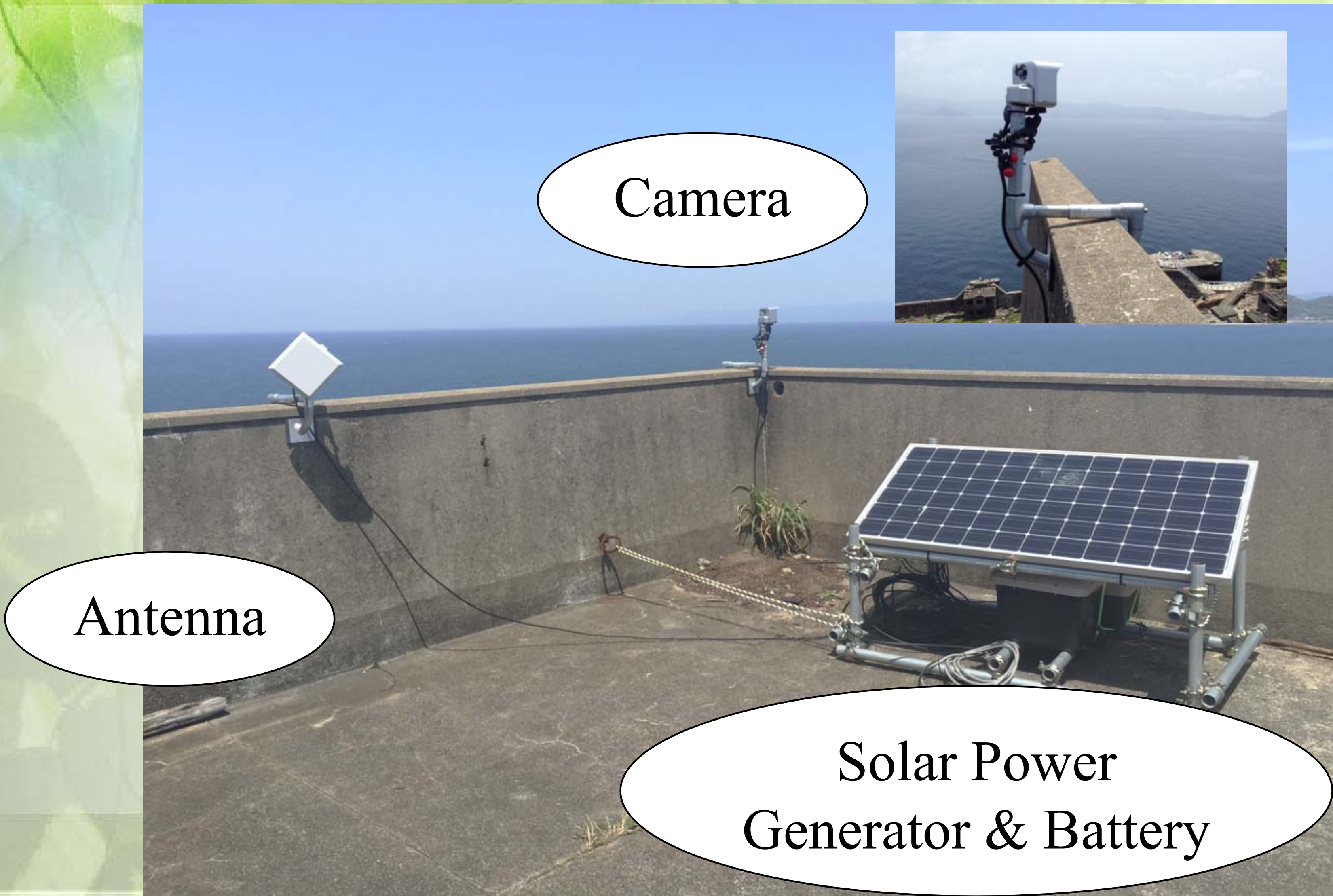


Station in Main Land



Residence for Executives

Solar Power Generator, Battery, Antenna, and Camera installed on the Rooftop

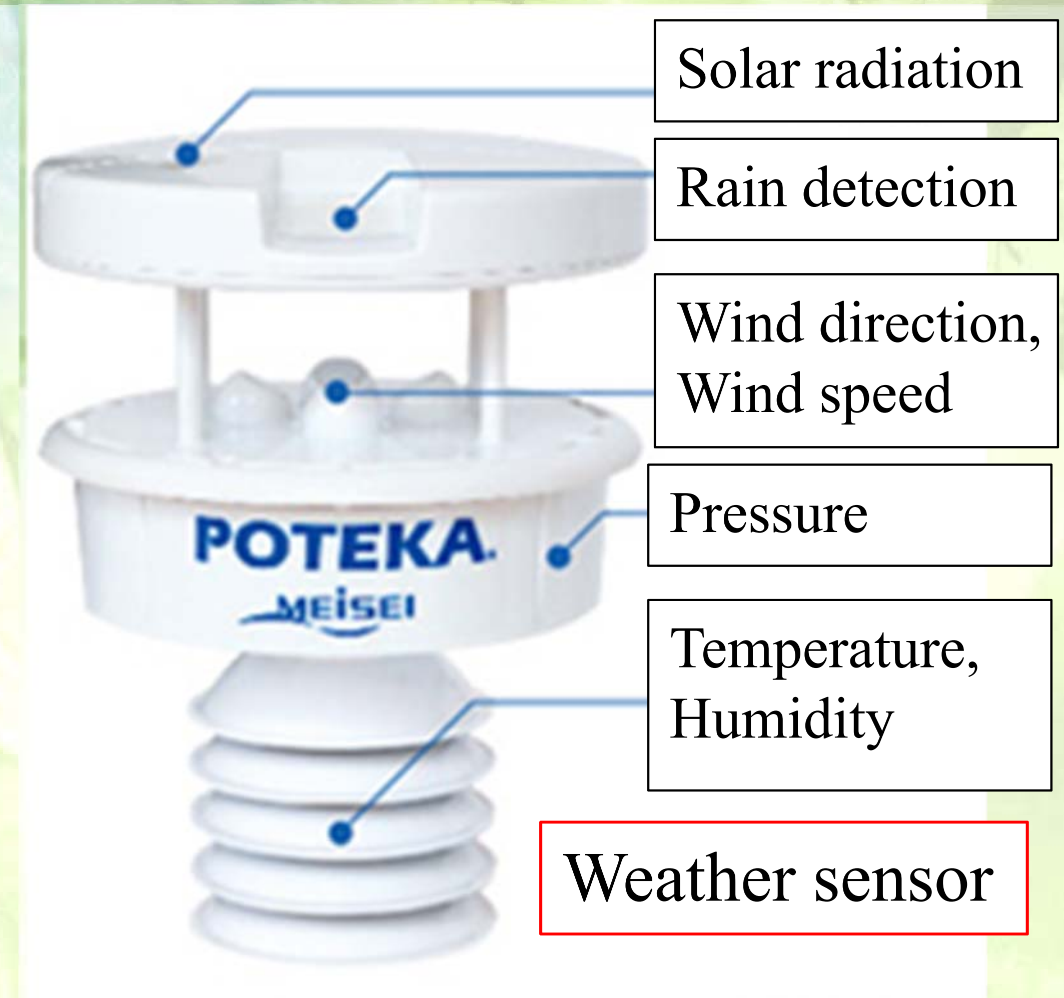


Antenna Installed on Building in the Main Land

Gunkan-jima (Battleship-island)

Acceleration Sensor System

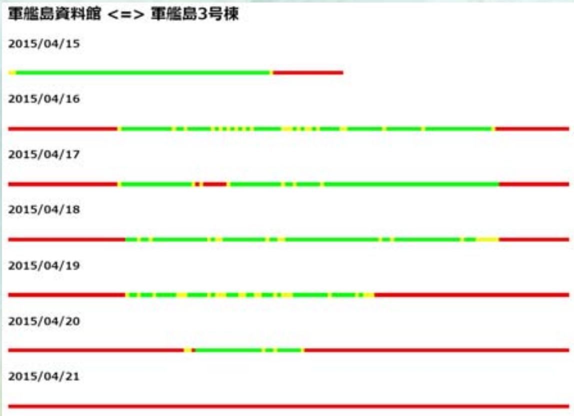
Weather Sensors

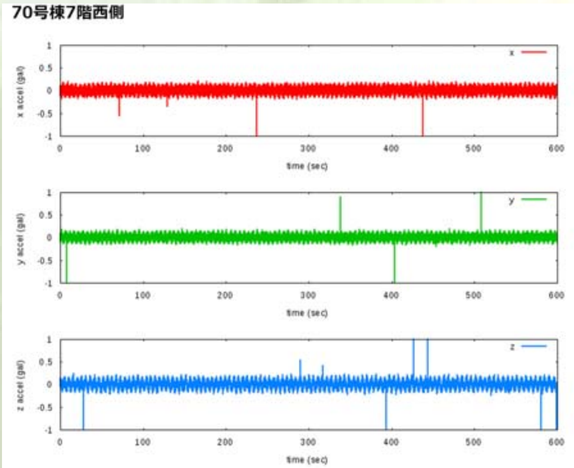


http://www.meisei.jp/poteka/

Digital Data Preservation by Sensor Information

Data Release for Various Applications





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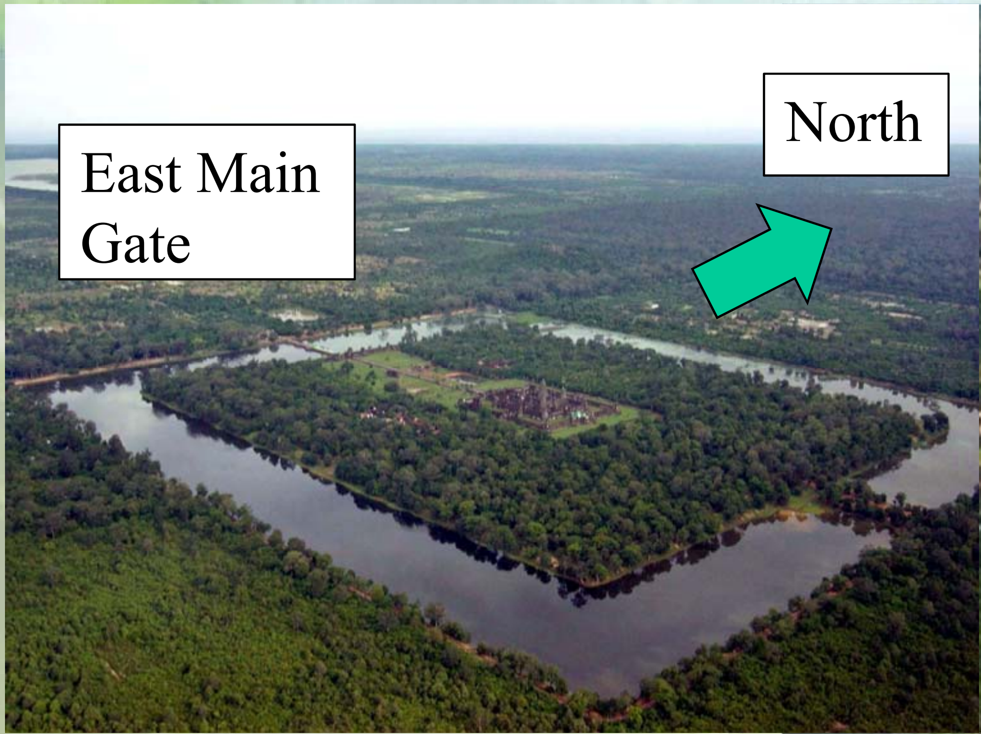
http://www.nippon.com/ja/features/h00144/

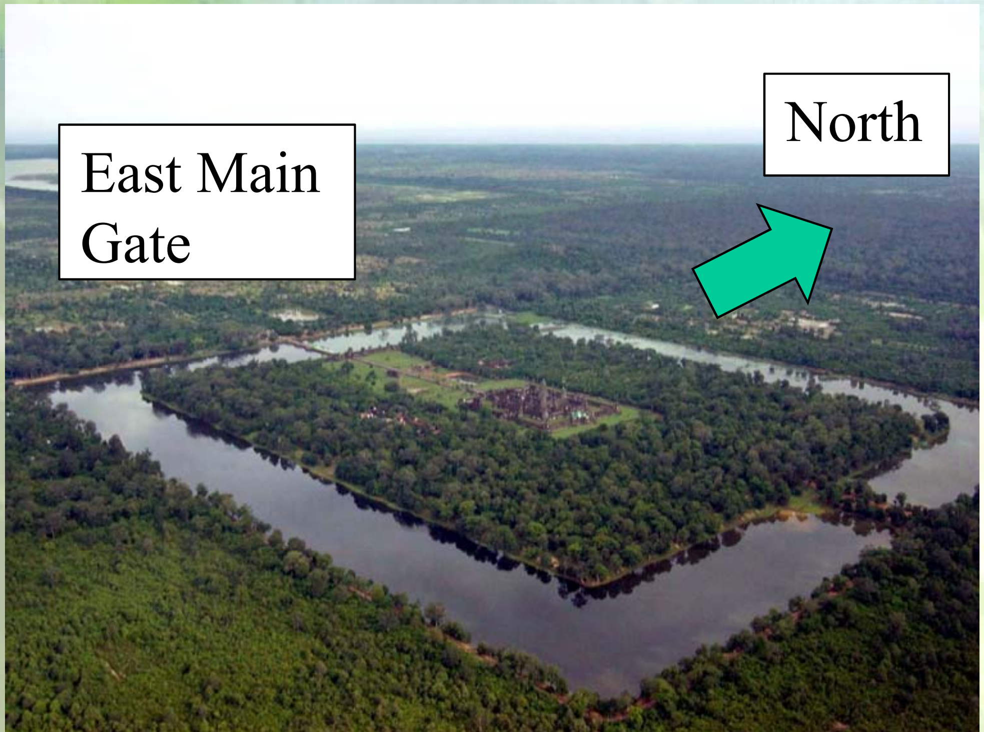
Monitoring of Angkor Wat site in Cambodia

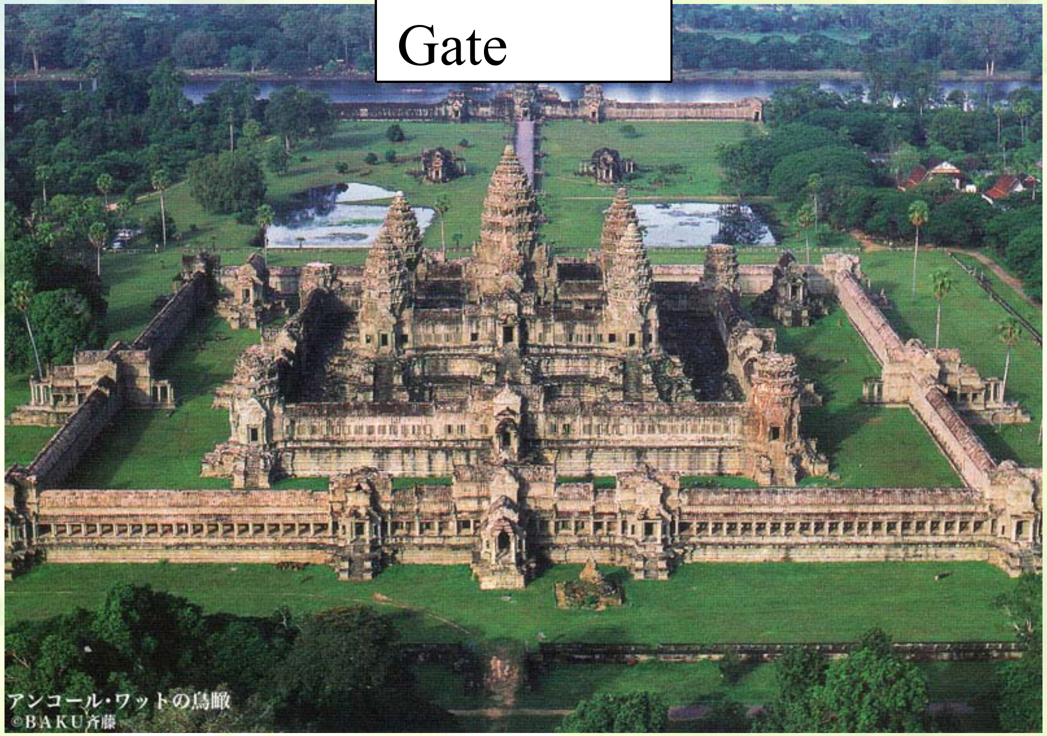
http://adcculture.com/silkroad/shiratori-10/

Angkor Wat

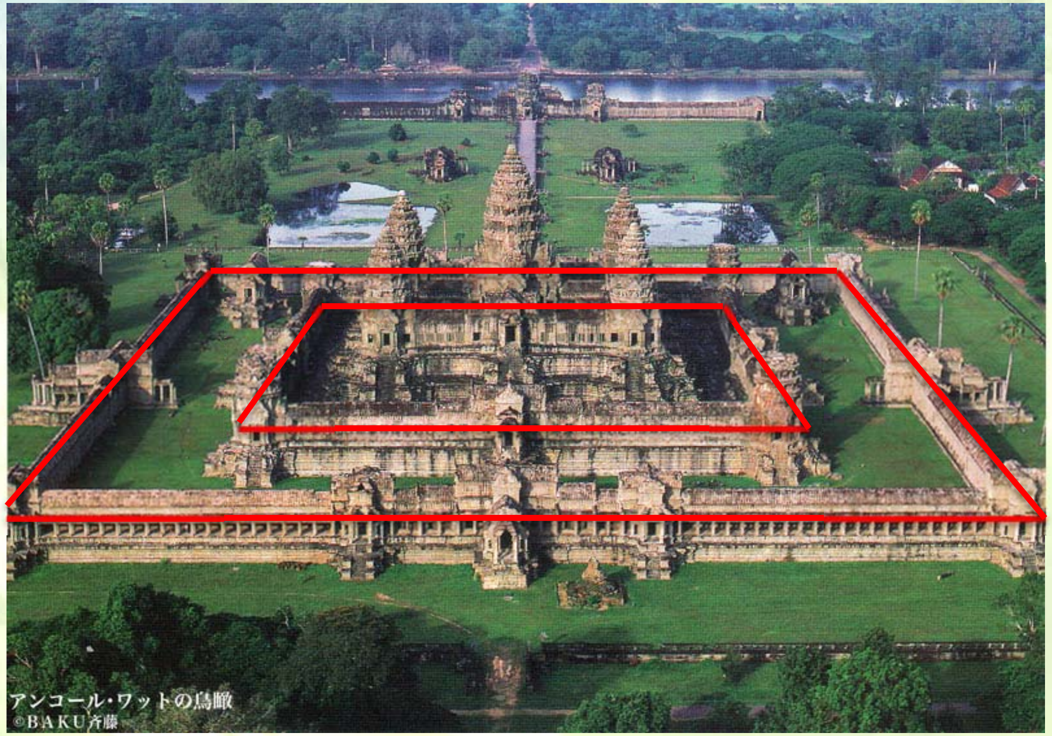


Angkor Wat

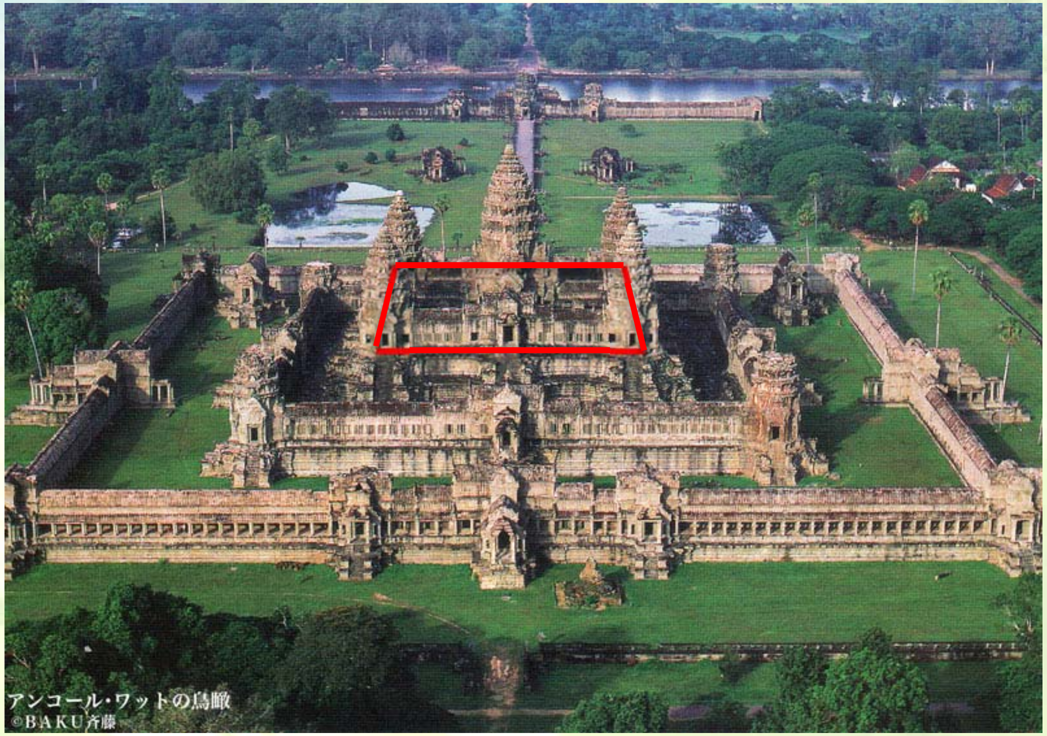




Angkor Wat



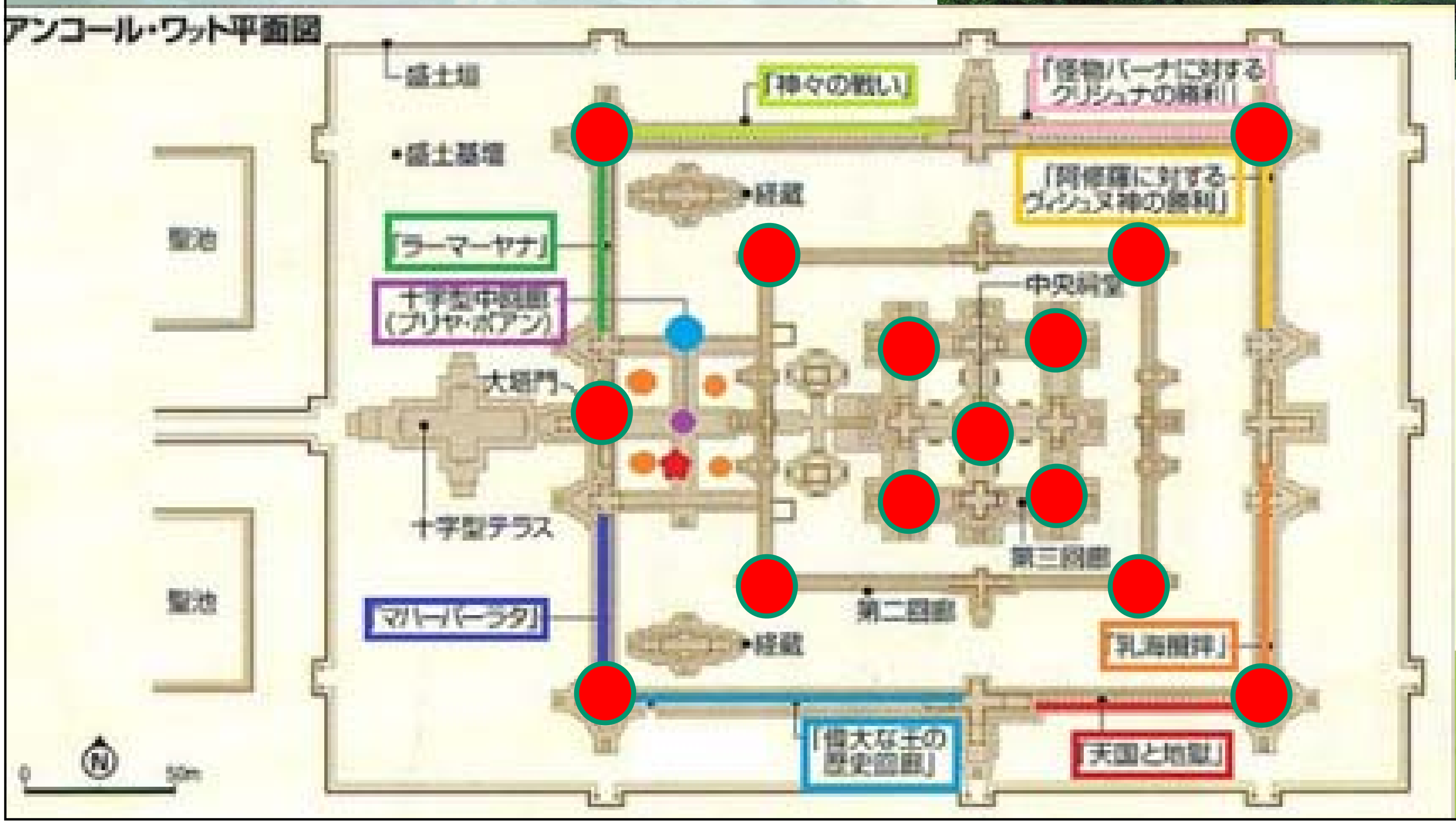
Angkor Wat



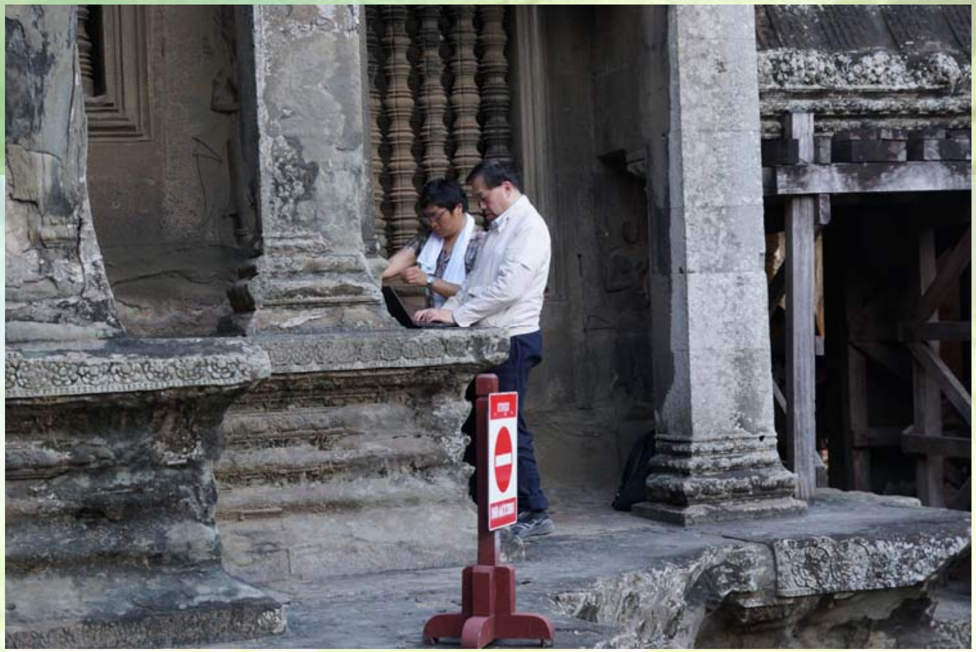
Acceleration Sensor for Vibration Measurement of Buildings and Structures

