Im PACT Tough Robotics Challenge
- A National Project of Japan Cabinet Office on Disaster Robotics

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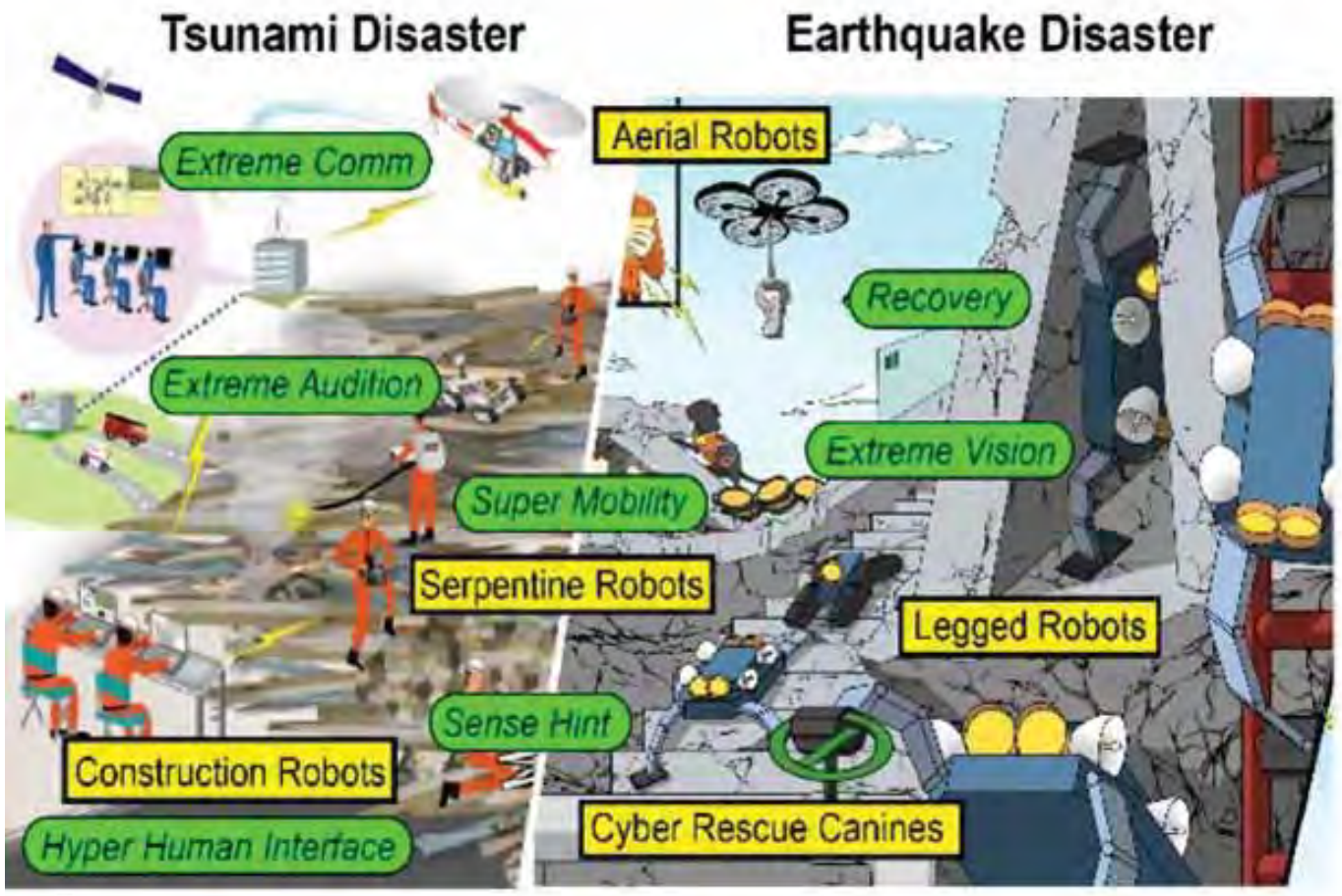
President, International Rescue System Institute
Past President, IEEE Robotics and Automation Society

ImPACT-TRC: Background

- **Target: Frequent natural and man-made disaster Robotics for Effective Solution**
  - Preparedness, Response and Recovery, Search and Rescue
  - Impossible for Human, High Risk for Human, Rapid/Efficient Task Execution
- **Objective: Tough