- High performance 3-axis acceleration sensor
- 24 bit A/D
- Built-in data logger
- Accurate Time Information by GPS

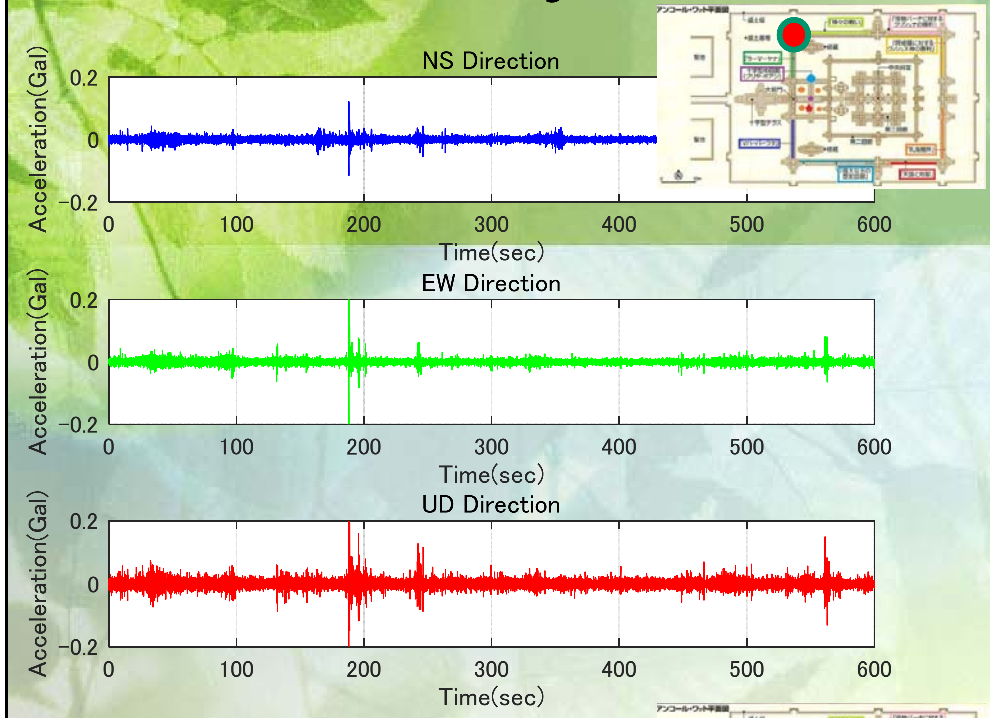
Plan of Angkor Wat and Measurement Points ●

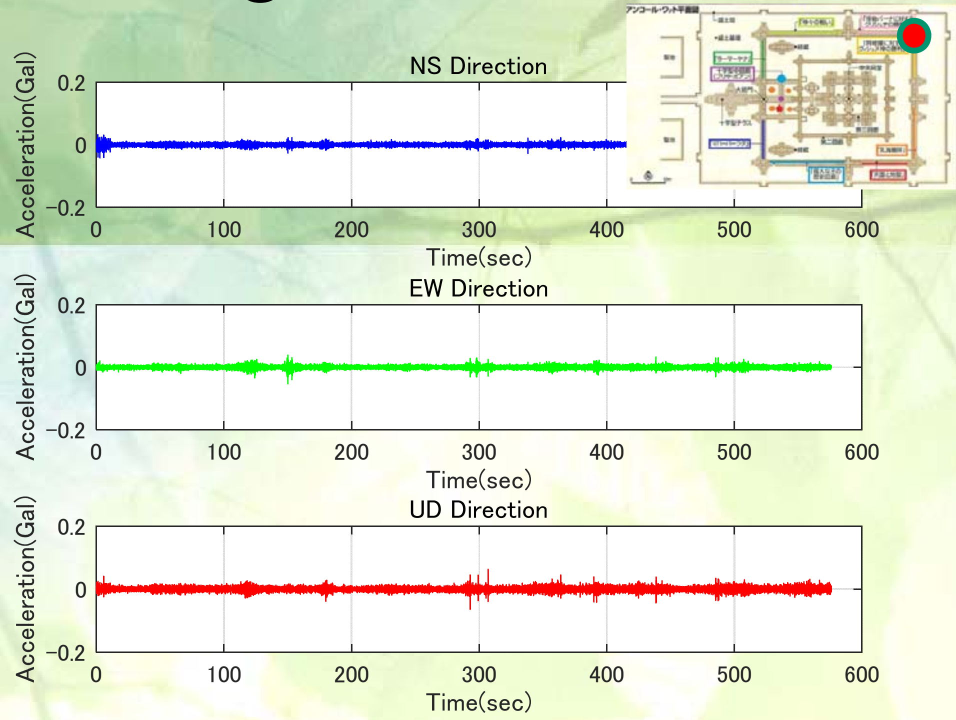


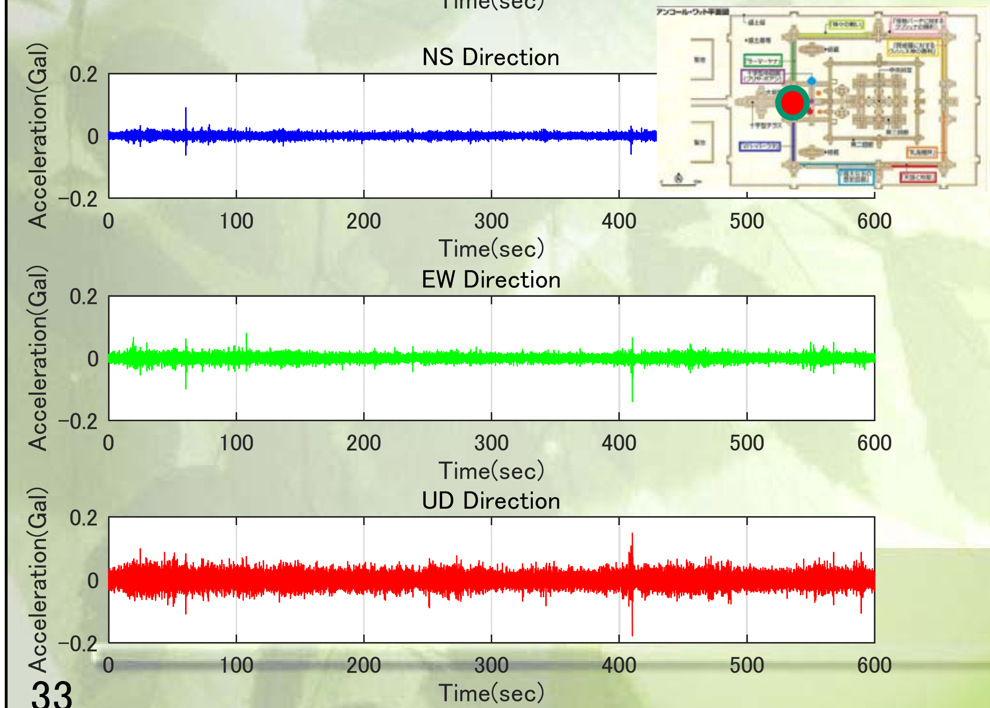
Measurement and Lecture in the 3rd Corridor



Vibration by Tourists Walking







Brue : North-South direction

Green : East-West direction

Red : Up-Down direction

Maintenance and Management of World Heritage Structures

- Accumulate and analyze data by monitoring

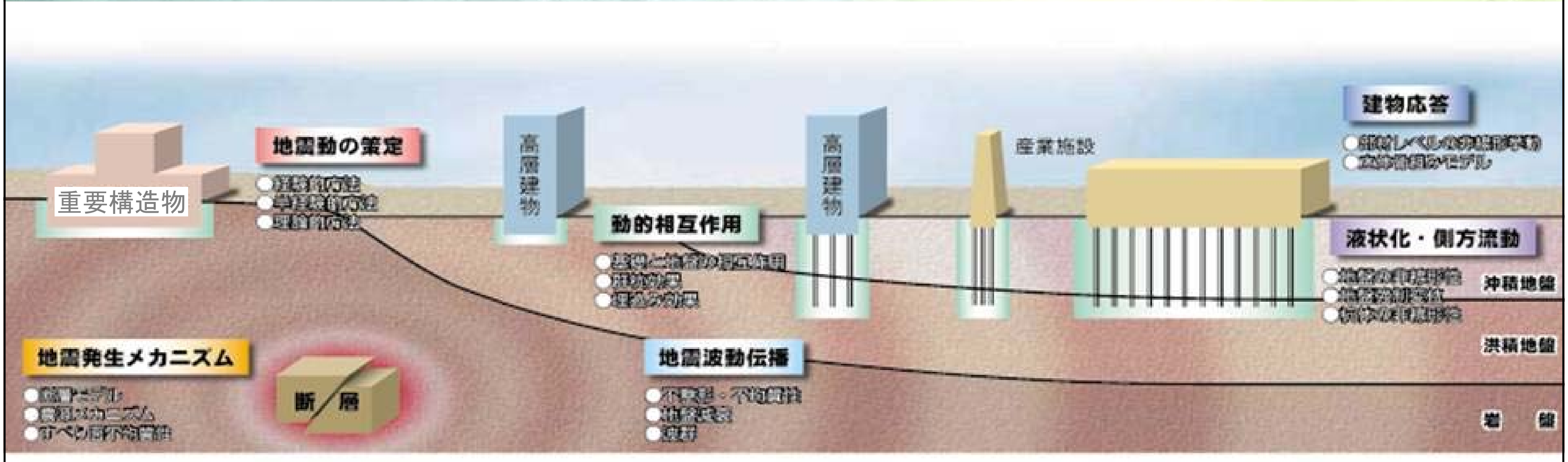
Desirable Sensor Technology for Gunkan-jima Site

- Aged deterioration of the building structure is progressing
- Autonomous energy supply system and sensor network system with low power consumption

Desirable Sensor Technology for Angkor Wat Site

- Typical sightseeing spot
- Wireless IoT sensor device with battery, and MEMS sensor with low power consumption and high accuracy

Cyber Physical Systems for Earthquake Hazard Mitigation



Japanese Earthquake and Tsunami

- the Great Hanshin-Awaji Earthquake in 1995
- the Great East Japan Earthquake in 2011

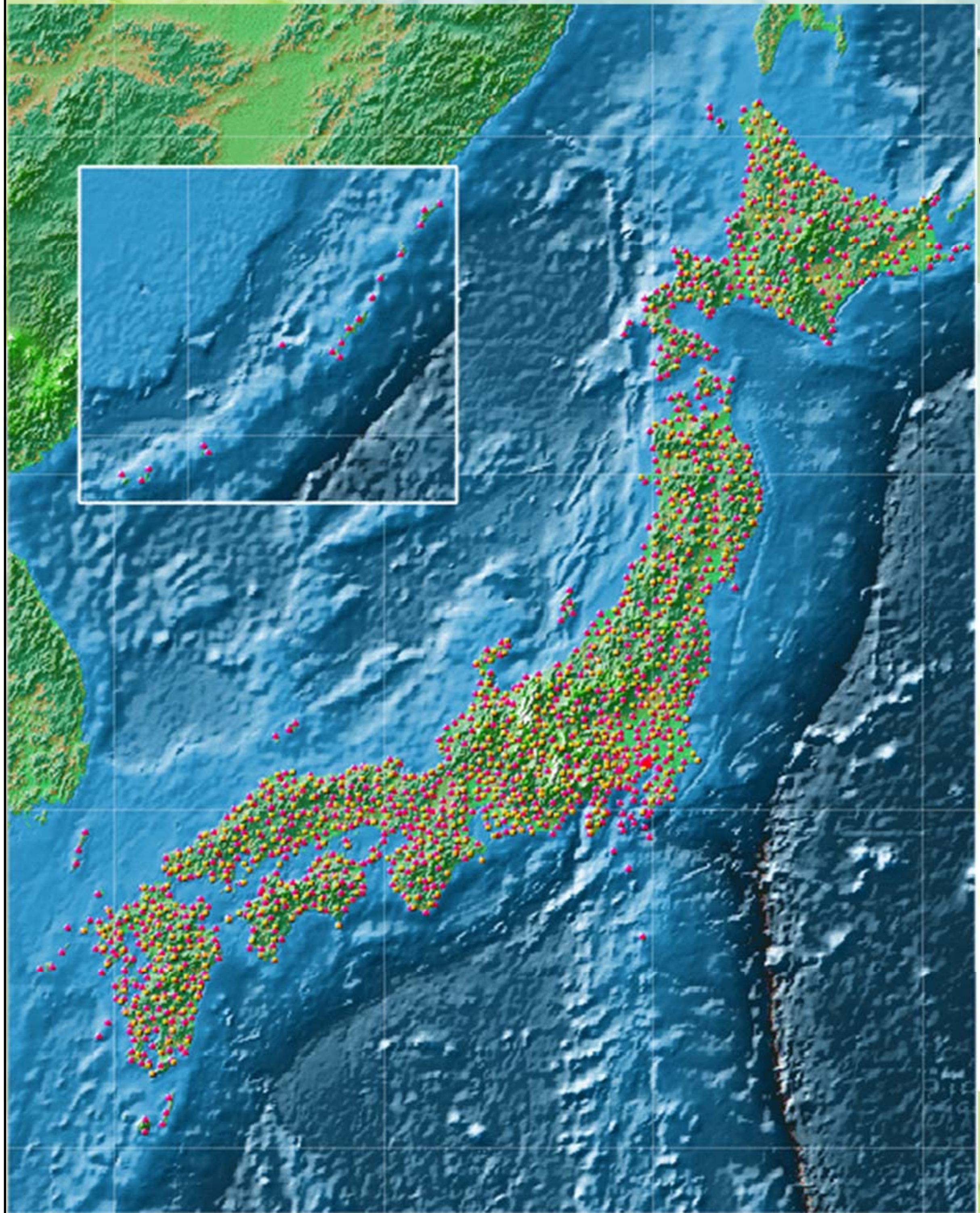
Great Hanshin-Awaji Earthquake (Kobe Earthquake) , 1995.1.17

- 6,434 people were killed

Japanese Earthquake and Tsunami

- the Great Hanshin-Awaji Earthquake in 1995
- the Great East Japan Earthquake in 2011

The Great East Japan Earthquake Tsunami Disaster



Japanese Earthquake Observation

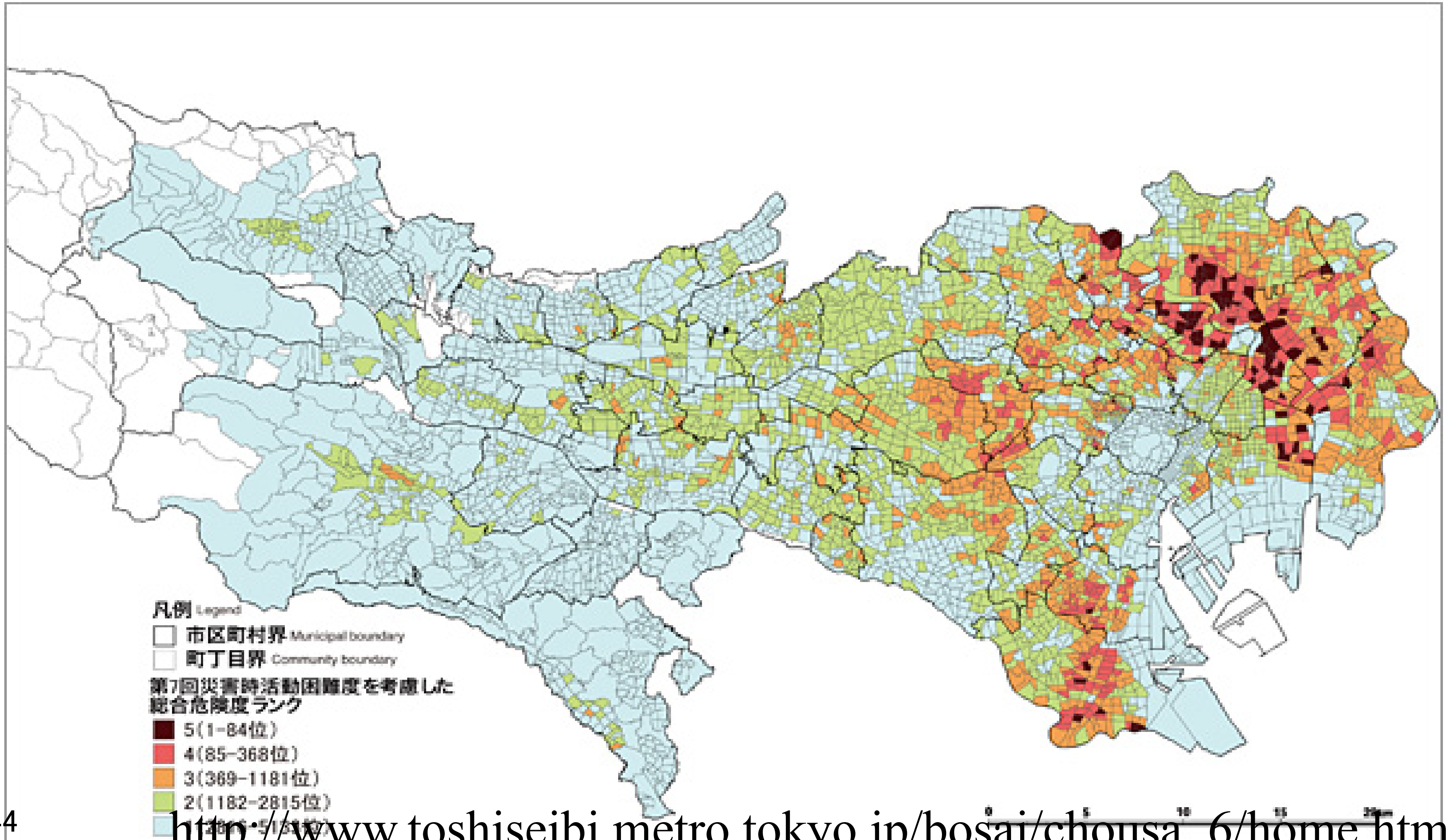
- Earthquake data is obtained from 1,742 observatories deployed all over Japan
- The average station to station distance is about 25km
- However, it is not enough for installation for all cities

http://www.bosai.go.jp/

Report of Regional Hazard Measurement of Each Town in Tokyo

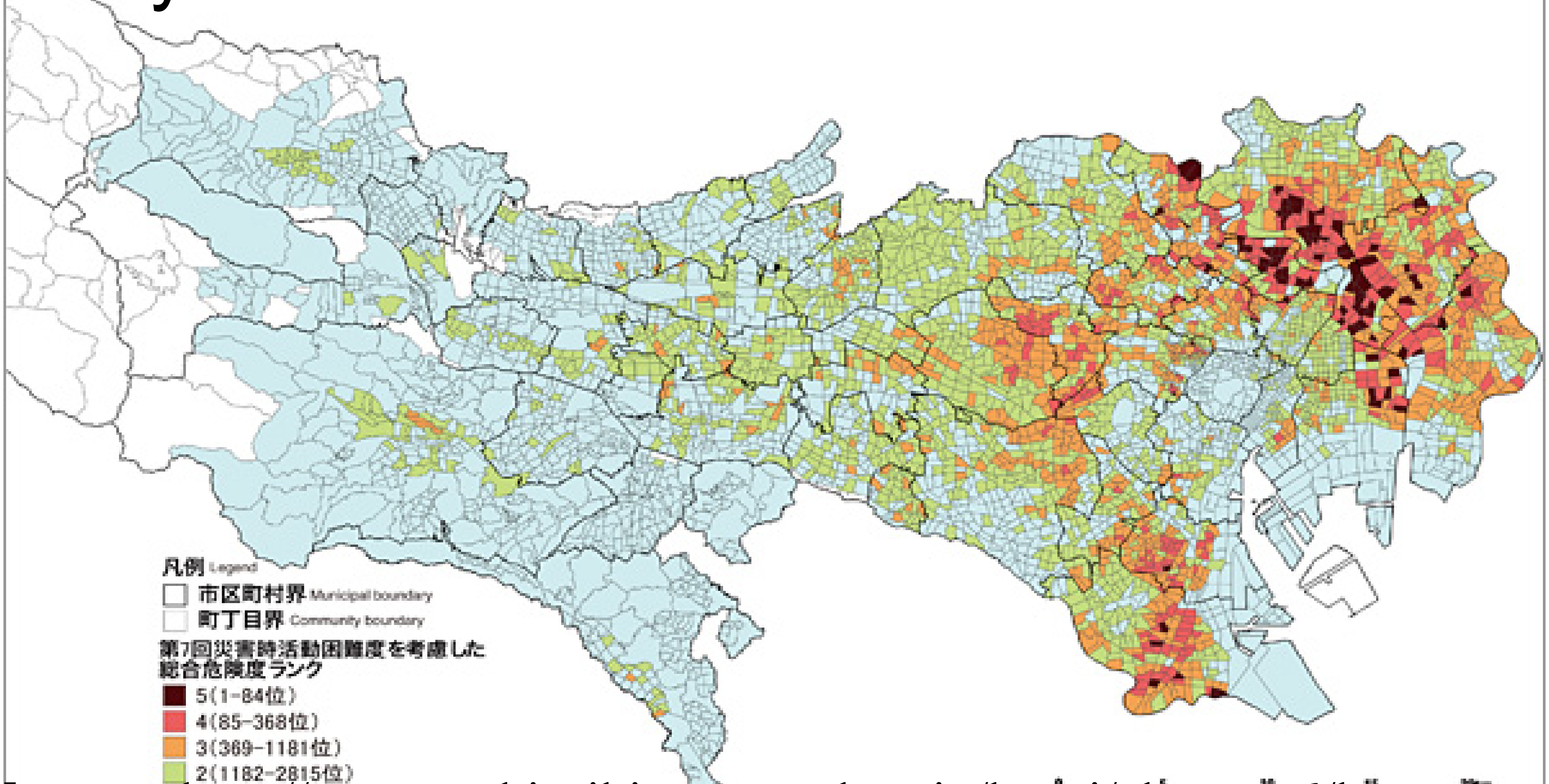
http://www.toshiseibi.metro.tokyo.jp/bosai/chousa_6/home.htm

Total Risk Ranking of Each Town in Tokyo



http://www.toshiseibi.metro.tokyo.jp/bosai/chousa_6/home.htm

Real-time risk monitoring of each town in Tokyo is desirable



http://www.toshiseibi.metro.tokyo.jp/bosai/chousa_6/home.htm

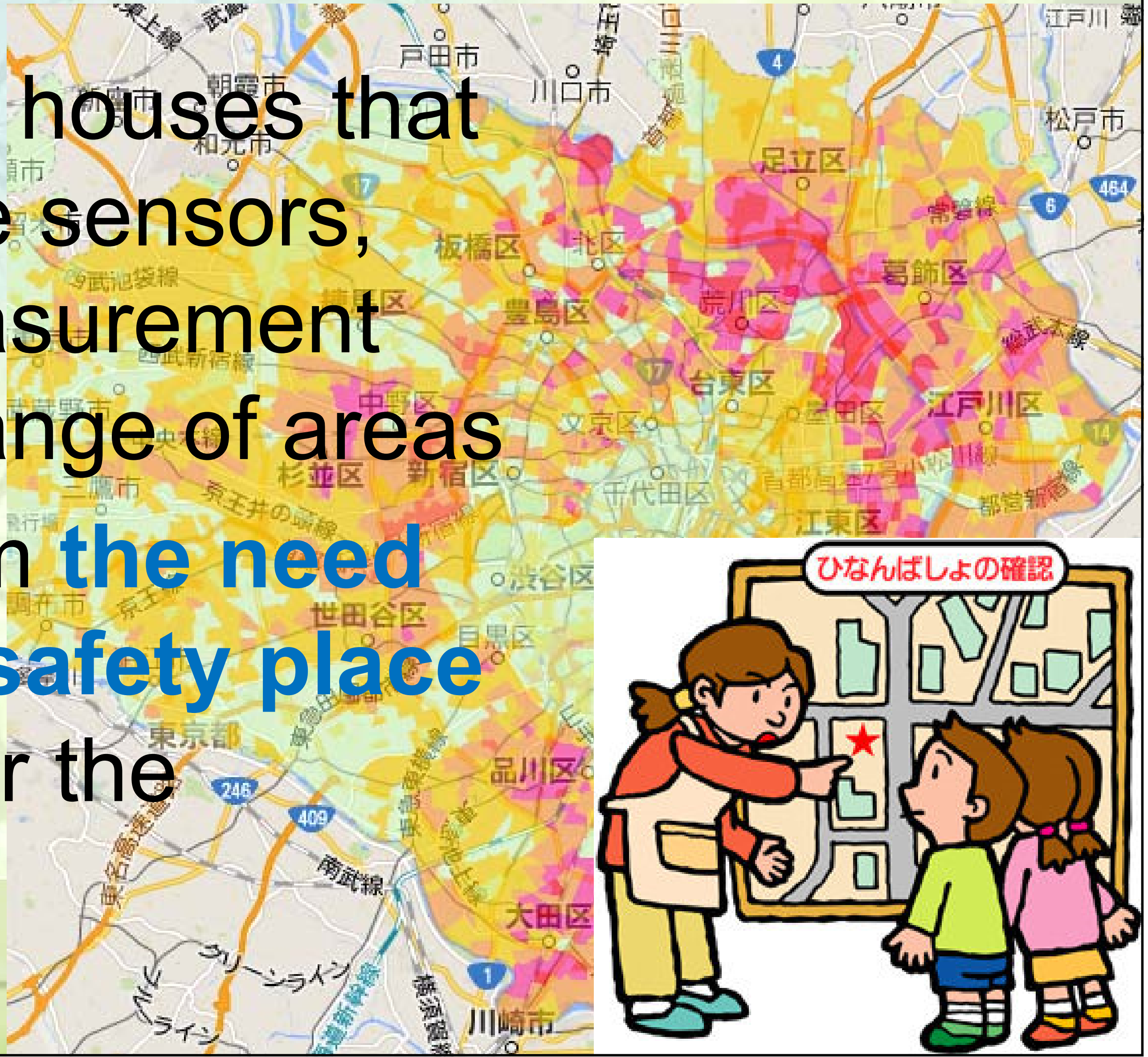
Benefits of installing earthquake sensors to all the houses

- Situation just after the earthquake can be grasped in a single house by the local government

- The data can be used in decision-making of crisis management

Benefits of installing earthquake sensors to all the houses

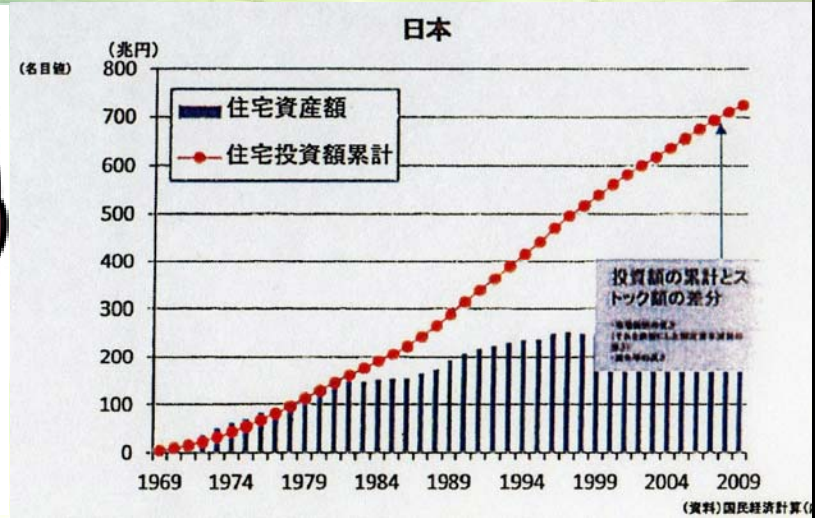
- Residents of the houses that have earthquake sensors, can see the measurement data of a wide range of areas
- They can confirm **the need for refuge and safety place** immediately after the earthquake



Benefits of installing earthquake sensors to all the houses

- From sensors installed on the ground (first) floor, liquefaction of the ground can be detected
- The data has a significant effect on the real estate price

Benefits of installing earthquake sensors to all the houses and buildings



- From sensors installed on the roof, earthquake data over a lifetime of house can be stored
- This data affects the price of used houses

Benefits of installing earthquake sensors to all the houses and buildings

- We can also take advantage to traffic vibration pollution caused by large trucks to pass through the road in front of the house
- This is also a serious problem to be solved

Earthquake Sensors in all Wi-Fi Hotspot in Japan

- For wide-spread deployment of sensors , collaboration with the nation-wide chain stores that offers a Wi-Fi hotspot is effective
- Just placing a sensor that can be connected to Wi-Fi, it is possible to collect earthquake data easily

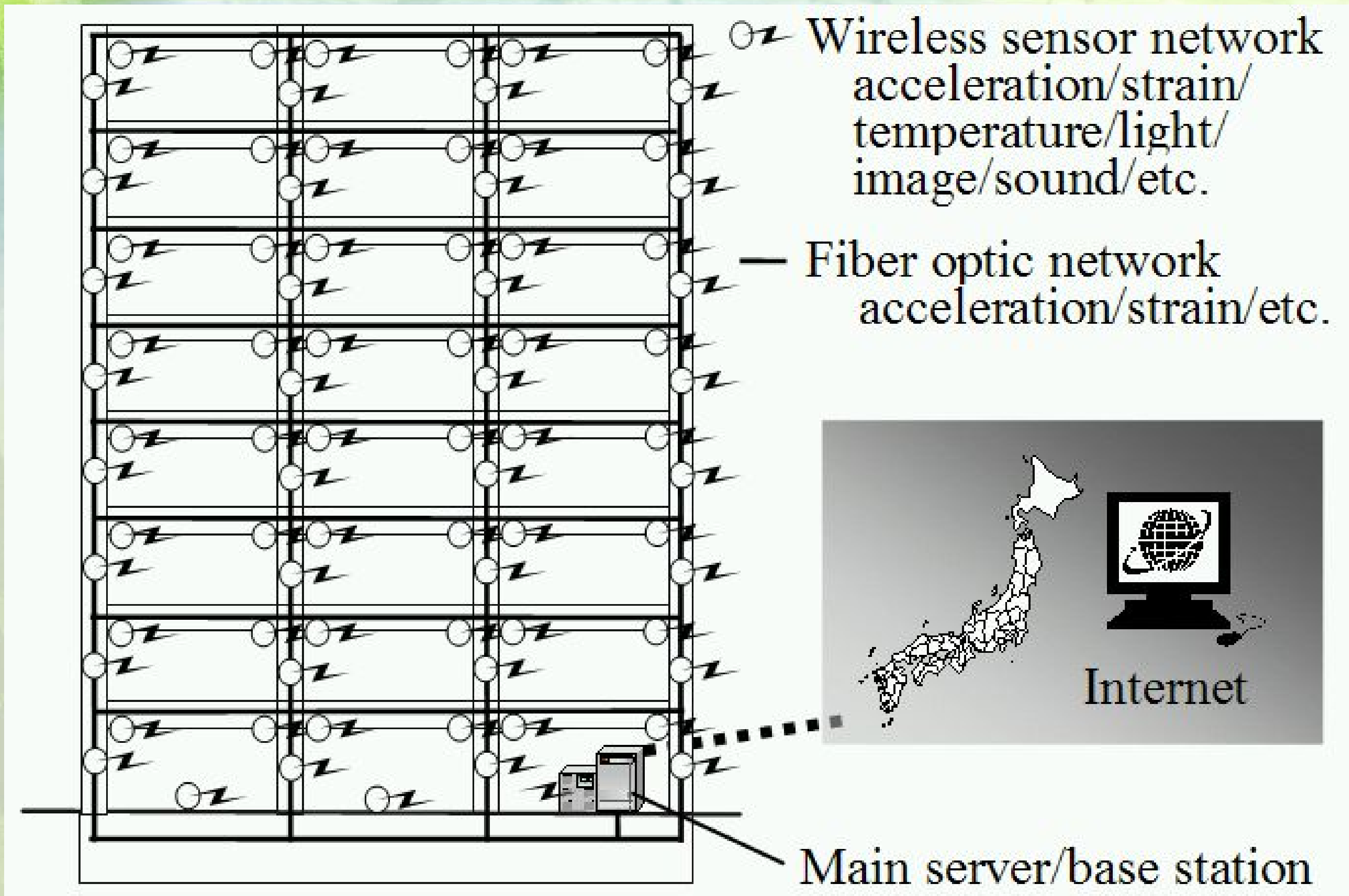
Number of Nation-Wide Chain Stores

Store Name	Number of Stores	Reference Timeframe
Seven Eleven	17,569	2017
Lawson	12,276	2017
Familymart	11,399	2017
Circle K Sunkus	6,330	2017
McDonalds	3,065	2014
Mini Stop	2,162	2017
Doutor Coffee	1,025	2017
Starbacks	1,096	2014

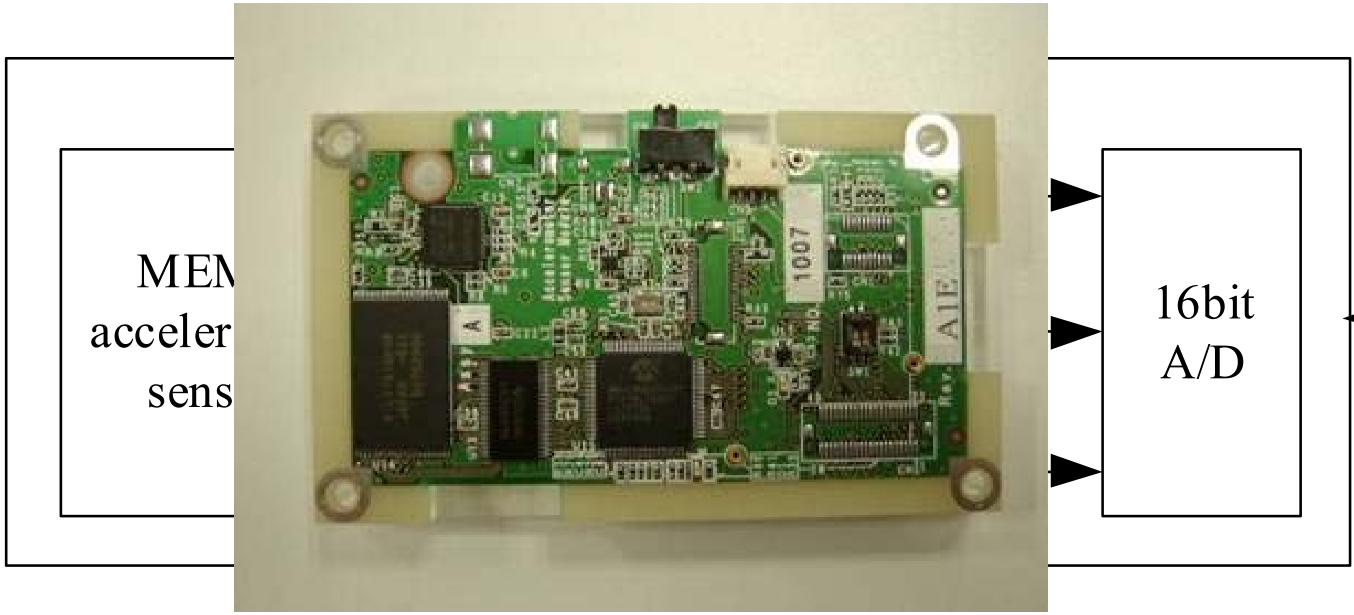
The need for accurate time information

- Accurate time information as well as location information are necessary to develop the Disaster Big Data Infrastructure and analyze the data
- Time synchronization between the sensors in a wide area is not easy
  - GPS cannot be used in the houses and buildings
  - The wire and wireless communication is limited

Sensor Networks in the Future Smart Building



Development of Wireless Sensor Network Module for Ubiquitous Structural Monitoring

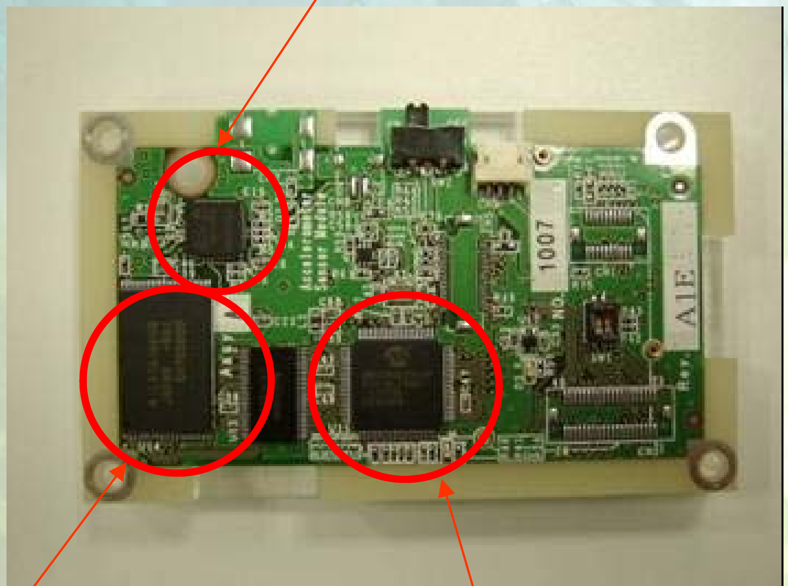


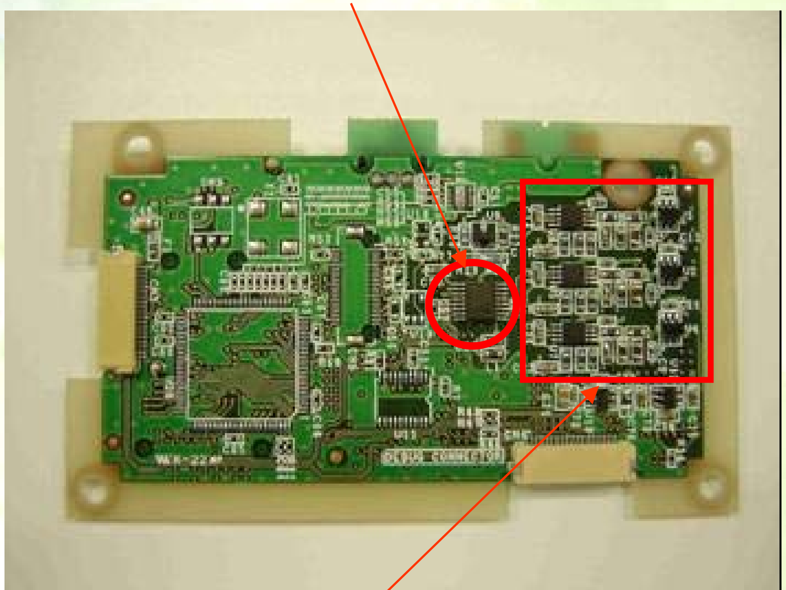
Acceleration Sensor Board

Wireless Network Module

Kurata N, Suzuki M, Saruwatari S, Morikawa H. Application of Ubiquitous Structural Monitoring System by Wireless Sensor Networks to Actual High-rise Building. Proc. of 5th World Conference on Structural Control and Monitoring. 2010

Development of Sensor Board





MEMS acceleration sensor

SRAM (2MB)

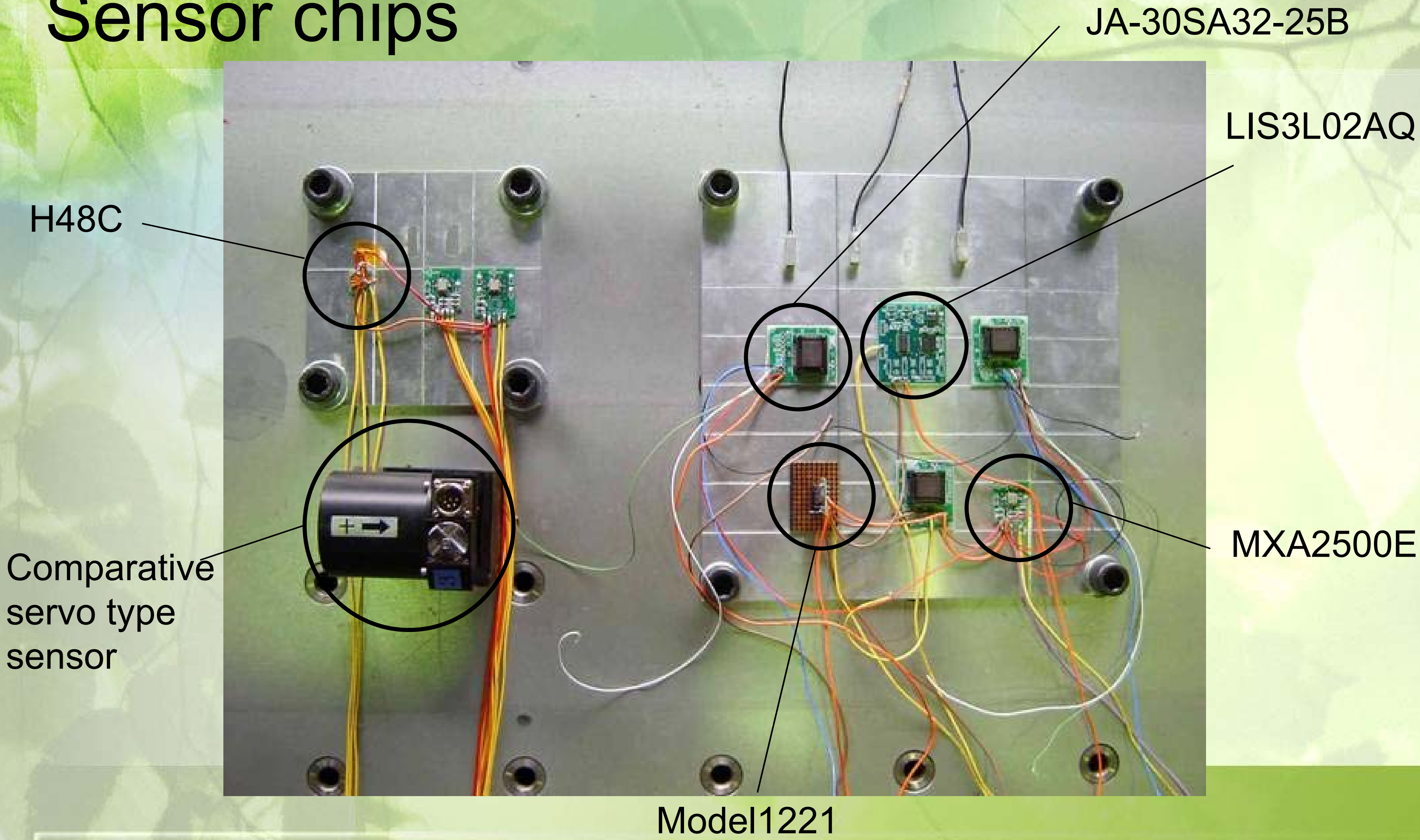
CPU

16 bit A/D converter

Anti areasing filter

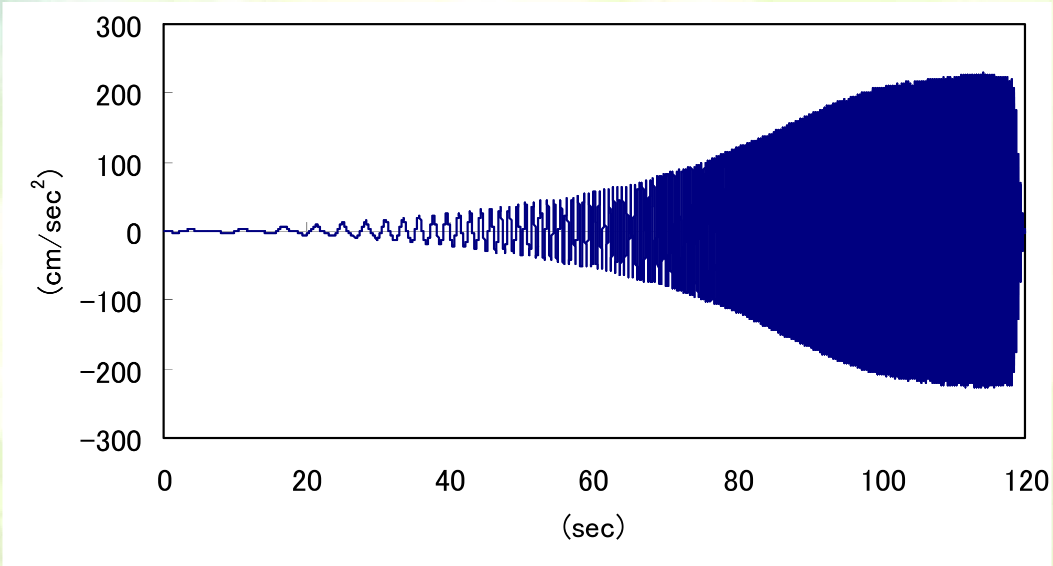
Kurata N, Suzuki M, Saruwatari S, Morikawa H. Application of Ubiquitous Structural Monitoring System by Wireless Sensor Networks to Actual High-rise Building. Proc. of 5th World Conference on Structural Control and Monitoring. 2010

Benchmark Test for MEMS Acceleration Sensor chips



Kurata N, Saruwatari S, Morikawa H. Ubiquitous Structural Monitoring using Wireless Sensor Networks. Proc. of 2006 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS2006). 2006

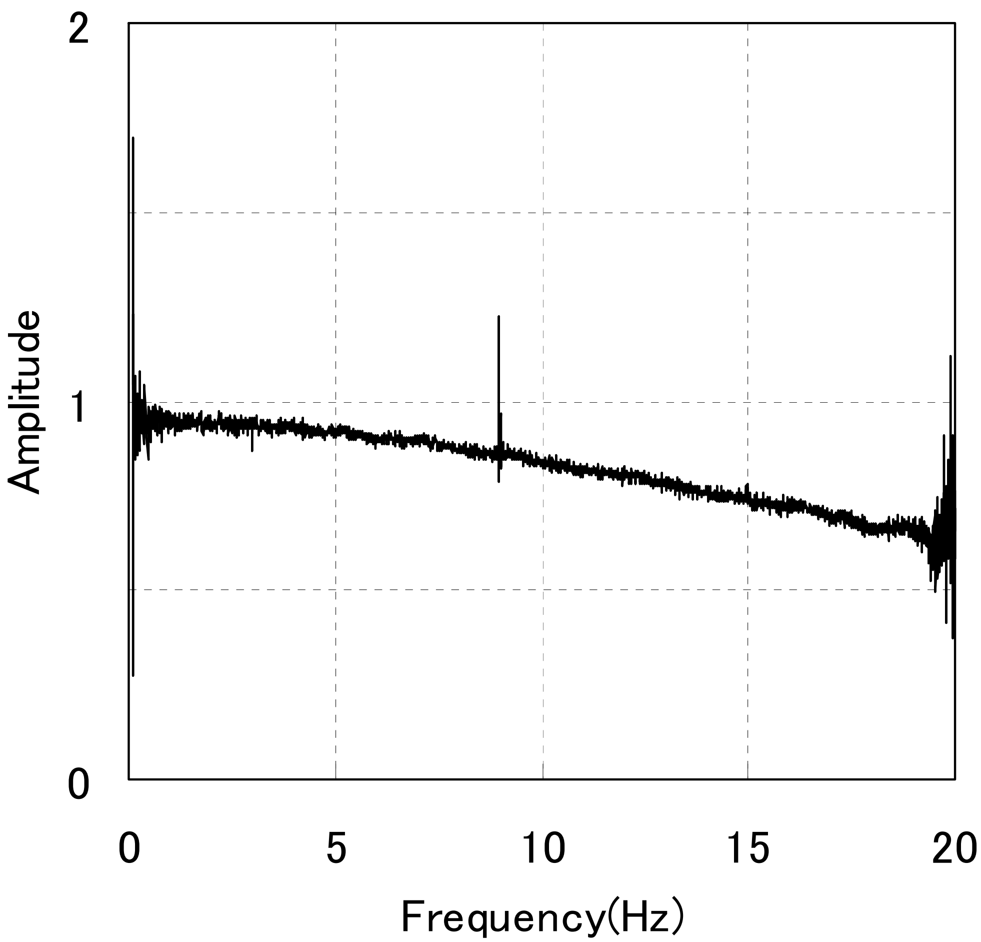
Input wave: Swept sine wave with 0.2 to 20Hz

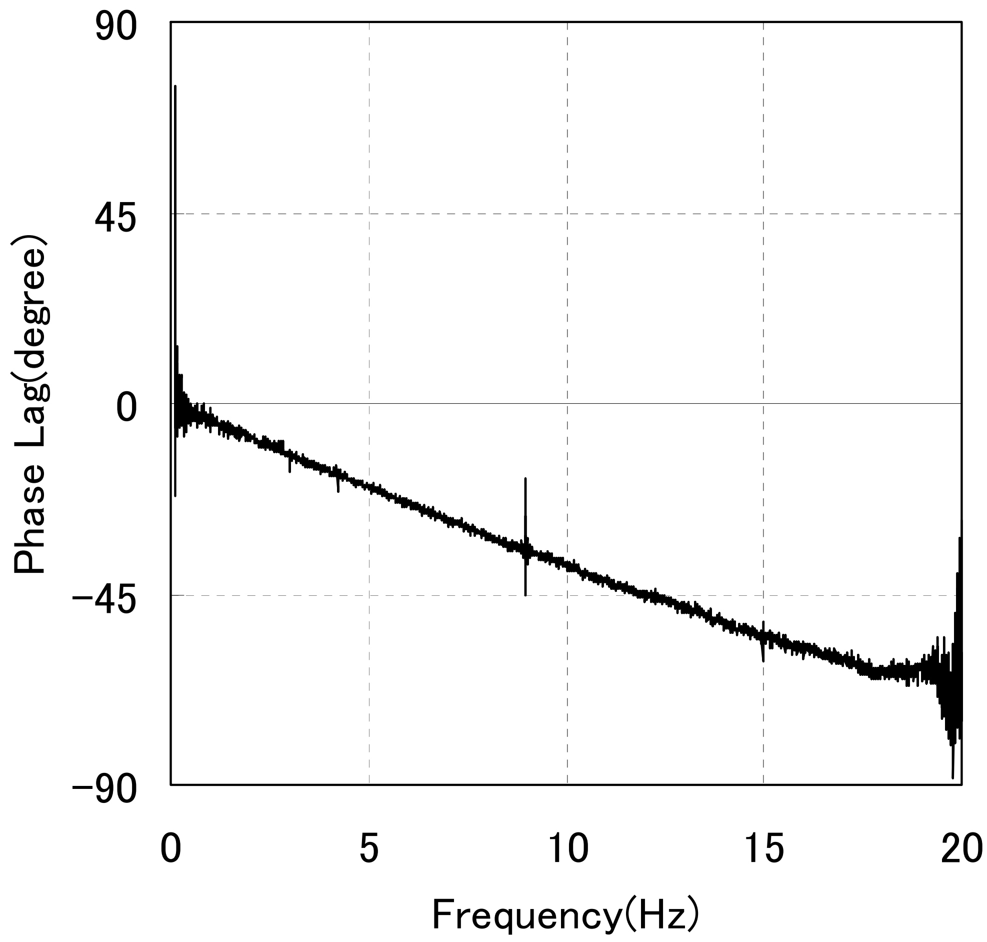


The sampling frequency was 100 Hz and 16 bit A/D converter was used in the test

Kurata N, Saruwatari S, Morikawa H. Ubiquitous Structural Monitoring using Wireless Sensor Networks. Proc. of 2006 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS2006). 2006

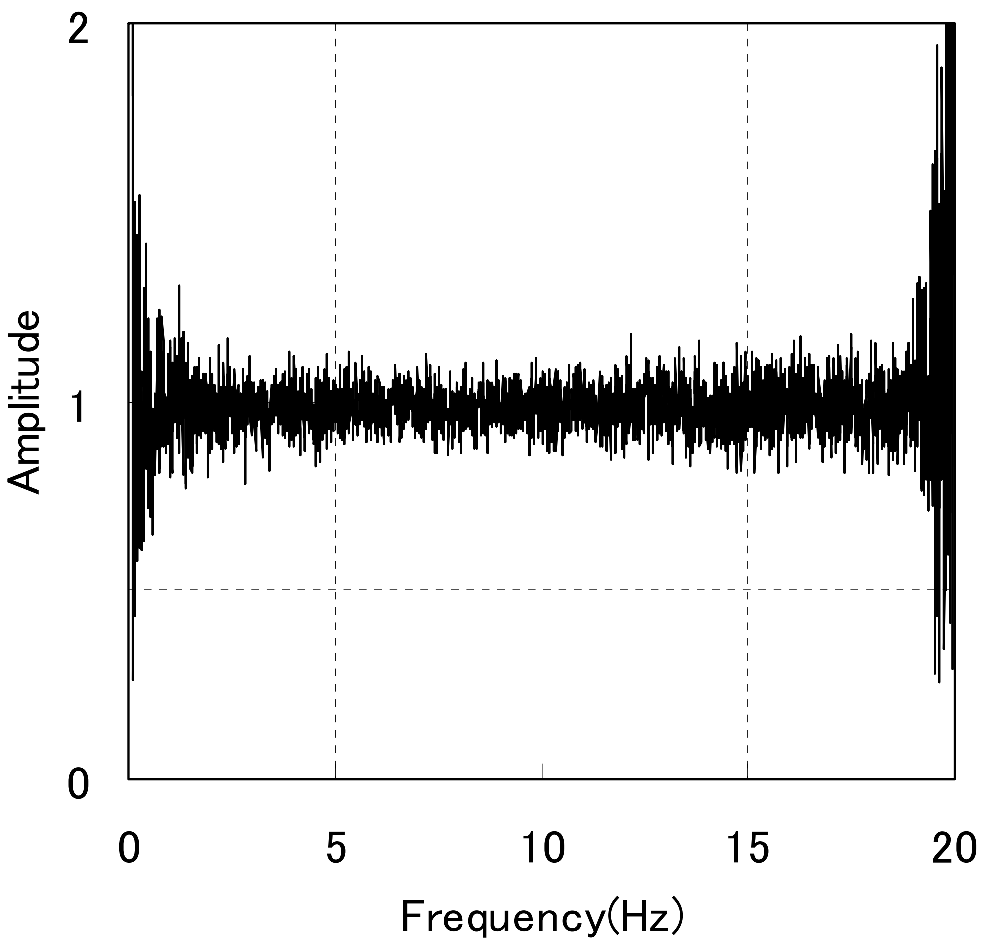
Swept Sine Wave Input MXA2500E

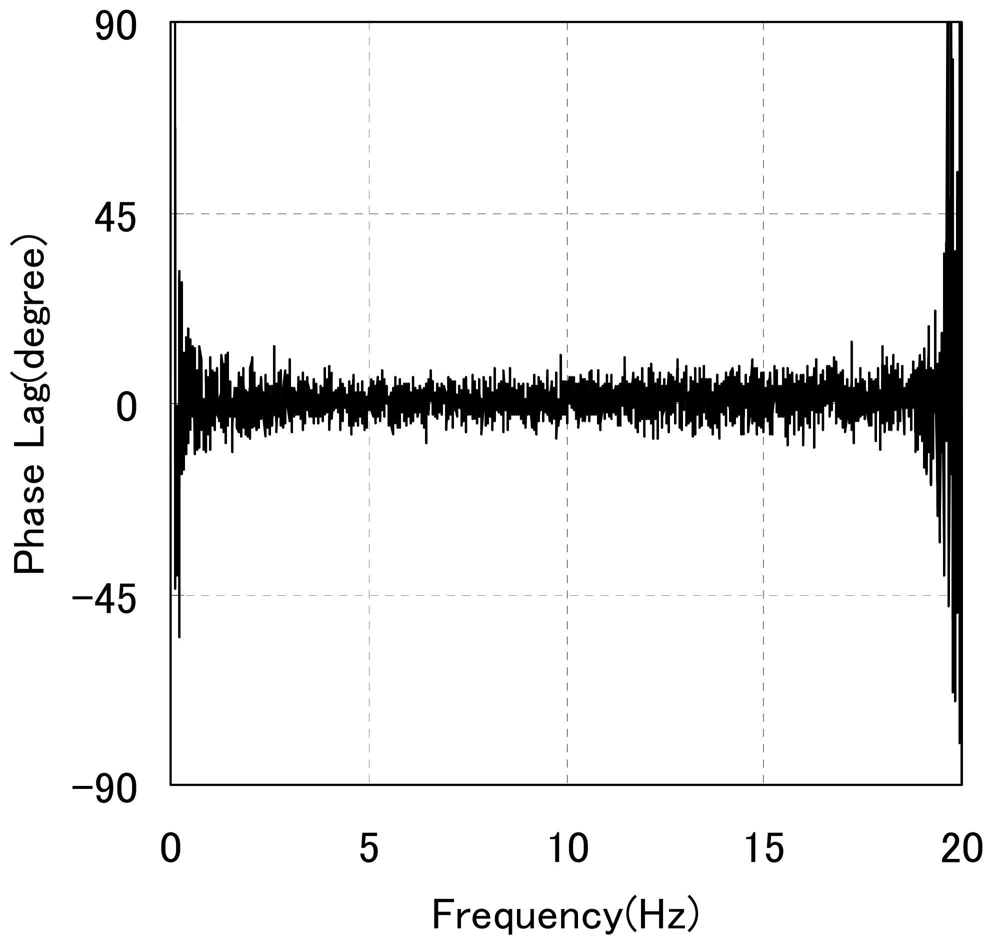




Kurata N, Saruwatari S, Morikawa H. Ubiquitous Structural Monitoring using Wireless Sensor Networks. Proc. of 2006 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS2006). 2006

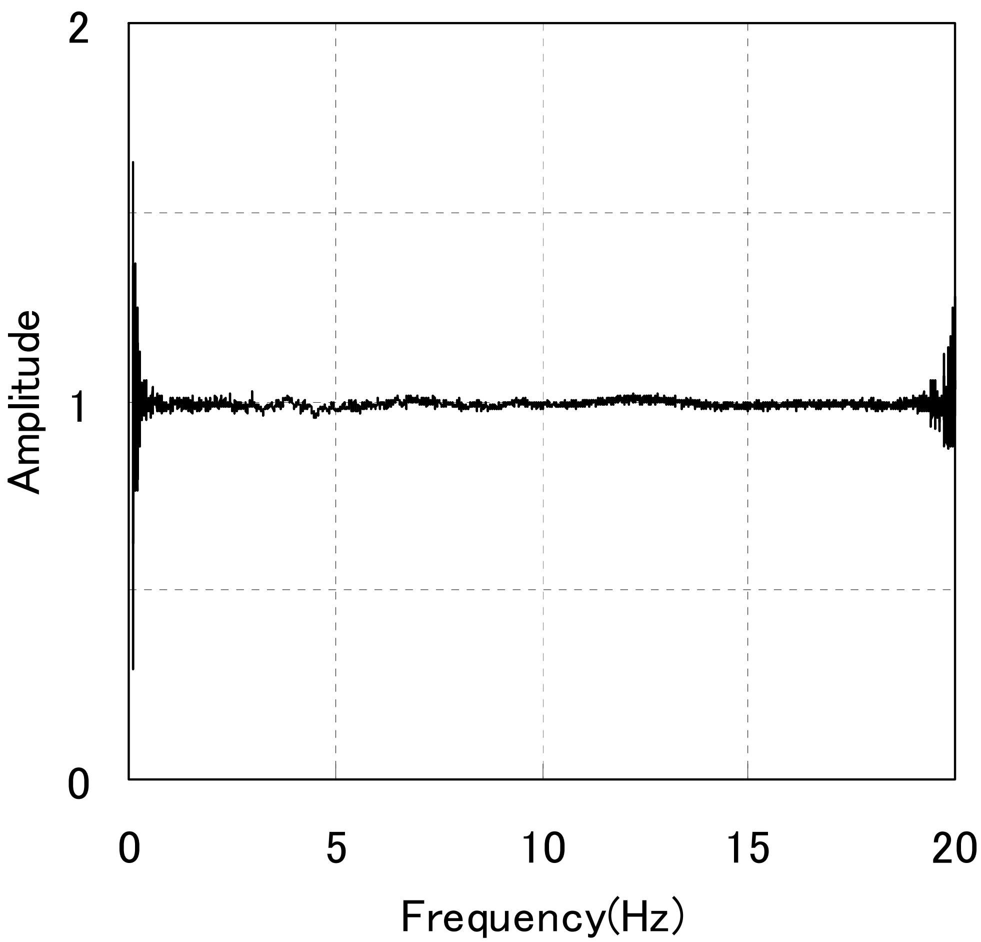
Swept Sine Wave Input
H48C

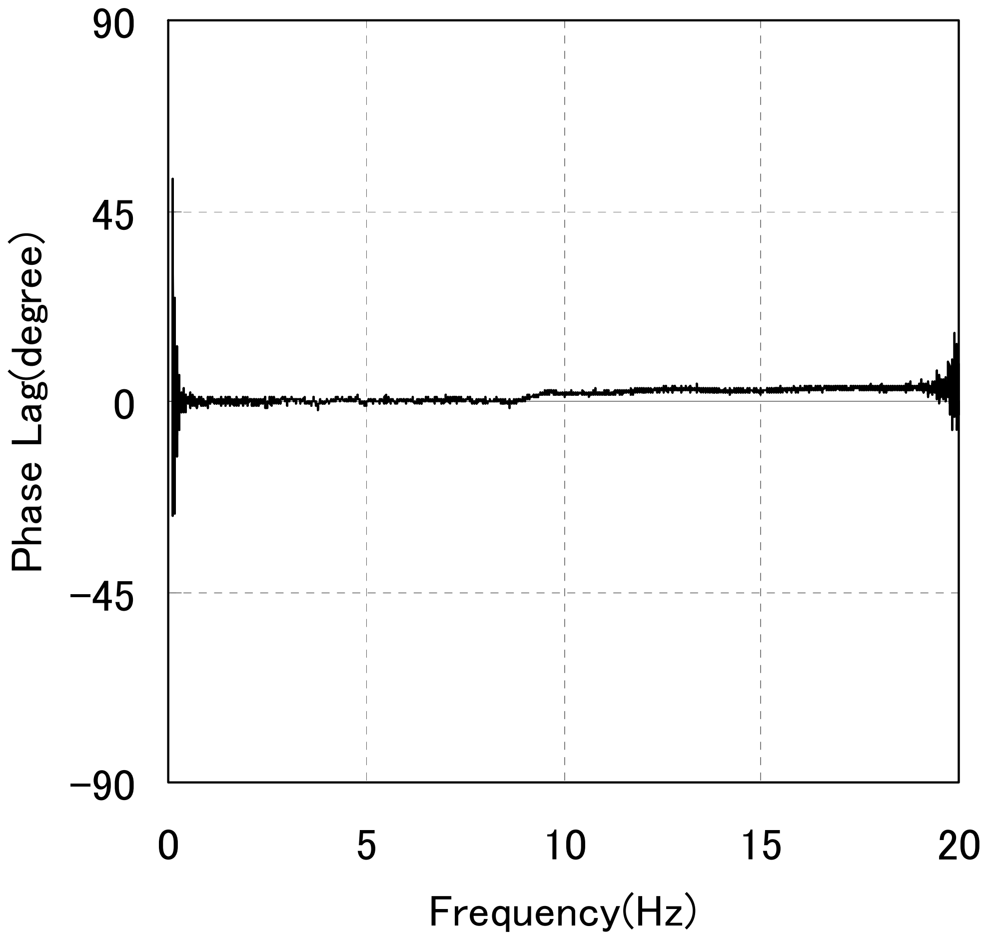




Kurata N, Saruwatari S, Morikawa H. Ubiquitous Structural Monitoring using Wireless Sensor Networks. Proc. of 2006 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS2006). 2006

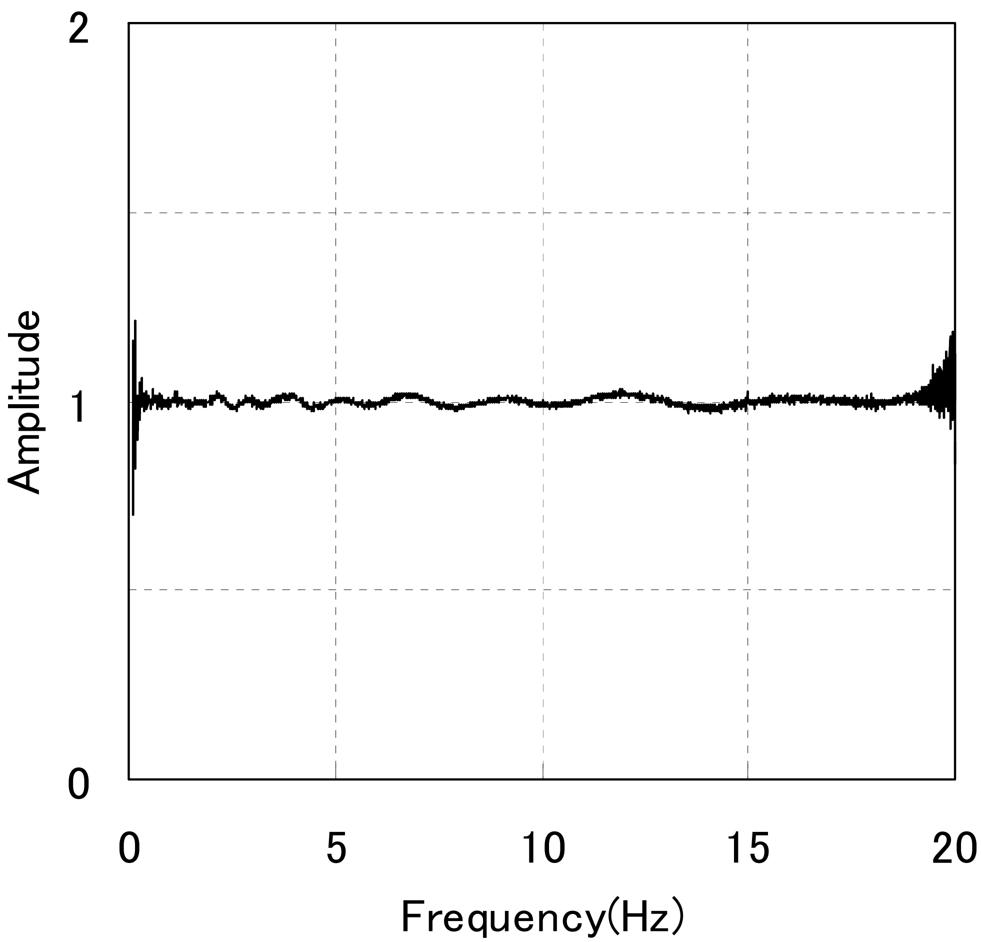
Swept Sine Wave Input Model1221

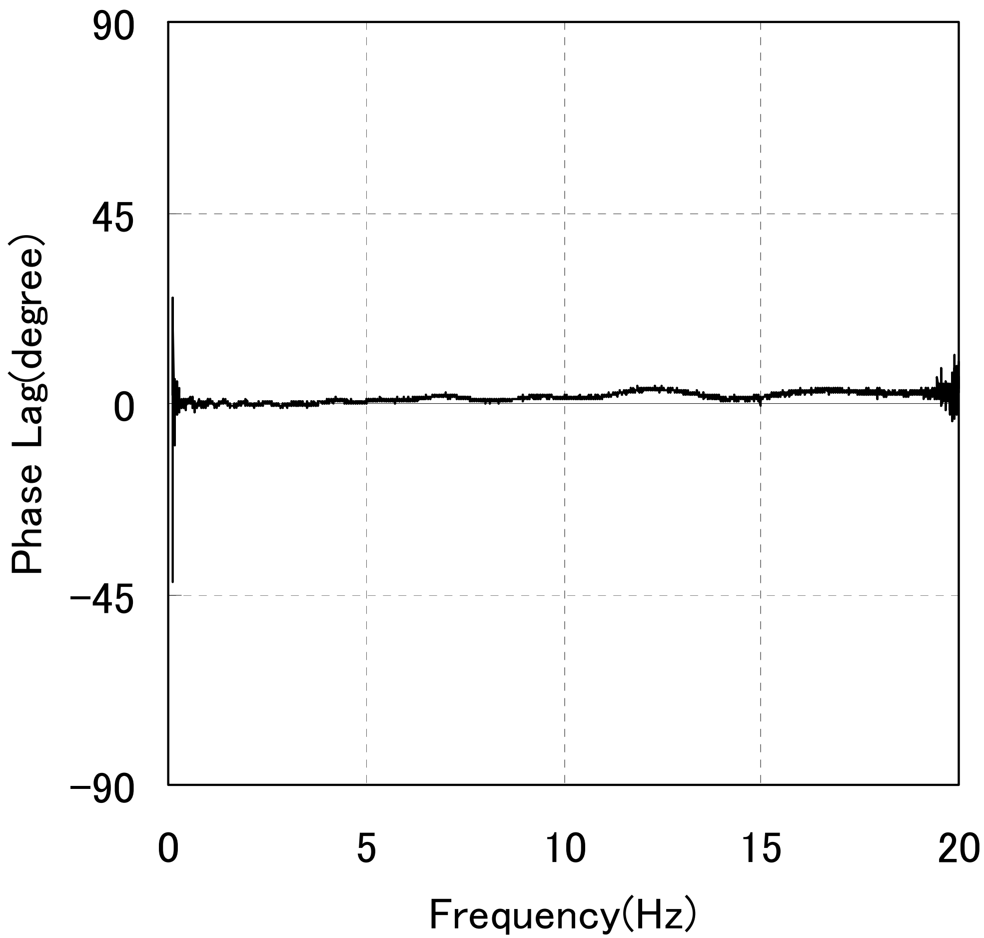




Kurata N, Saruwatari S, Morikawa H. Ubiquitous Structural Monitoring using Wireless Sensor Networks. Proc. of 2006 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS2006). 2006

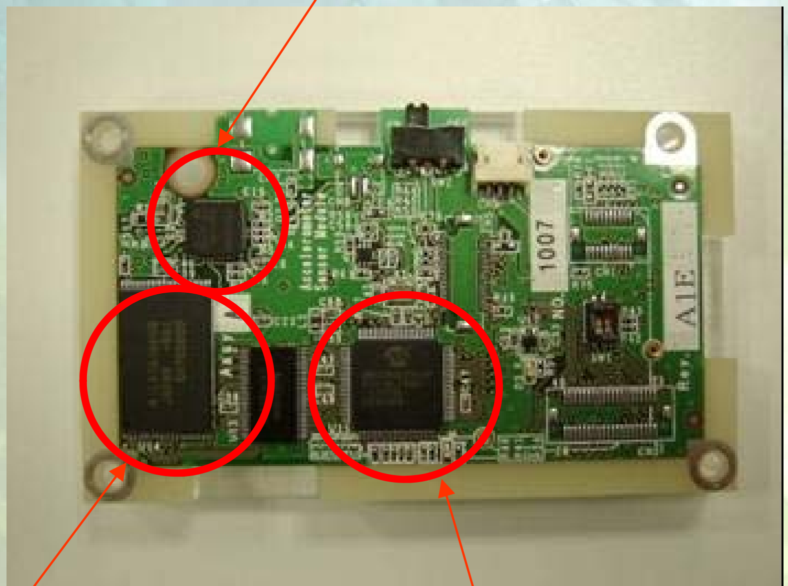
Swept Sine Wave Input
LIS3L02AQ

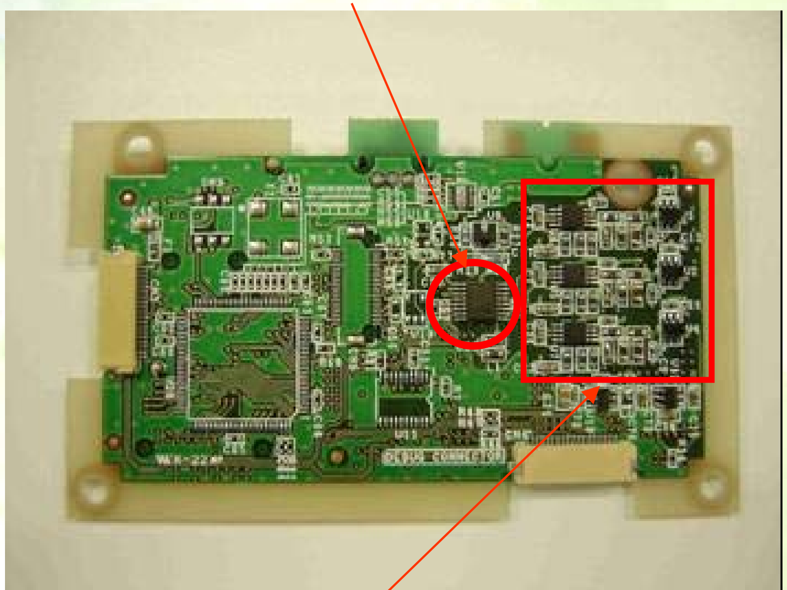




Kurata N, Saruwatari S, Morikawa H. Ubiquitous Structural Monitoring using Wireless Sensor Networks. Proc. of 2006 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS2006). 2006

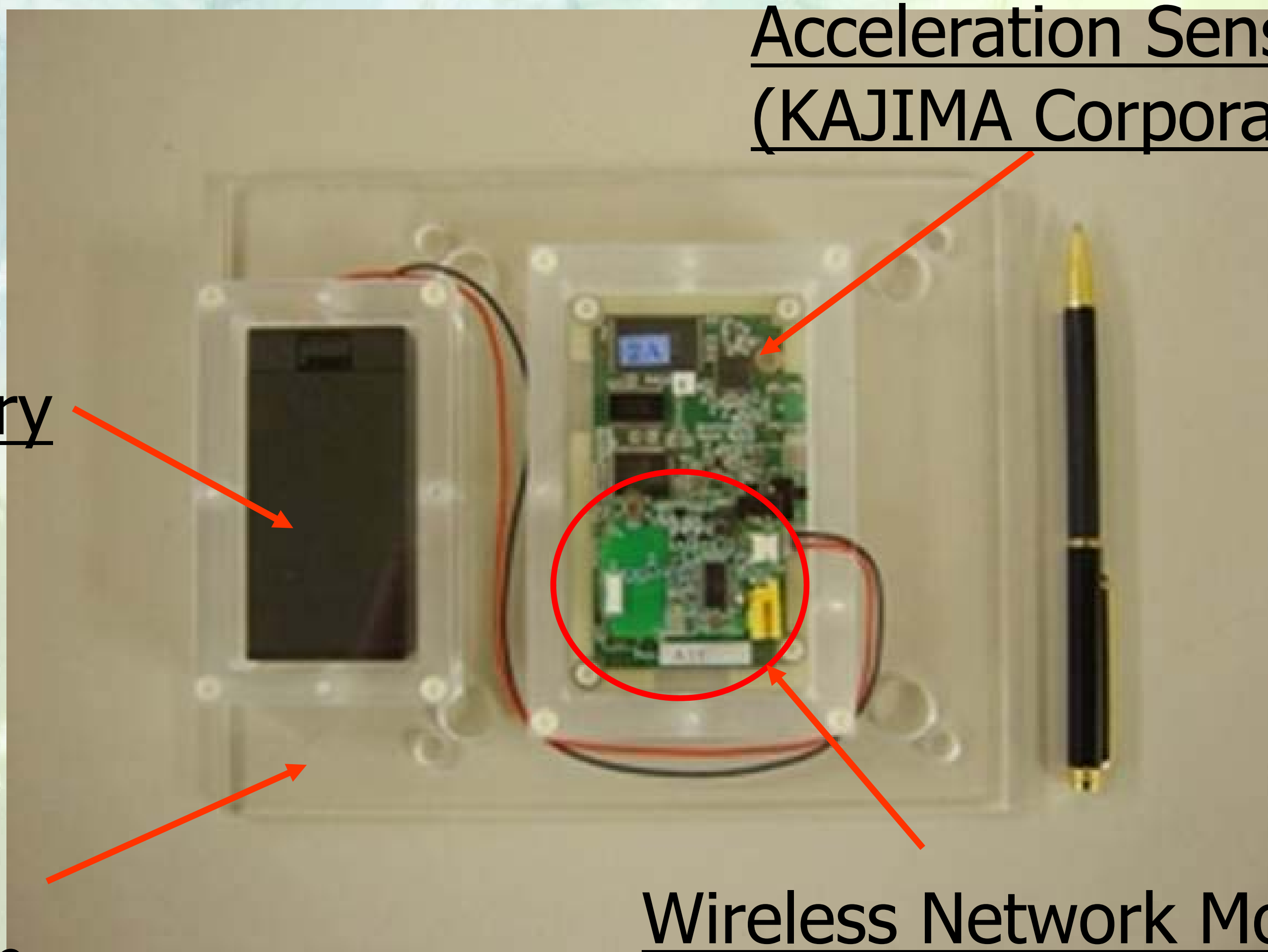
Development of Sensor Board





Kurata N, Suzuki M, Saruwatari S, Morikawa H. Application of Ubiquitous Structural Monitoring System by Wireless Sensor Networks to Actual High-rise Building. Proc. of 5th World Conference on Structural Control and Monitoring. 2010

Package of Wireless Sensor Network Module for Ubiquitous Structural Monitoring



Acceleration Sensor Board (KAJIMA Corporation)

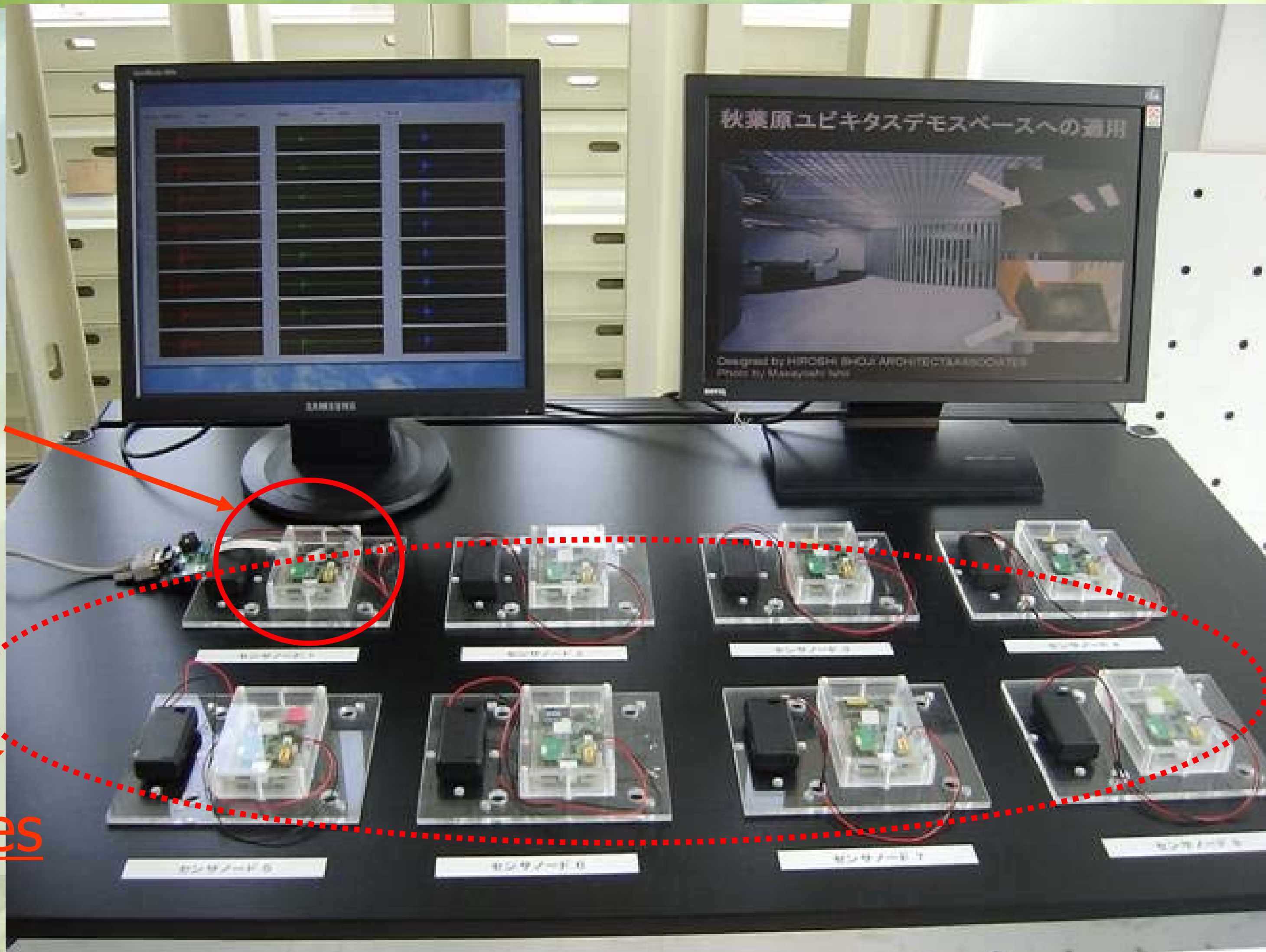
Battery

Casing for Installation

Wireless Network Module

Kurata N, Suzuki M, Saruwatari S, Morikawa H. Application of Ubiquitous Structural Monitoring System by Wireless Sensor Networks to Actual High-rise Building. Proc. of 5th World Conference on Structural Control and Monitoring. 2010

Ubiquitous Structural Monitoring System

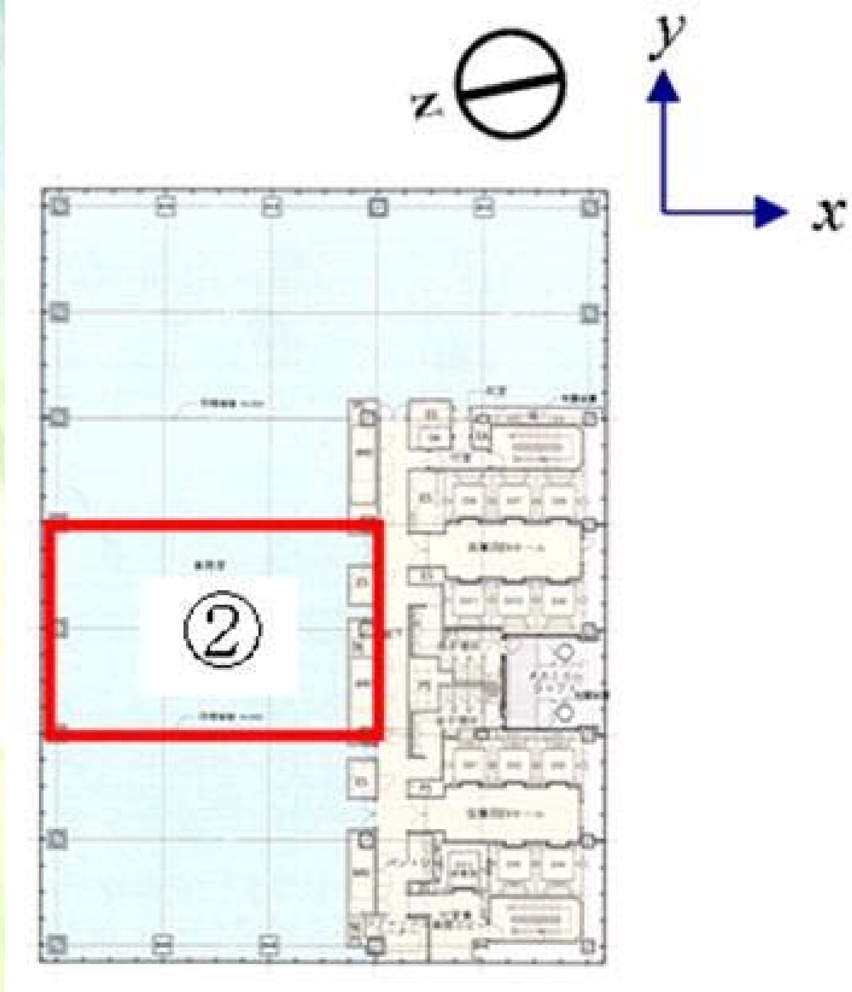


Sink node

Sensor nodes

Kurata N, Suzuki M, Saruwatari S, Morikawa H. Application of Ubiquitous Structural Monitoring System by Wireless Sensor Networks to Actual High-rise Building. Proc. of 5th World Conference on Structural Control and Monitoring. 2010

Applied to High-rise Building in Akihabara, Tokyo

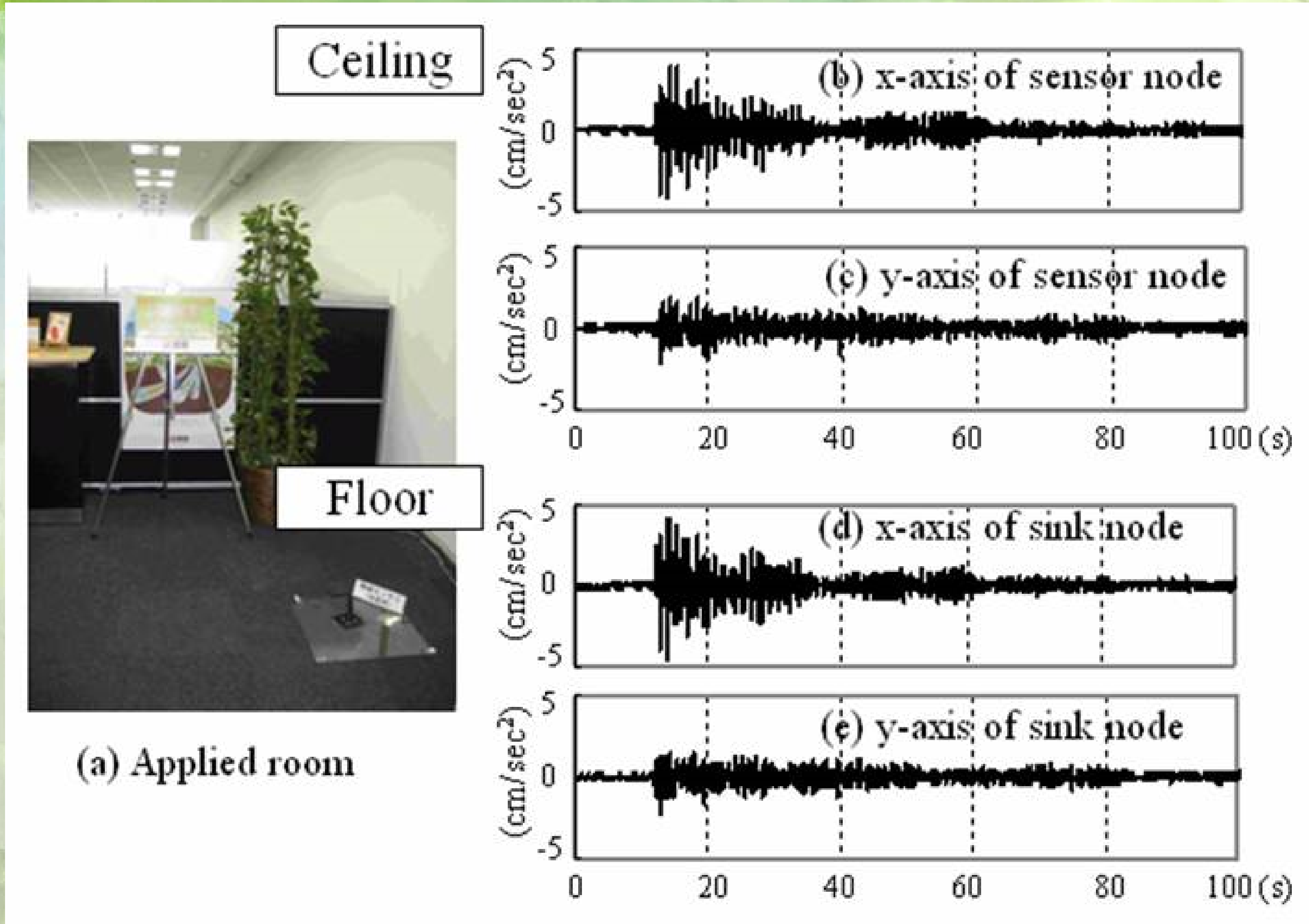


Kurata N, Suzuki M, Saruwatari S, Morikawa H. Application of Ubiquitous Structural Monitoring System by Wireless Sensor Networks to Actual High-rise Building. Proc. of 5th World Conference on Structural Control and Monitoring. 2010

Installation

Kurata N, Suzuki M, Saruwatari S, Morikawa H. Application of Ubiquitous Structural Monitoring System by Wireless Sensor Networks to Actual High-rise Building. Proc. of 5th World Conference on Structural Control and Monitoring. 2010

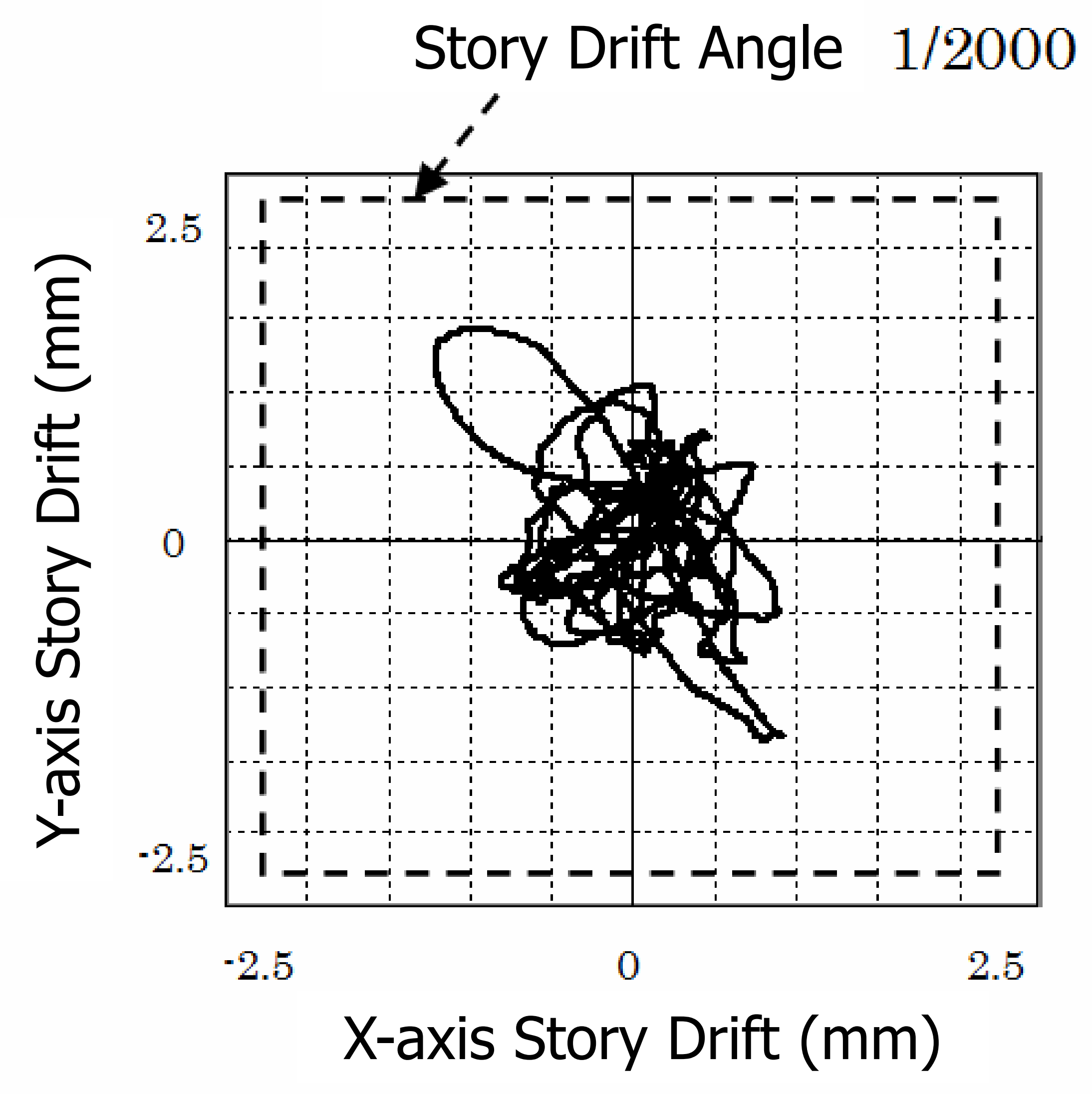
Example of Actual Earthquake Record



(a) Applied room

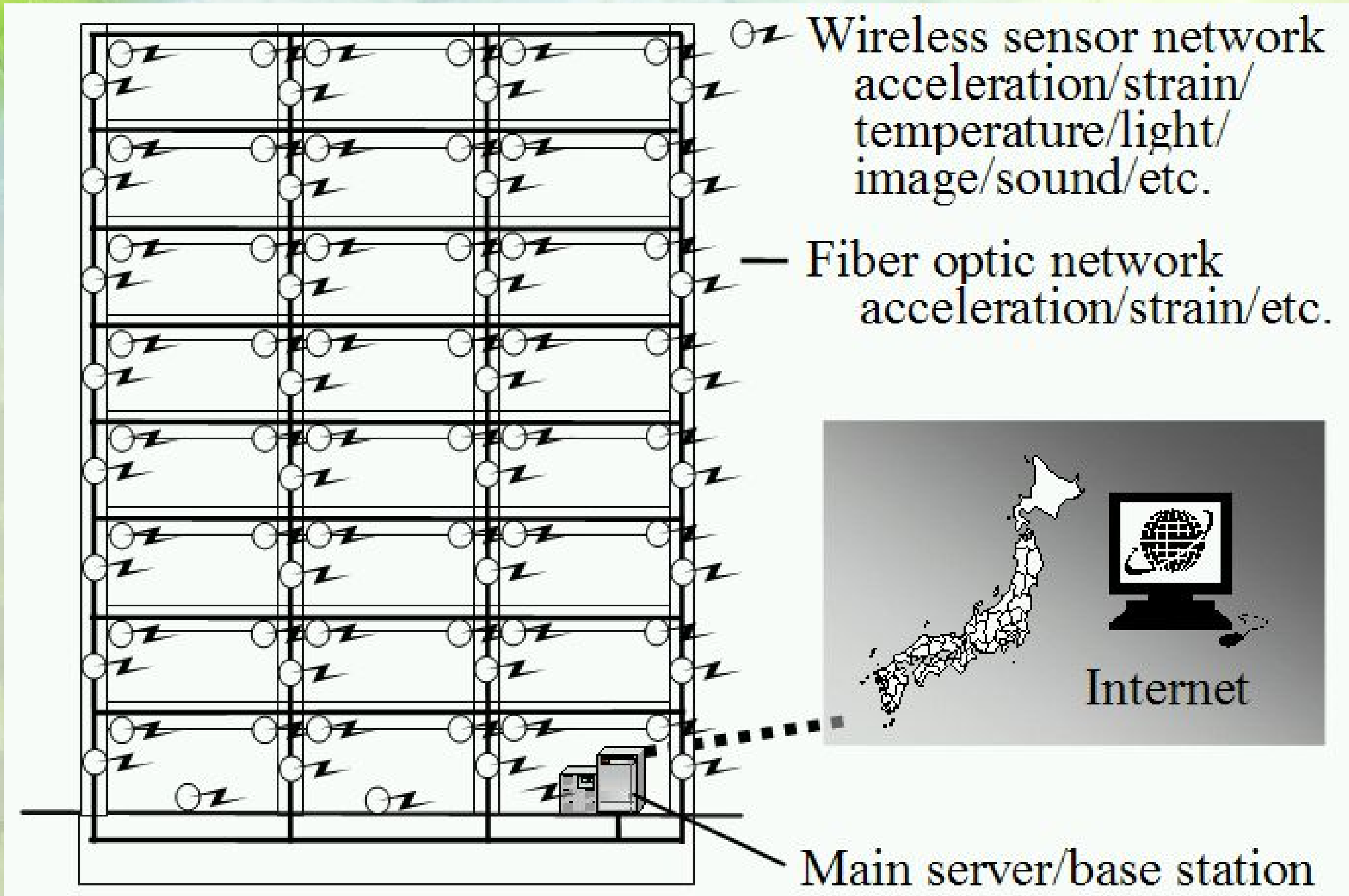
Kurata N, Suzuki M, Saruwatari S, Morikawa H. Application of Ubiquitous Structural Monitoring System by Wireless Sensor Networks to Actual High-rise Building. Proc. of 5th World Conference on Structural Control and Monitoring. 2010

Structural Health Monitoring by Story Displacement by Earthquake



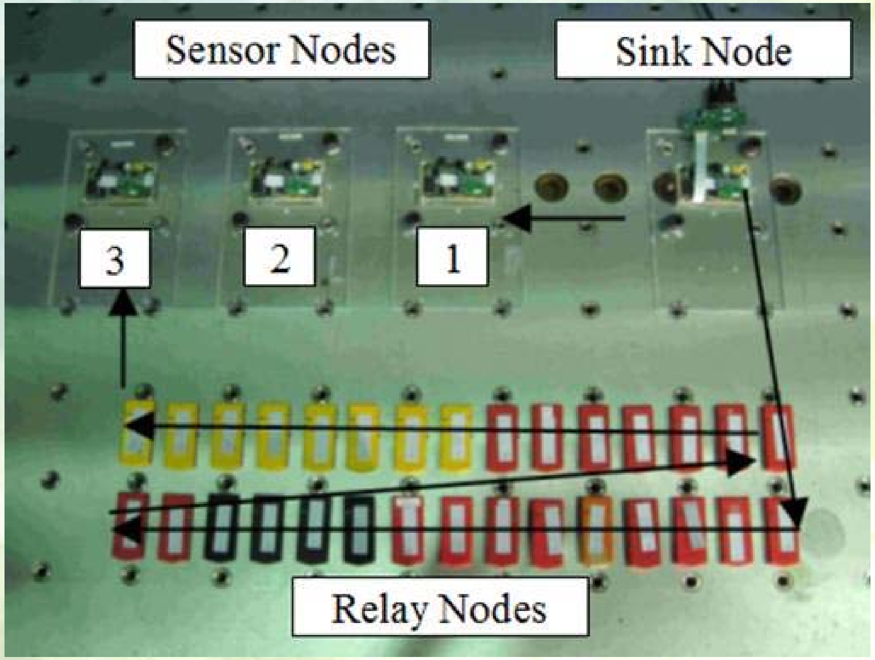
Kurata N, Suzuki M, Saruwatari S, Morikawa H. Application of Ubiquitous Structural Monitoring System by Wireless Sensor Networks to Actual High-rise Building. Proc. of 5th World Conference on Structural Control and Monitoring. 2010

Sensor Networks in the Future Smart Building



Kurata N, Suzuki M, Saruwatari S, Morikawa H. Application of Ubiquitous Structural Monitoring System by Wireless Sensor Networks to Actual High-rise Building. Proc. of 5th World Conference on Structural Control and Monitoring. 2010

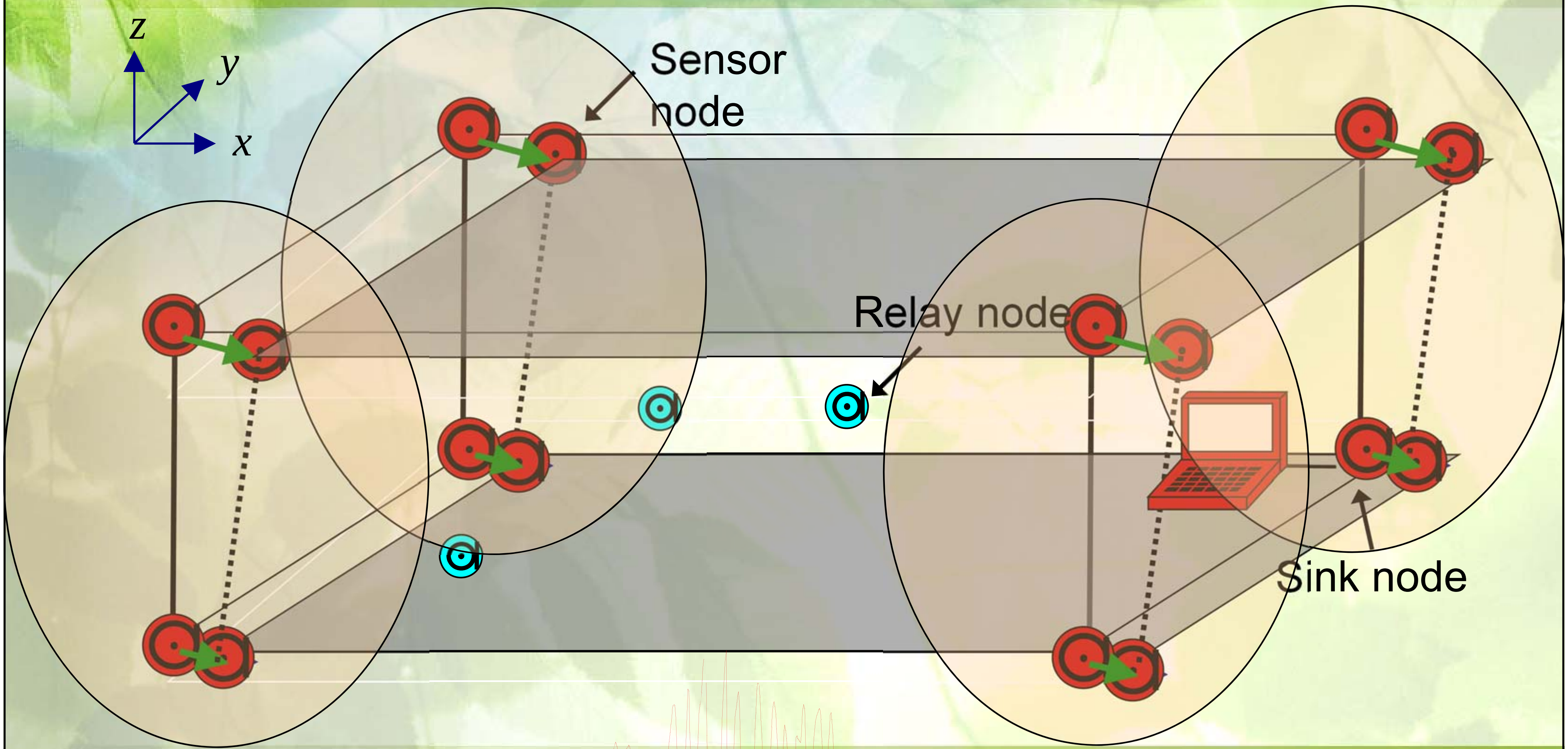
Verification of Ad-hoc Multi-hop Communication by Shaking Table



- Swept sine wave with 0.2 to 20 Hz was input to the shaking table
- Sensor node 1 received synchronization packets from sink node by single hop
- Sensor node 3 received them by multi-hop through thirty relay nodes

Kurata N, Suzuki M, Saruwatari S, Morikawa H. Application of Ubiquitous Structural Monitoring System by Wireless Sensor Networks to Actual High-rise Building. Proc. of 5th World Conference on Structural Control and Monitoring. 2010

Experiment of Ad Hoc Network and Multi-hop Communication Function



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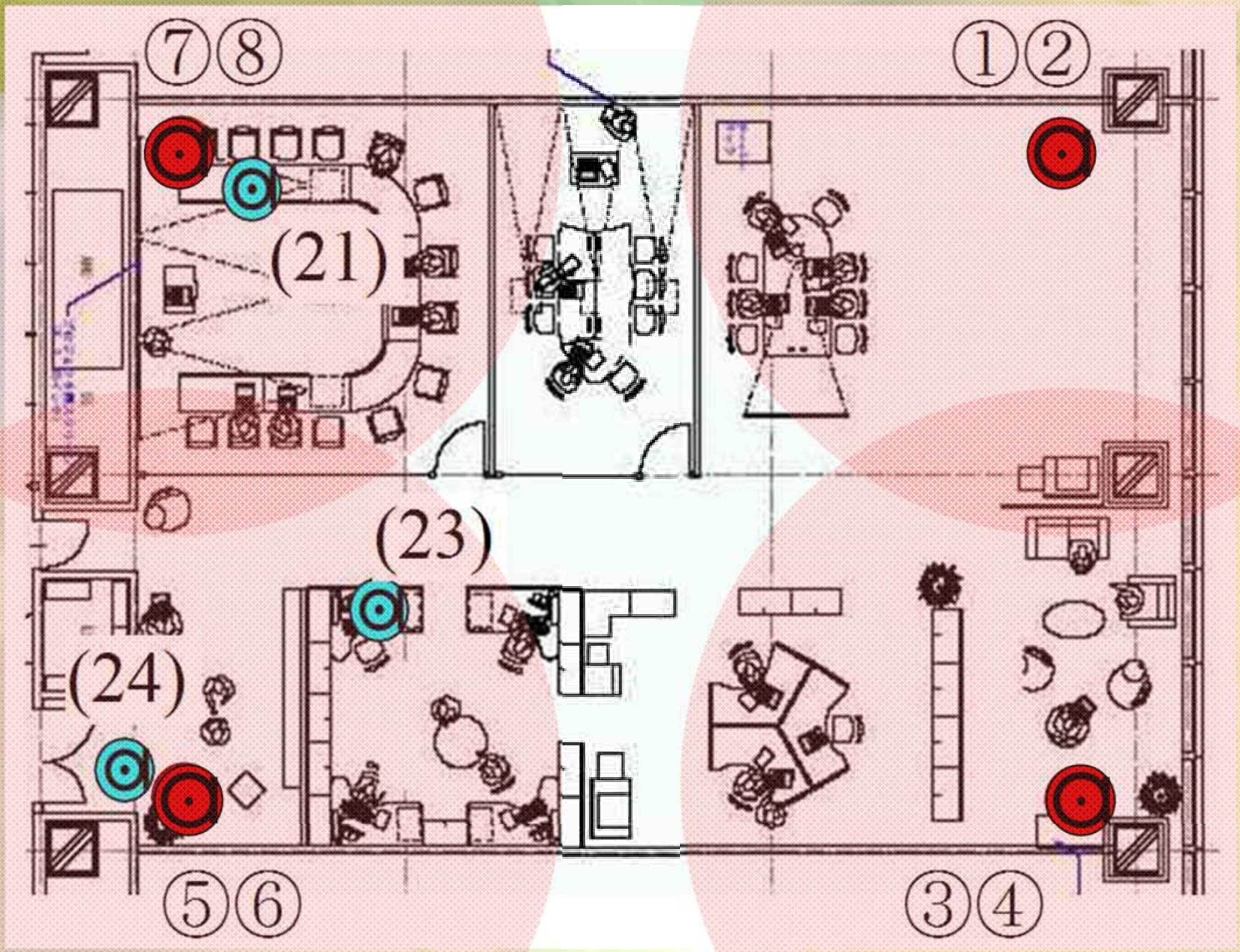

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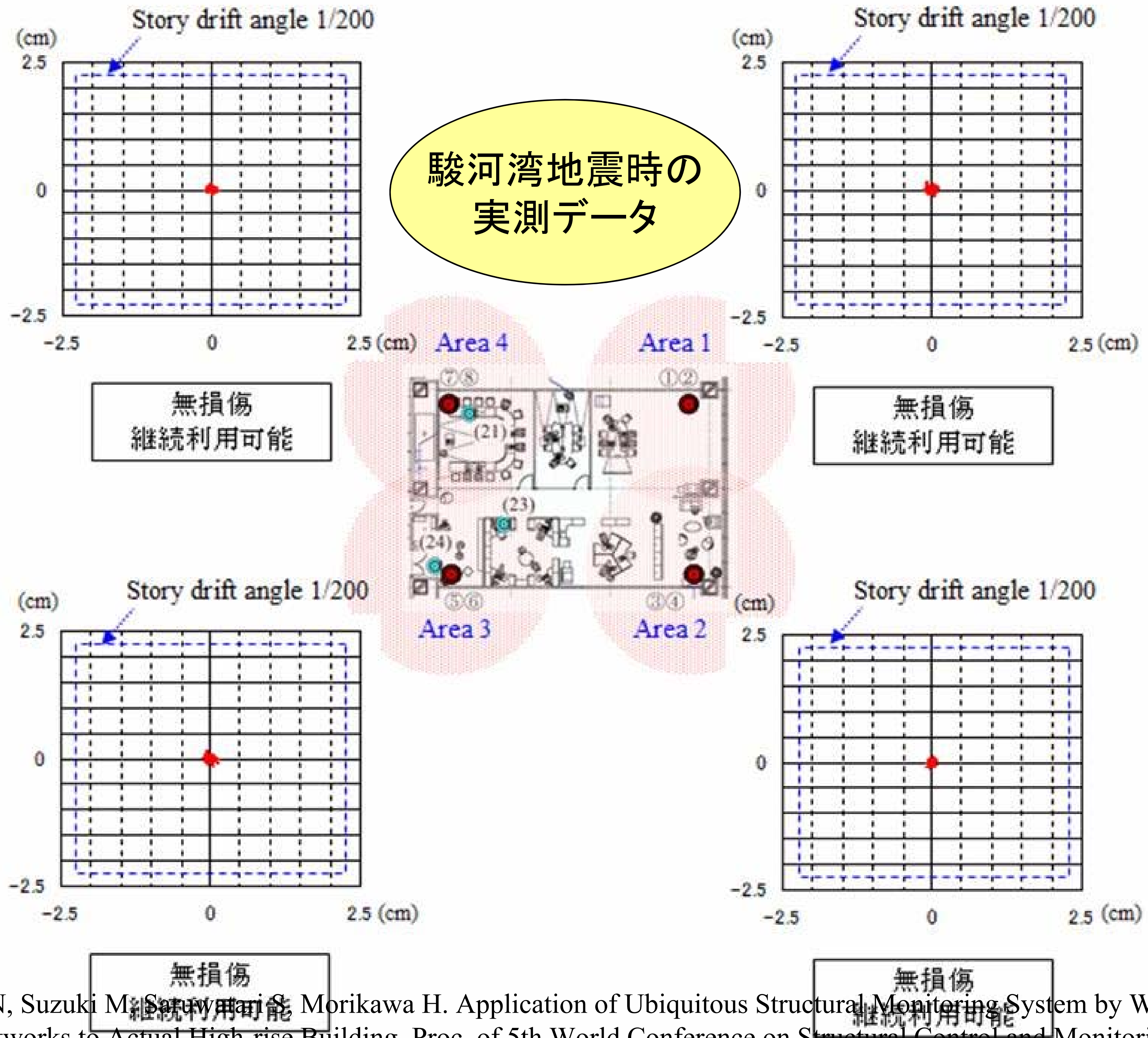

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AOKI

The need for accurate time information

- Accurate time information as well as location information are necessary to develop the Disaster Big Data Infrastructure and analyze the data
- Time synchronization between the sensors in a wide area is not easy
  – GPS cannot be used in the houses and buildings
  – The wire and wireless communication is limited
- It is desirable that the sensor itself has autonomously accurate time information

Development of a Sensor Module Equipped with an Atomic Clock

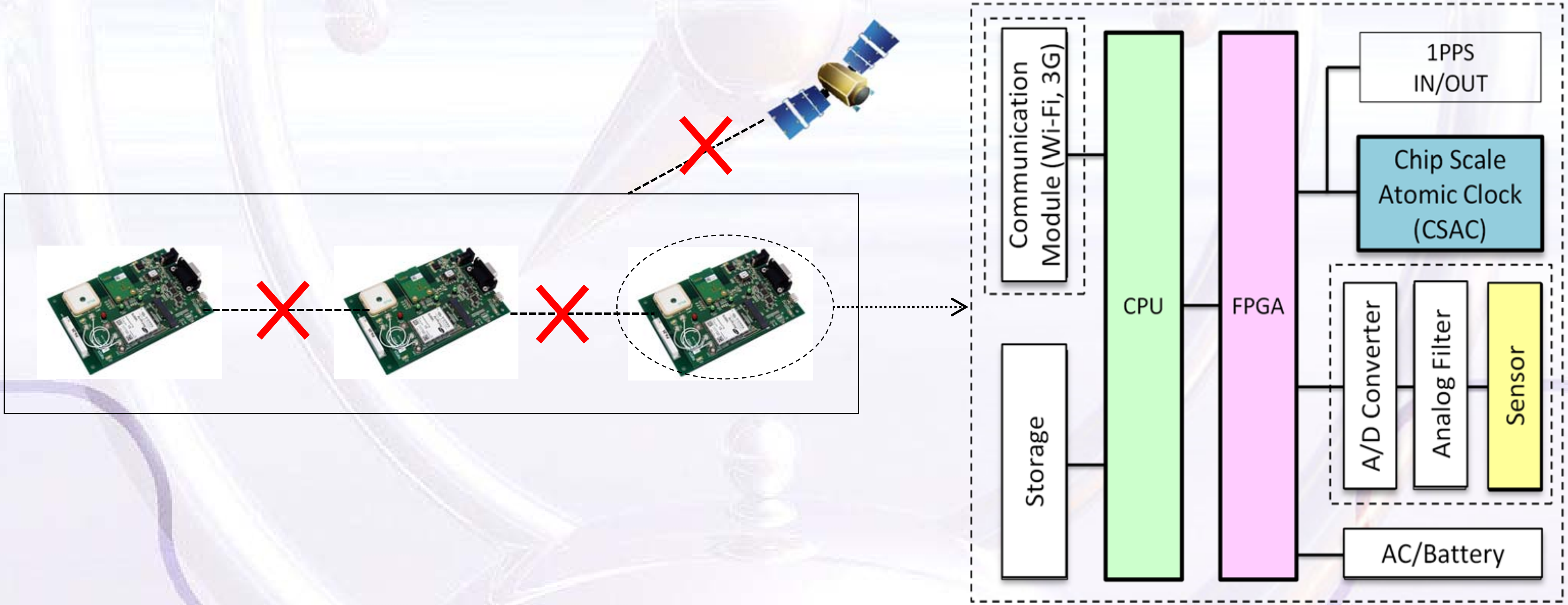
Chip Scale Atomic Clock (CSAC) is available

- Comparison among various atomic clocks and oscillator

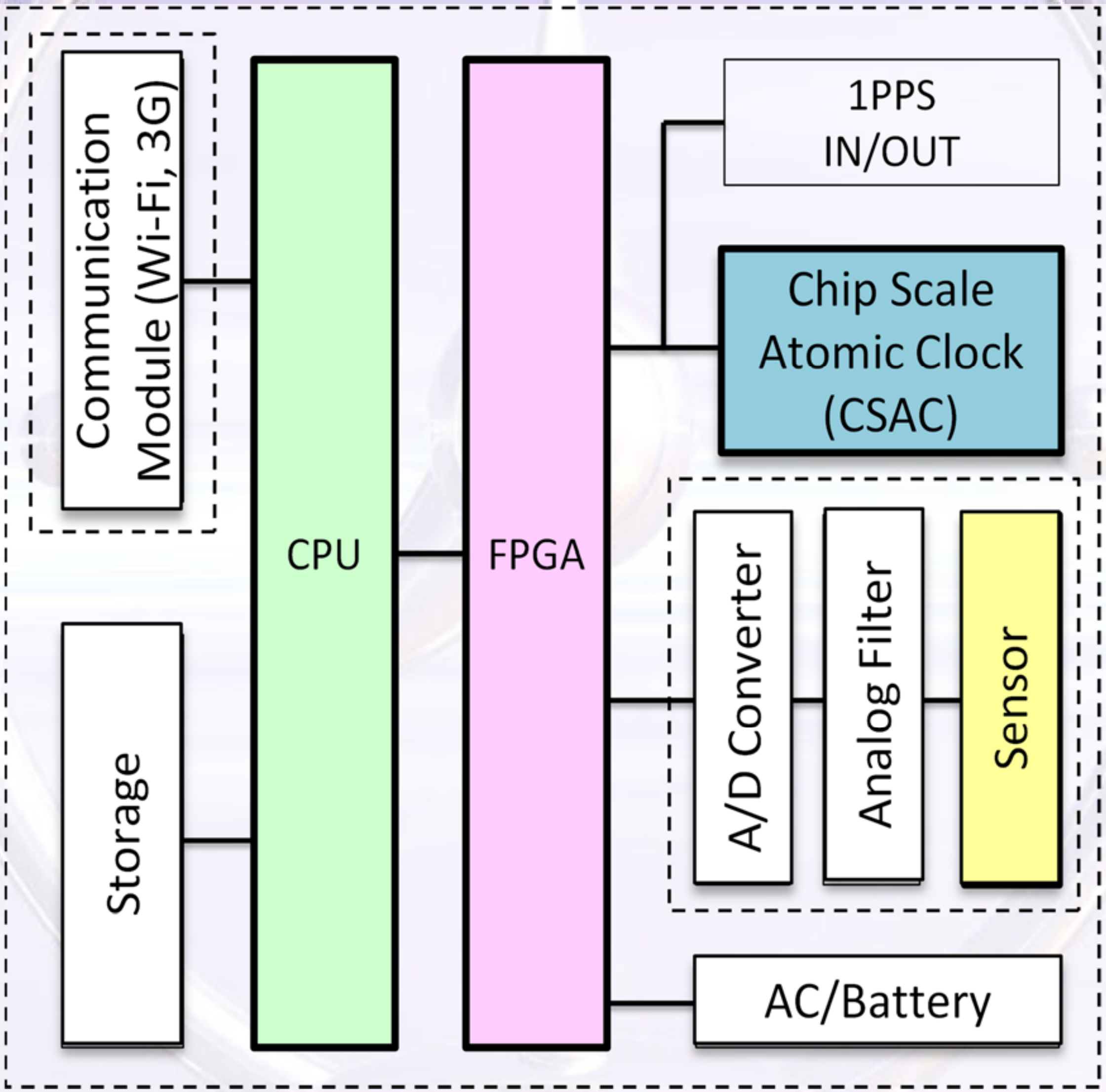
	Cesium atomic clock	Rubidium atomic clock	CSAC	Crystal oscillator
Time for 1-sec. delay	50,000 years	1000 years	1000 years	One day
Size	0.1 m^3	1000 cm^3	17 cm^3	10 mm^3
Power consumption	50 W	Several 10 W	120 mW	10 μW

Autonomous Time Synchronization Sensing Technology Applying the CSAC

- Sensor module architecture that realizes a high precision time index
- Applied to a wide variety of sensors

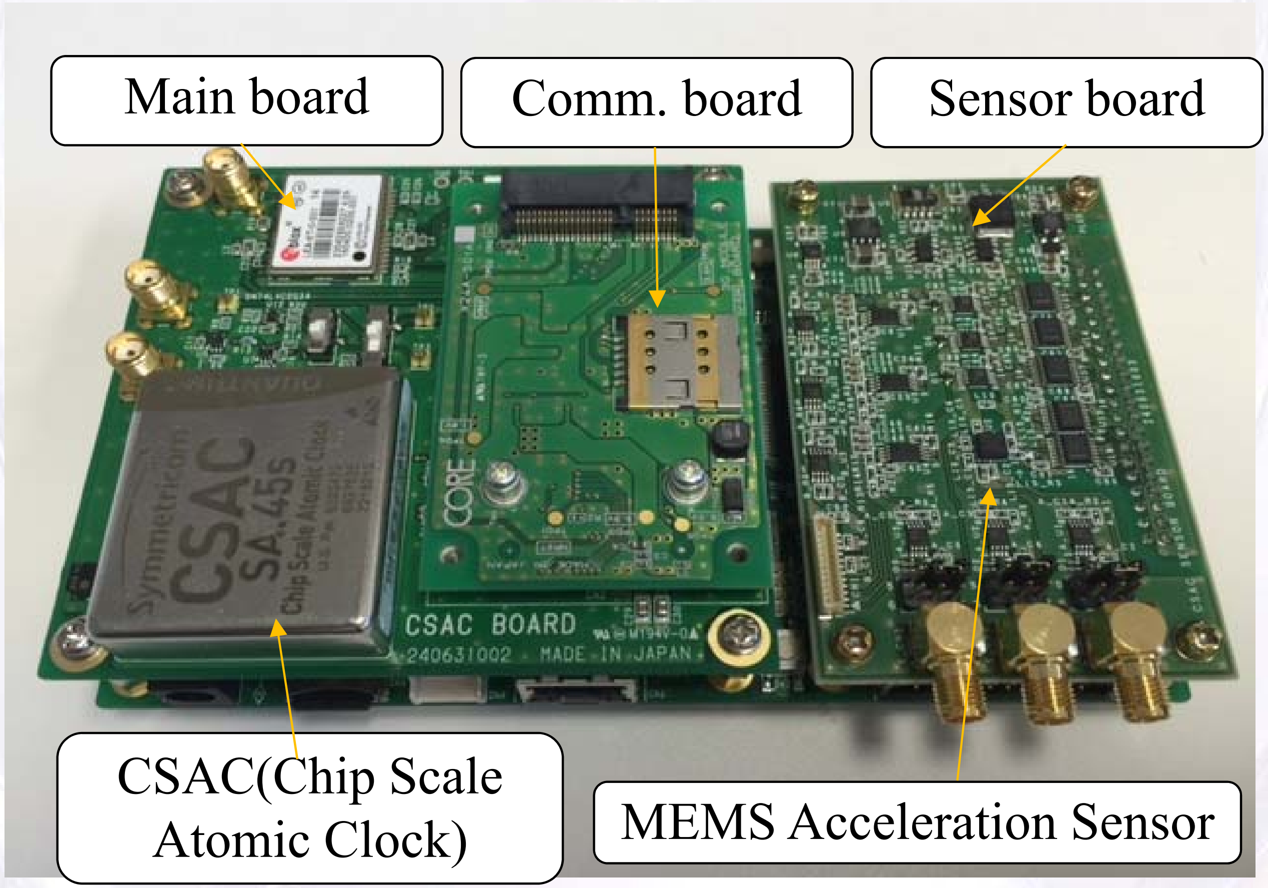


Mechanism of Sensor Module with CSAC

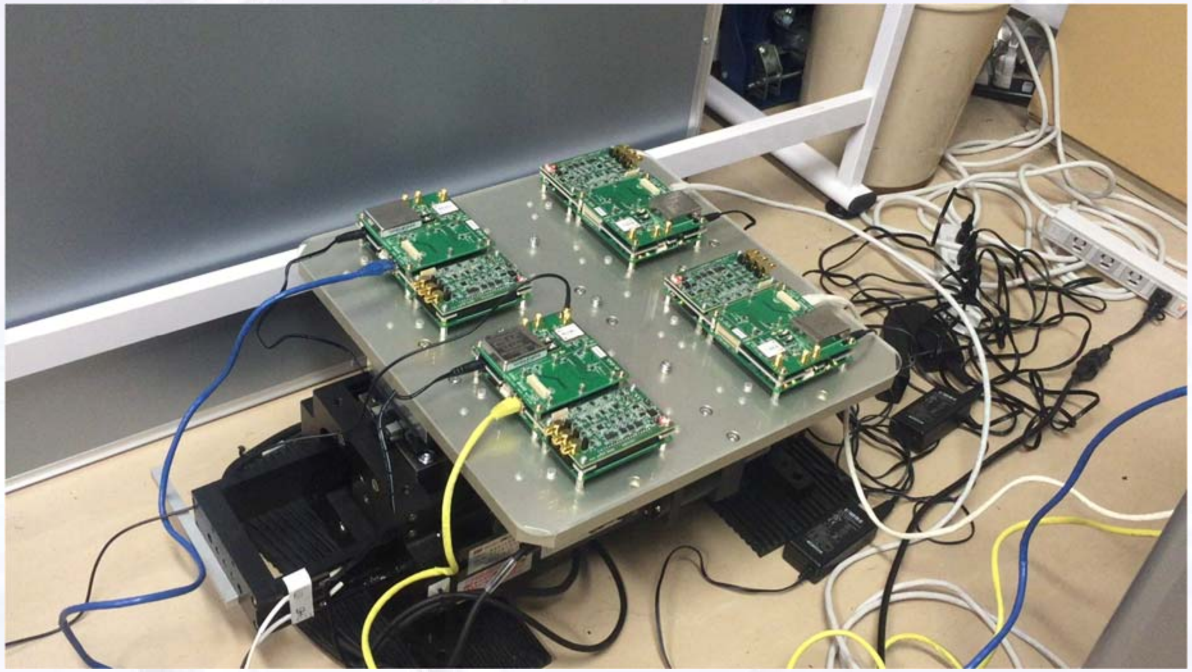


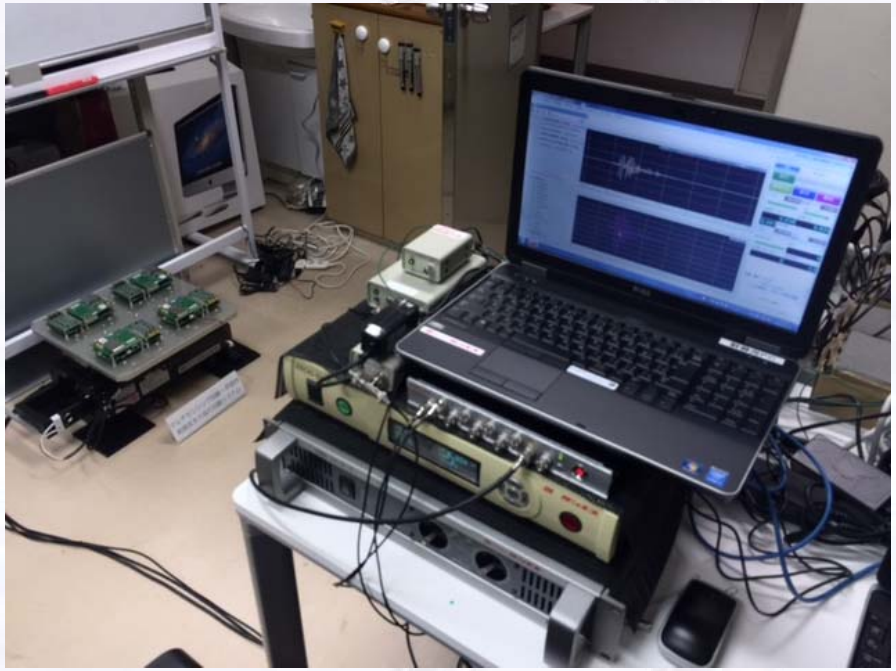
Development of Prototype Sensor Module with CSAC

- It consists of Main board with CSAC, Communication board with Wi-Fi, 3G, Ethernet, and Sensor board with MEMS acceleration sensor



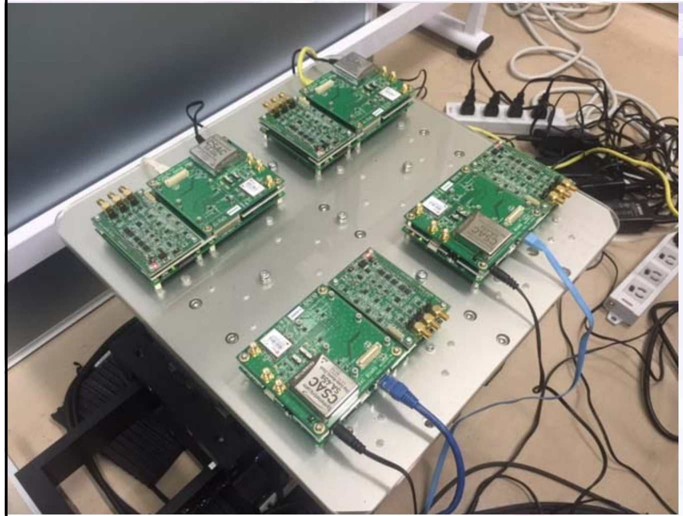
Shaking Table Test for Sensor Module with CSAC

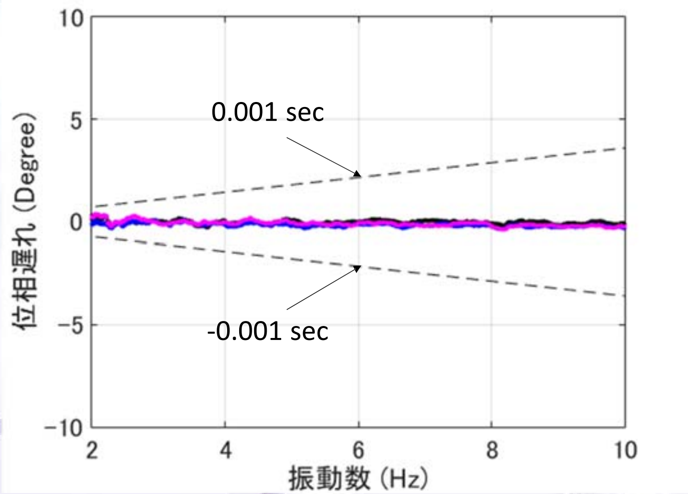




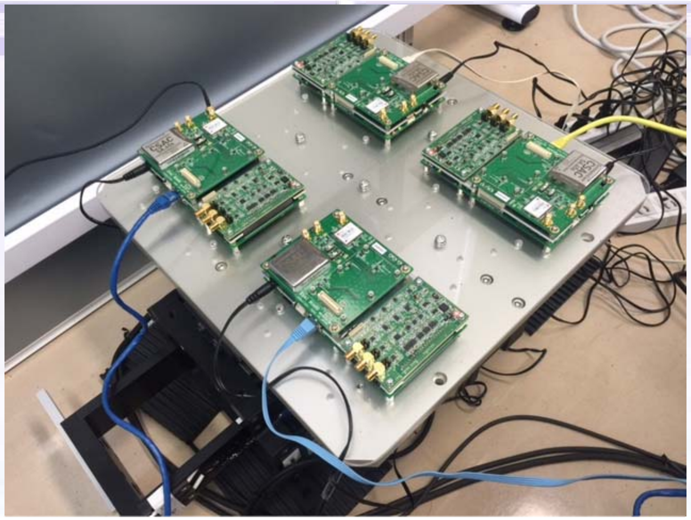
- Performance of time synchronization and accurate acceleration measurement was tested by using shaking table

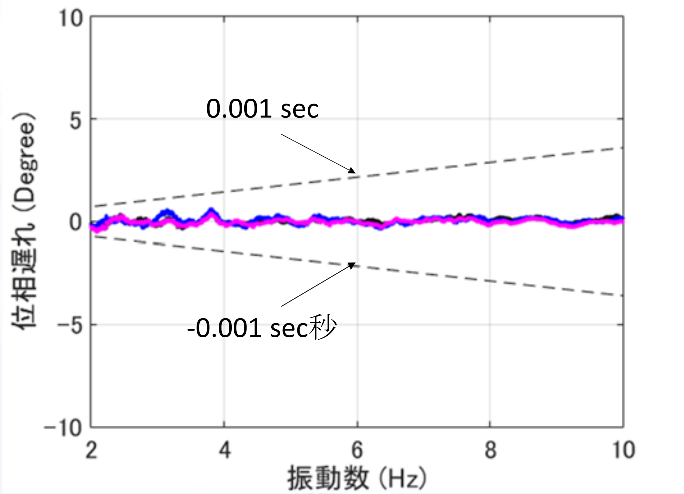
Example of Test Results



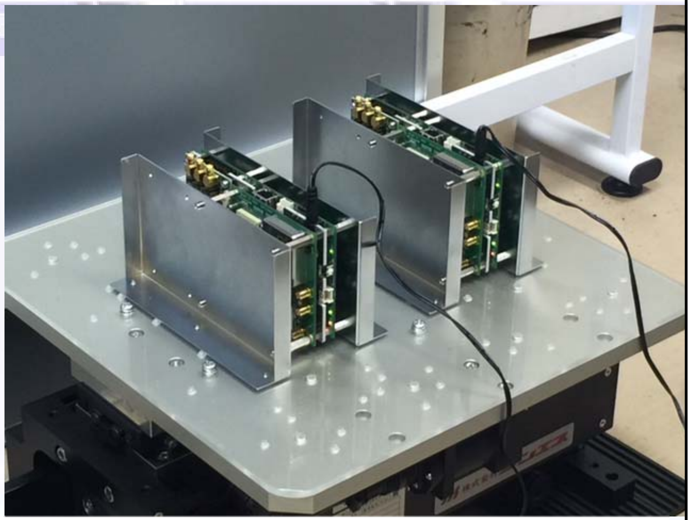


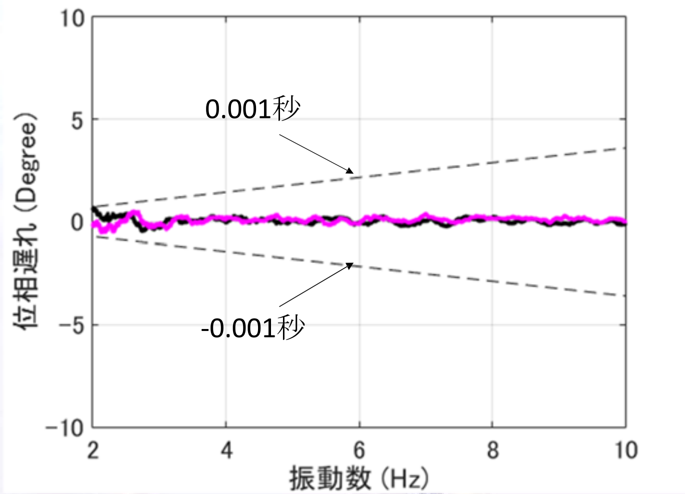
X−direction





Y−direction

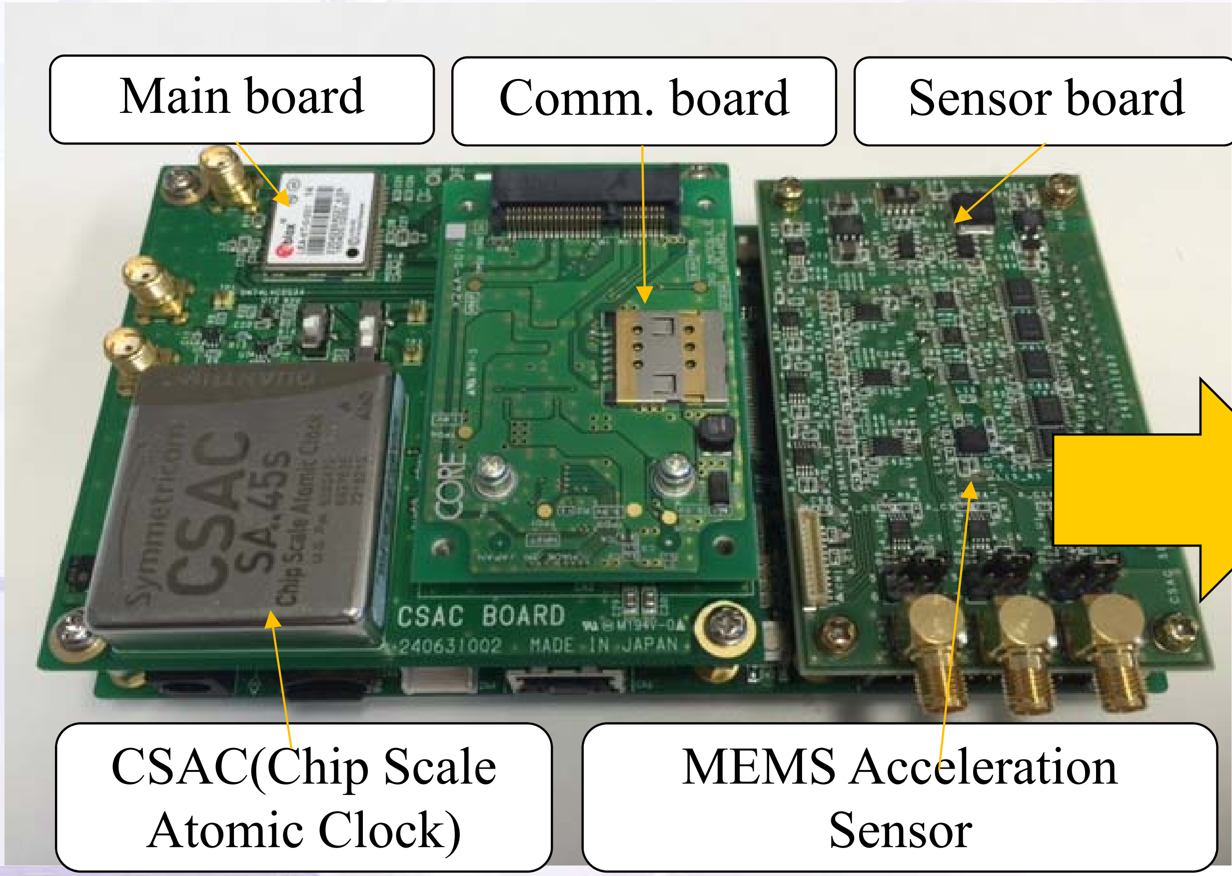




Z−direction

CSAC Module can be used as a data logger

- Sensor board with MEMS acceleration sensor can be exchanged with external input board
- Any analog sensors can be connected



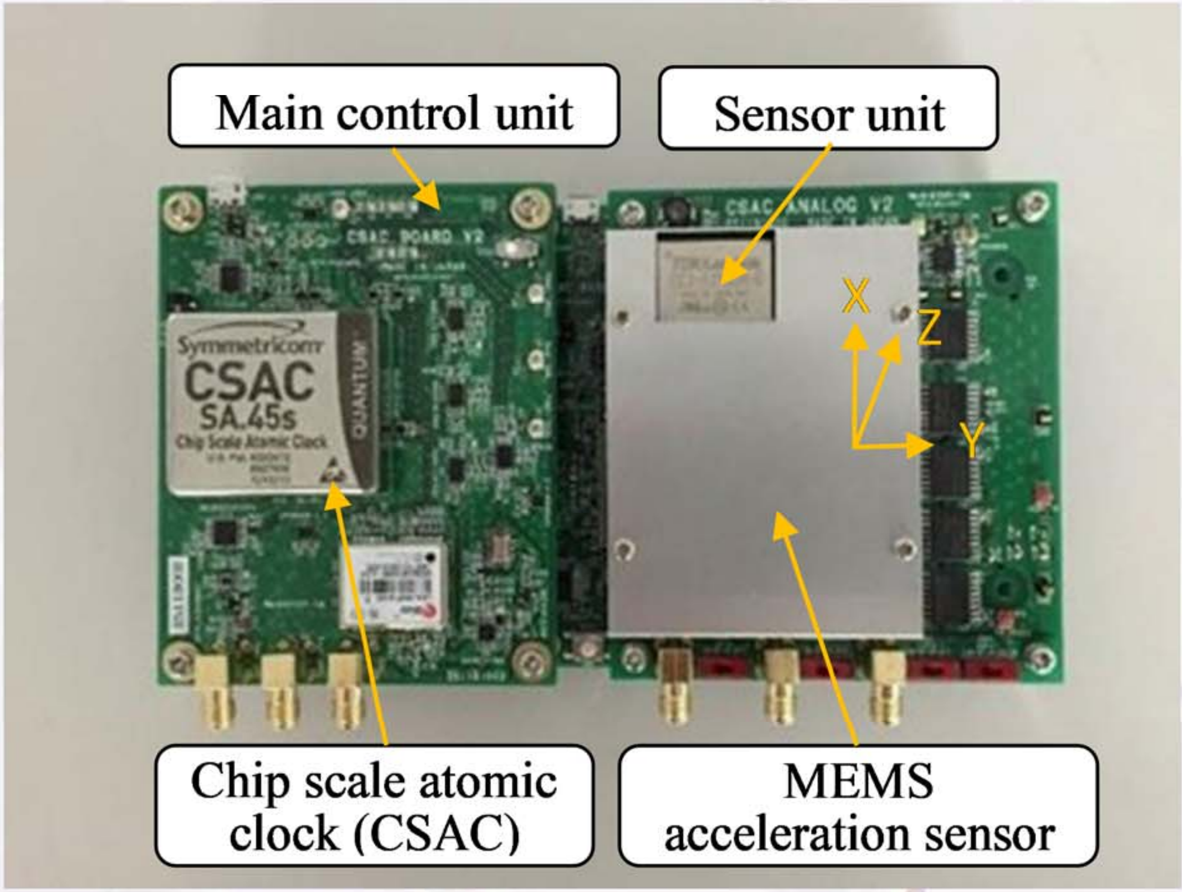
External Input Board

Application of Maintenance and Management of Civil Infrastructures

Development of Sensor Module with CSAC

- After the development of prototype module, improved module has developed

Prototype module



Improved module

Improvements from prototype module

(1) The external analog sensor input interface has been improved to include three channels.

(2) The A/D converter has been improved to feature 24-bit resolution.

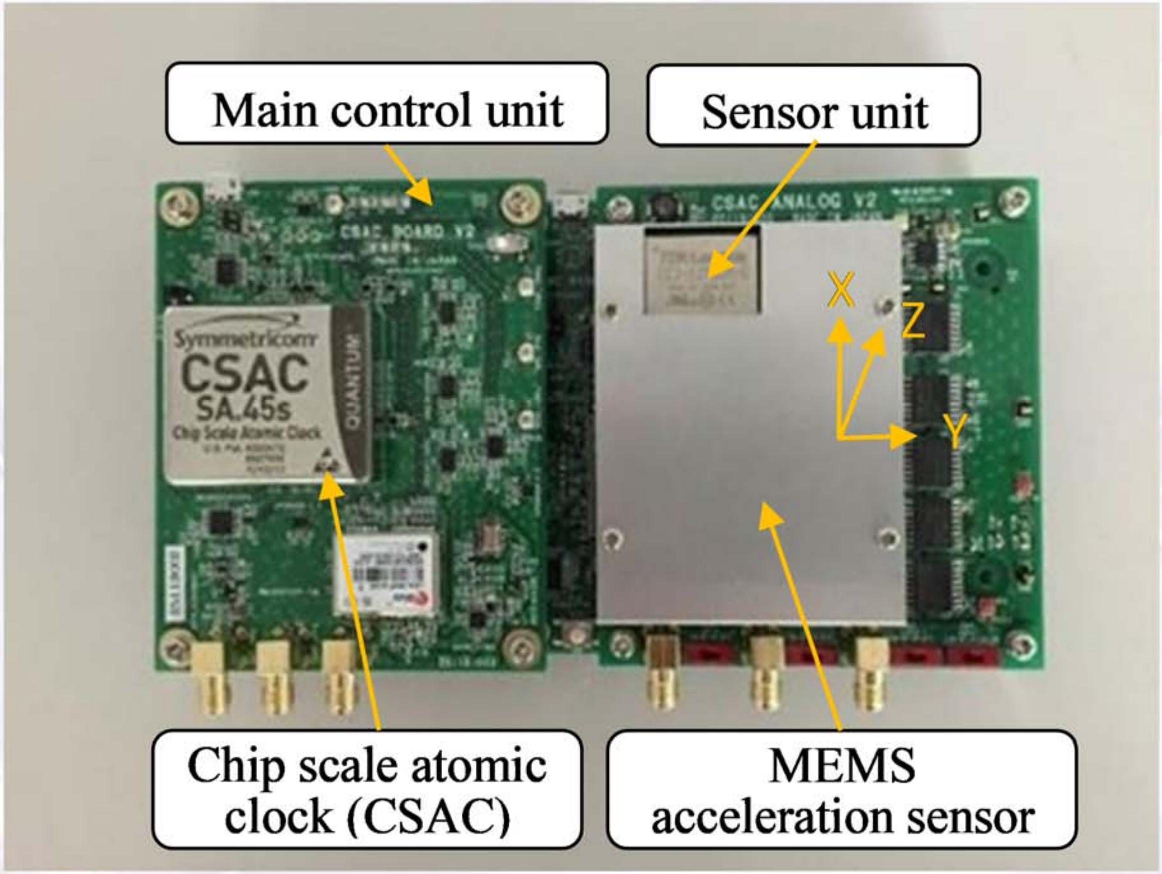
(3) The FPGA has been reinforced for the above items (1) and (2).

(4) The wireless communication unit has been separated, and it has been built using a Raspberry Pi 2 Model B, which is commercially available.

(5) Time synchronization using IEEE 1588 has been implemented.

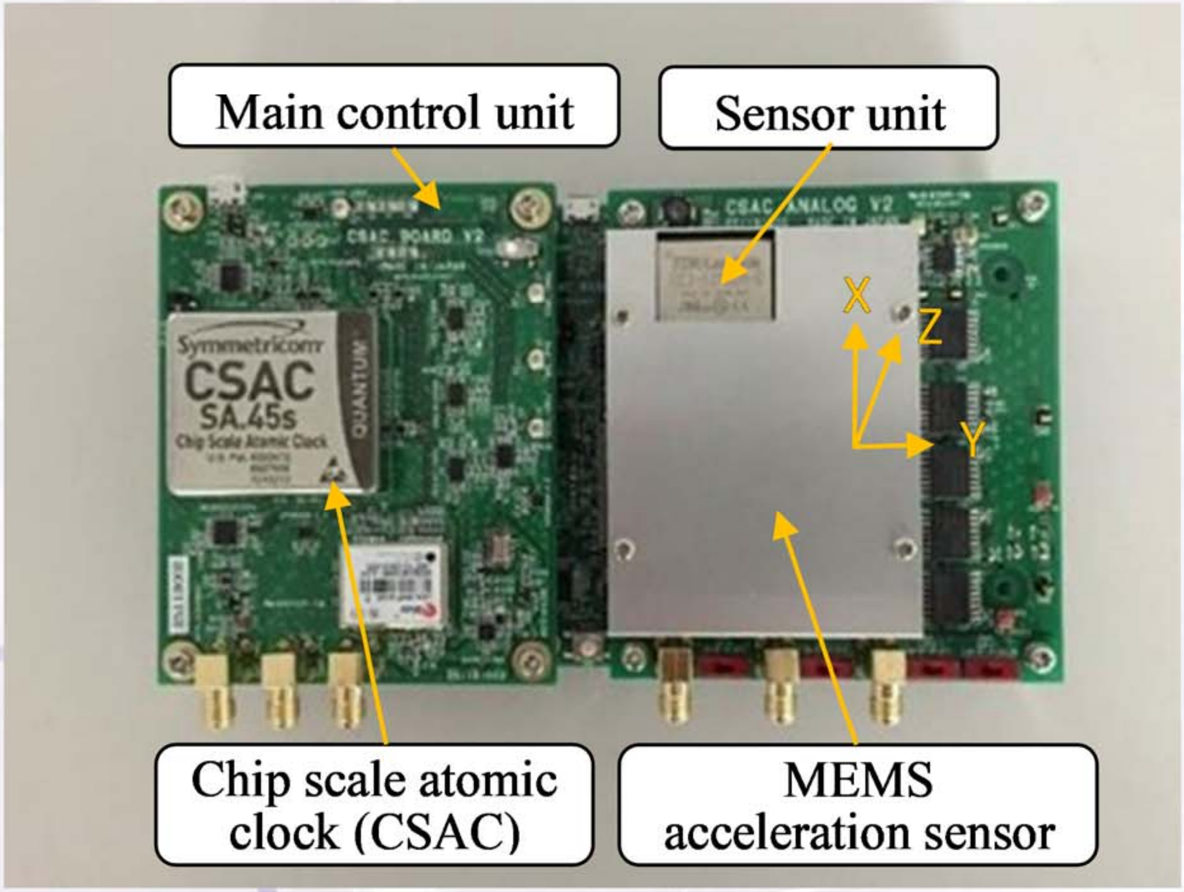
Improved Sensor Module with CSAC

- It consists of Main control unit with CSAC and Sensor unit with three axis MEMS acceleration sensor and three external analog sensor input interface

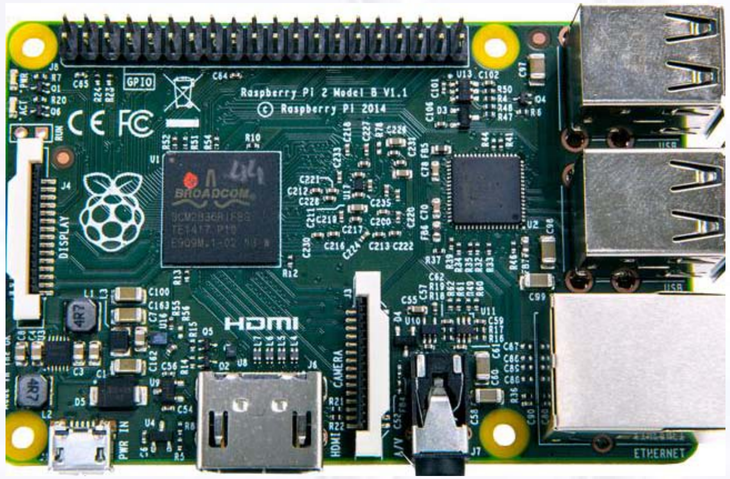


Development of Sensor Module with CSAC

- The wireless communication unit has been built using a Raspberry Pi 2 Model B



Main control unit and sensor unit

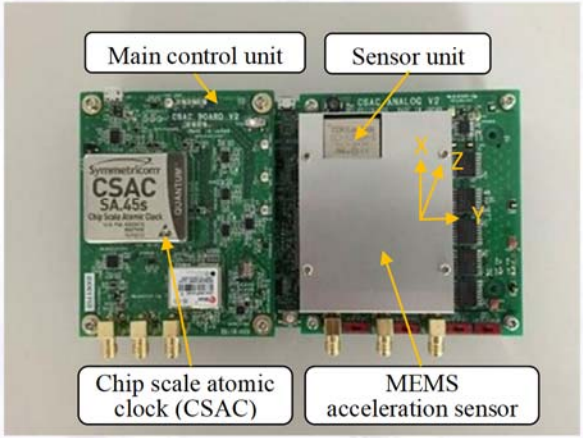


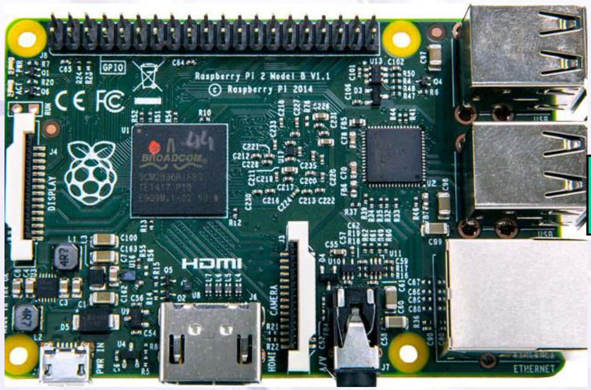
Raspberry Pi 2 Model B:

Ethernet, 3G and Wi-Fi are available

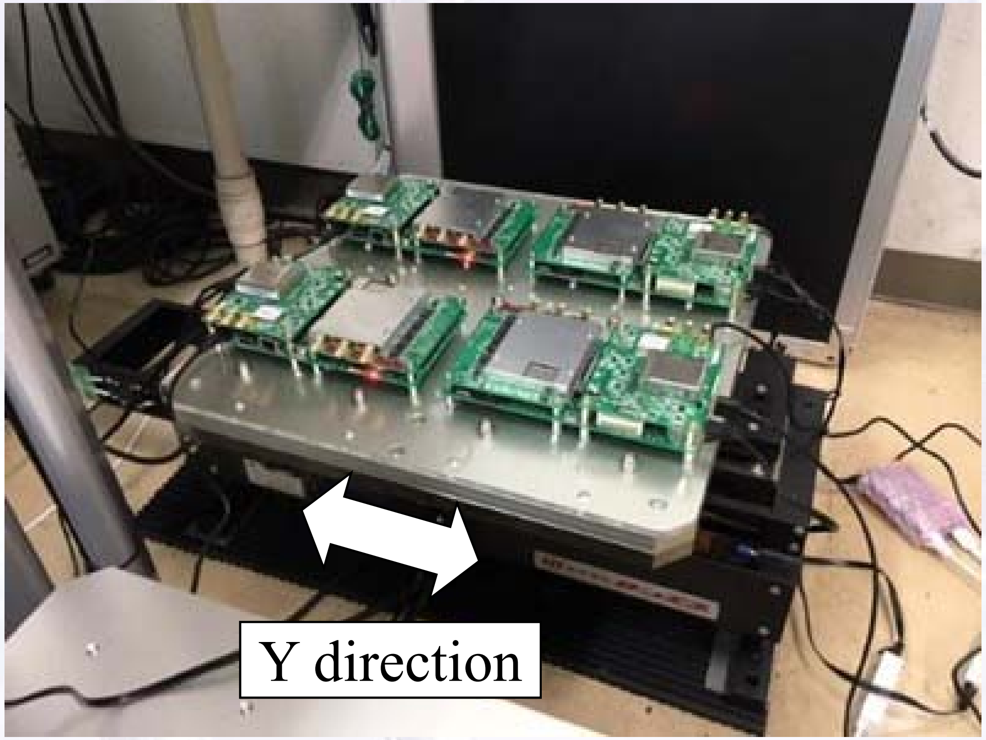
Development of Sensor Module with CSAC

- The case for units has developed
- All units and Raspberry Pi are integrated in the case



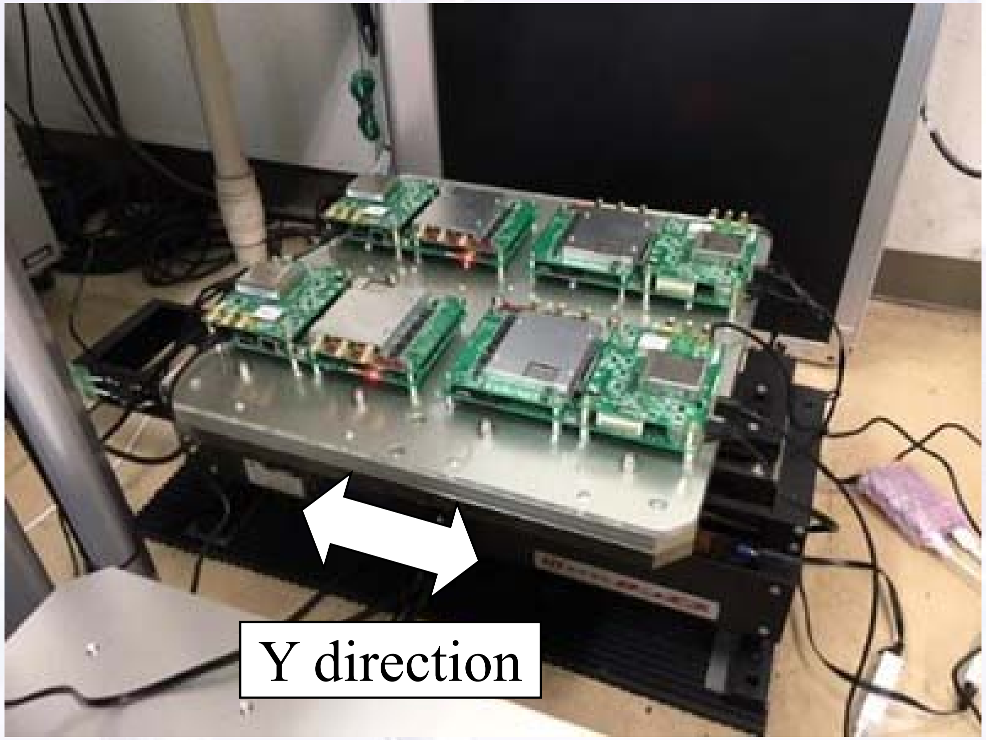


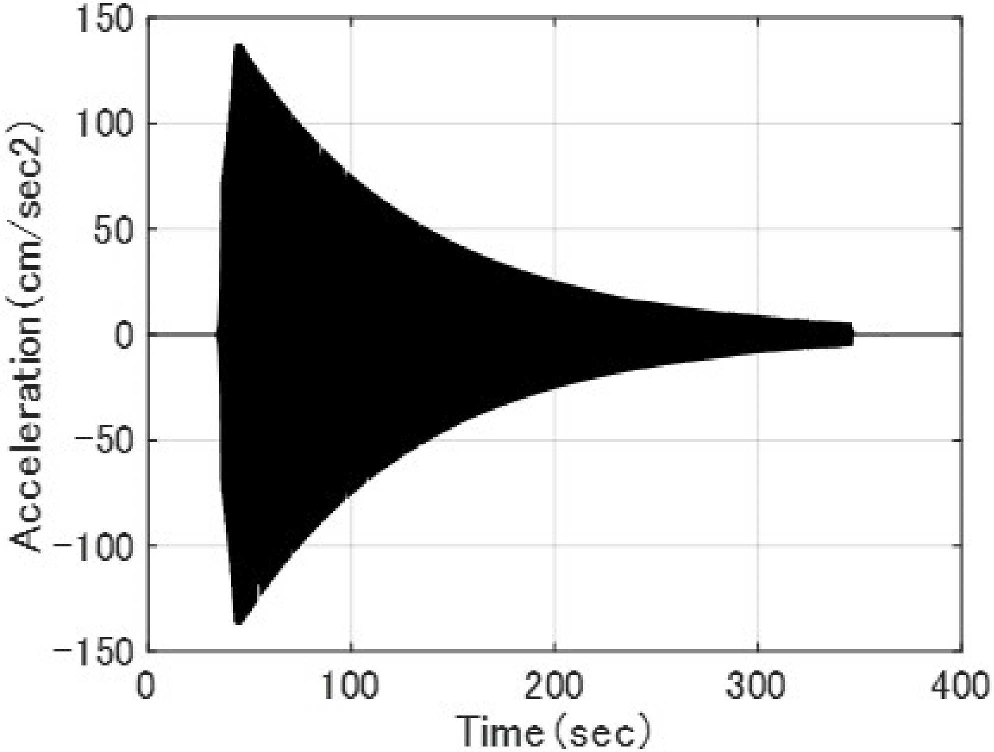
Shaking Table Test for Improved Sensor Module with CSAC



- Performance of time synchronization and accurate acceleration measurement was tested by using shaking table

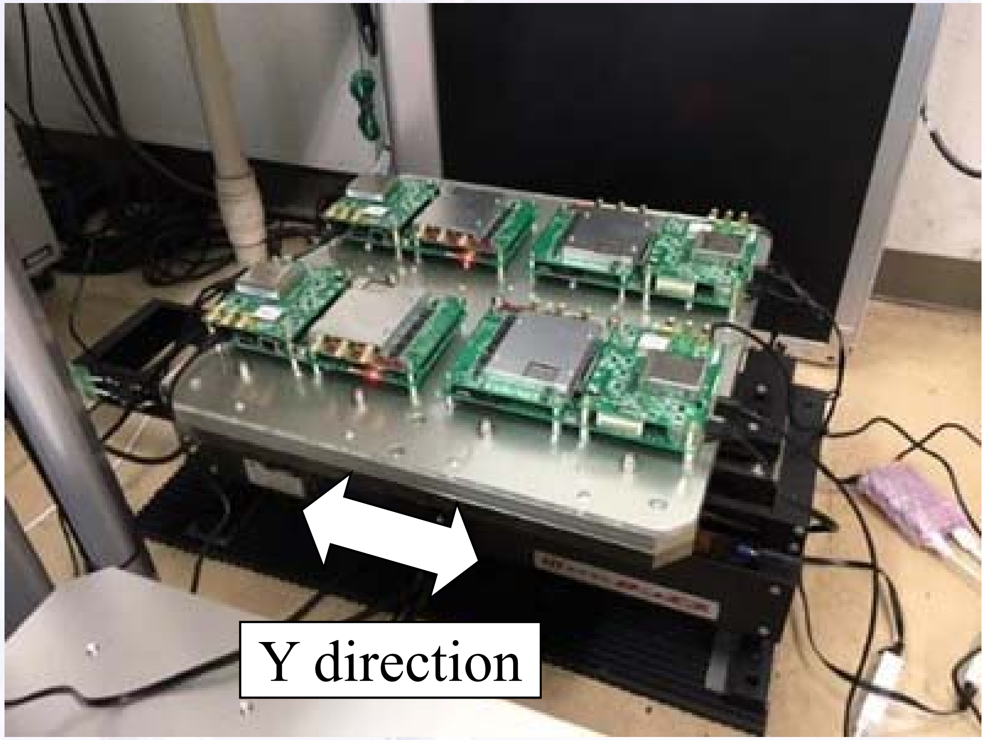
Shaking Table Test for Improved Sensor Module with CSAC

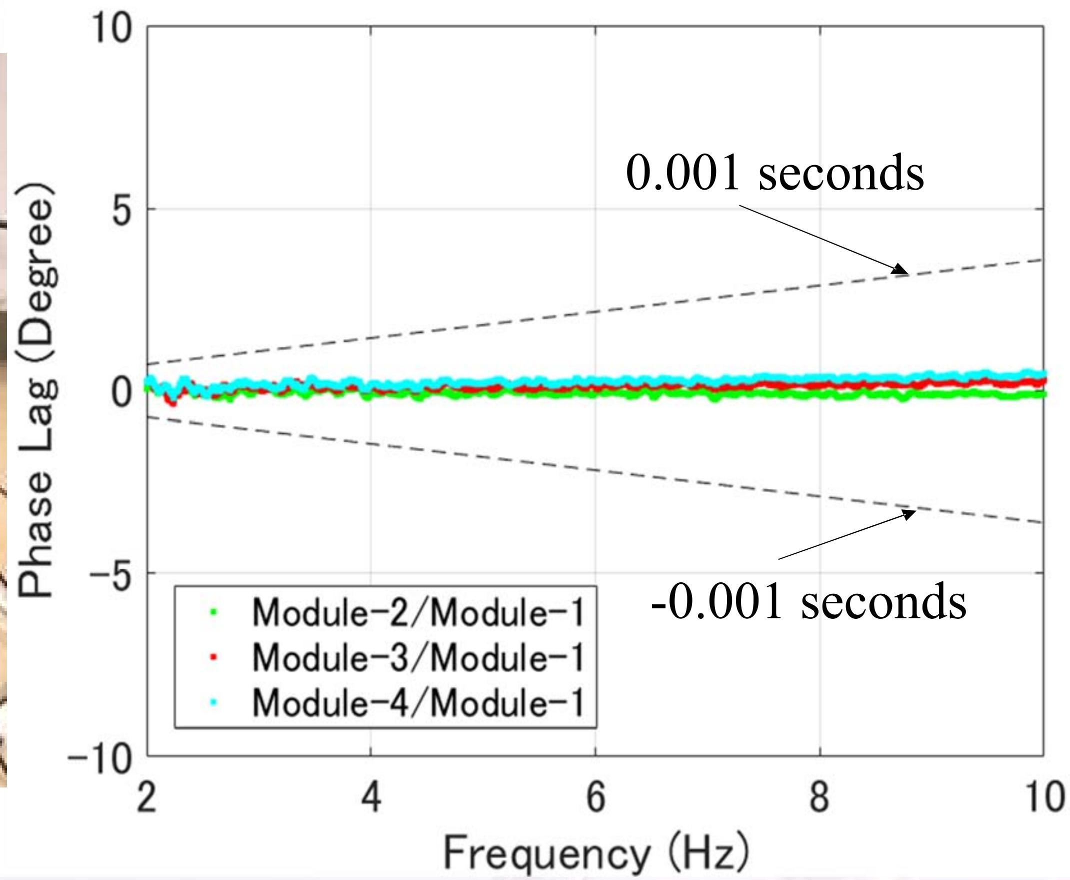




- Same vibration was applied in the horizontal direction
- Shaking table was vibrated using a 2–10 Hz swept sine wave

Example of Test Results

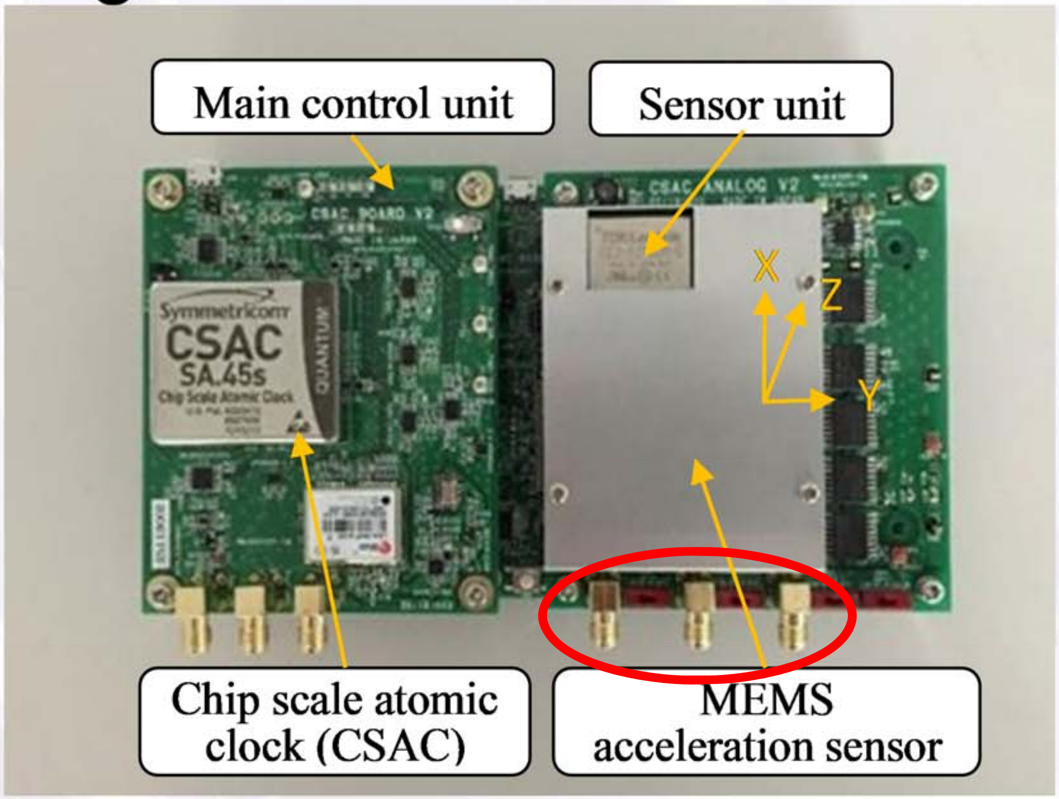




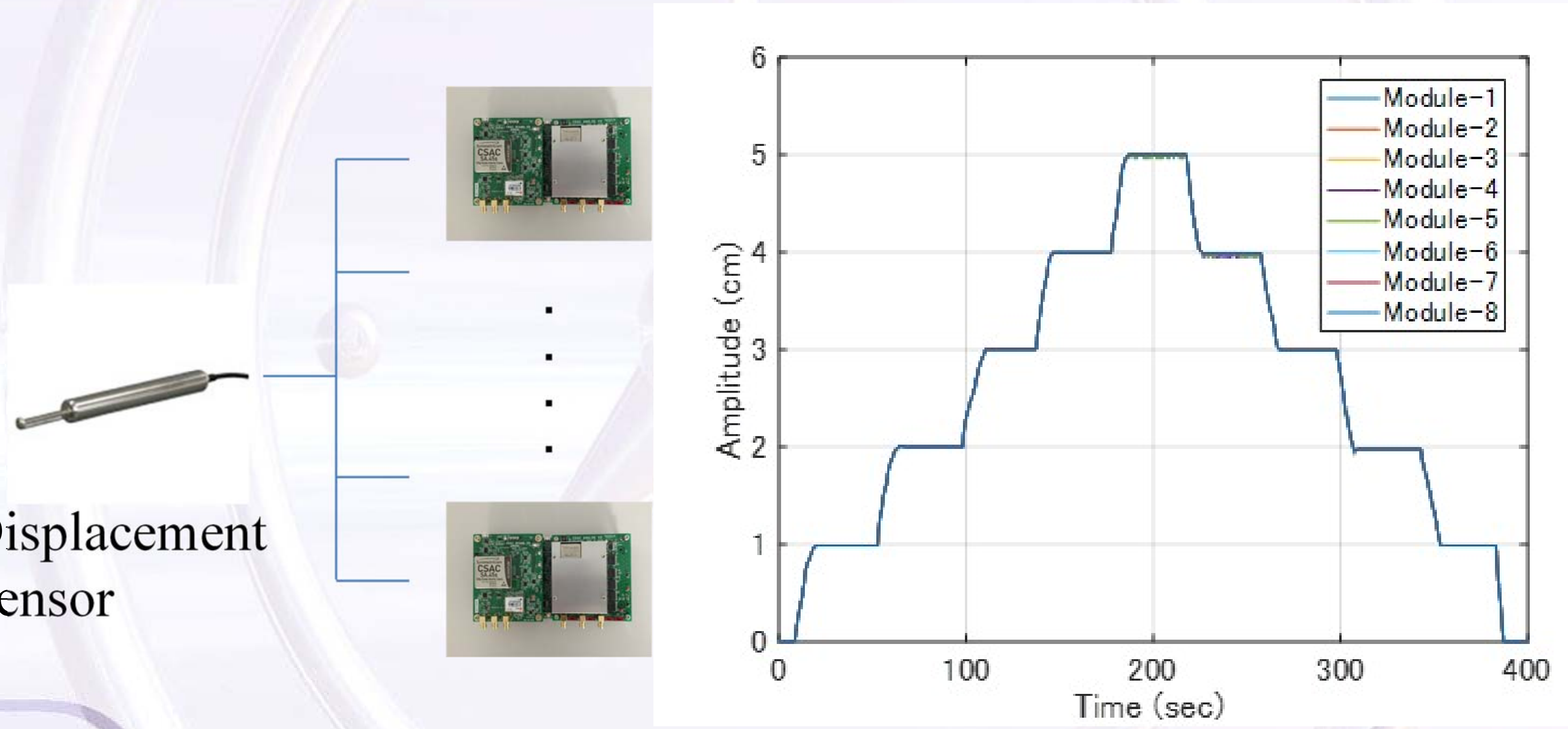
- Fourier phase spectrum ratio between three CSAC modules and one CSAC module as a master

CSAC Module can be used as a data logger

- Sensor unit with three axis MEMS acceleration sensor provides three external analog sensor input interface
- Any analog sensors can be connected to this unit



Example of Test Results

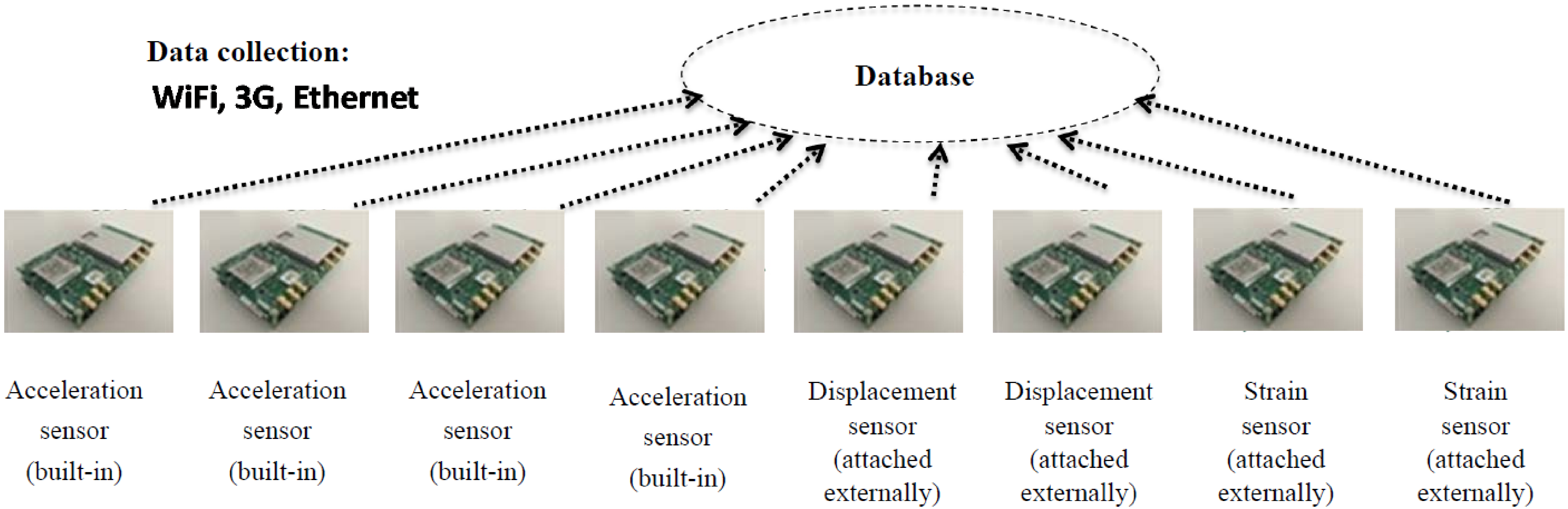


Displacement Sensor

Measured Displacement

- Measured displacement by eight CSAC modules are overlapped

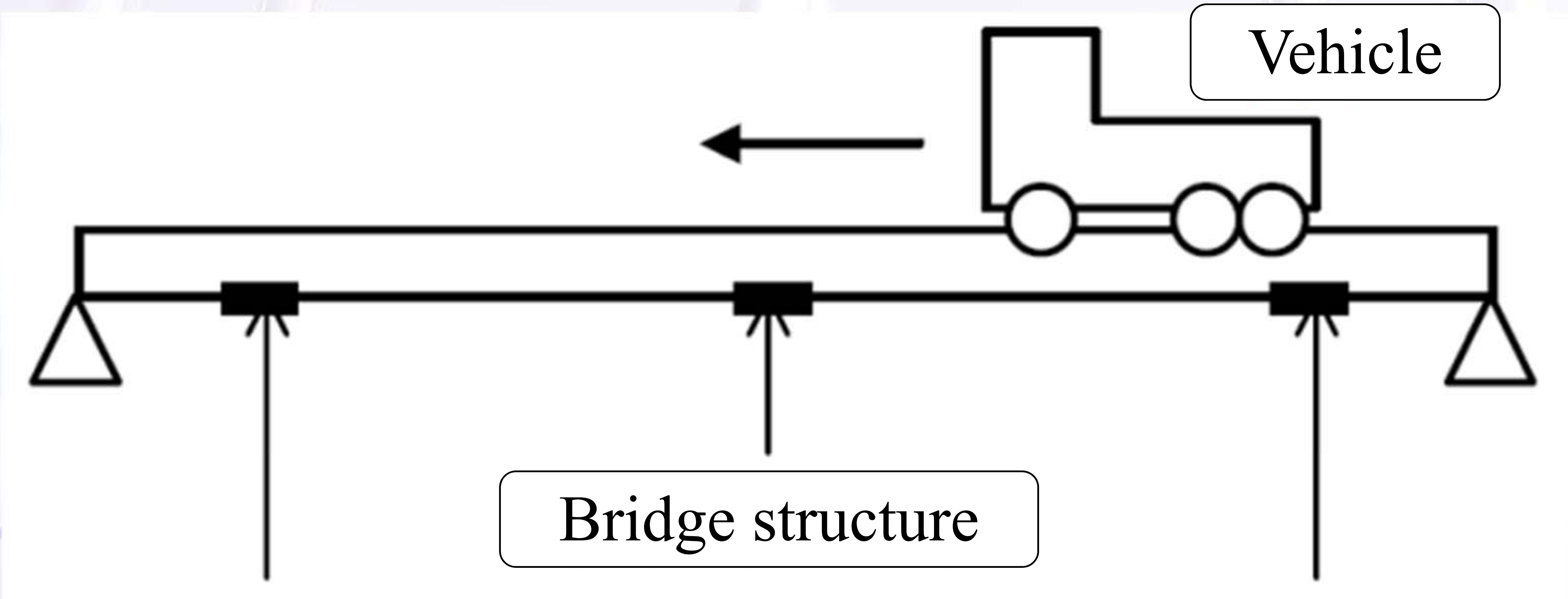
Construction of autonomous time synchronization sensor system



- Through use of the CSAC module equipped with a sensor unit incorporating a MEMS acceleration sensor or an external analog sensor, it allows for intermixed use of many kinds of sensors for the Disaster Big Data

Monitoring of Aging Bridges

Time Synchronization Measurement of Running Vehicle and Bridge Structure



http://www.nilim.go.jp/japanese/technical/bwim/program/kaisetsu.pdf

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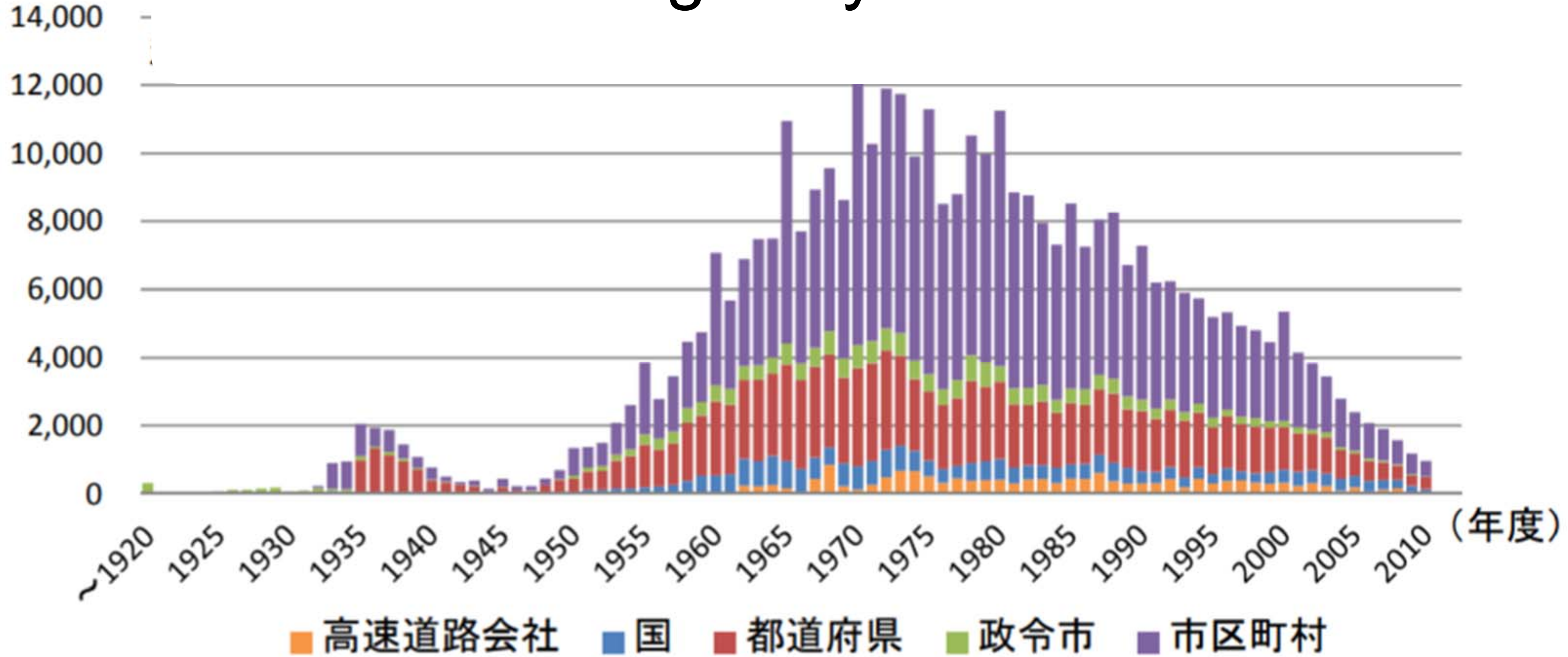
Cross-ministerial Strategic Innovation Promotion Program

インフラ維持管理・更新・マネジメント技術
～安全で強靭なインフラシステムの構築を目指して～

Number of Bridges by Construction Year



Summary

- Smart sensing technology
  - earthquake hazard mitigation
  - maintenance and management of civil infrastructures
  - maintenance and management of World Heritage Structures
- Case study
  - Wireless sensor network
  - Autonomous time synchronization sensing with CSAC

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Acknowledgement

This research was partially supported by the New Energy and Industrial Technology Development Organization (NEDO) through the Project of Technology for Maintenance, Replacement and Management of Civil Infrastructure, Cross-ministerial Strategic Innovation Promotion Program (SIP).

This research was also partially supported by JSPS KAKENHI Grant Number JP16K01283.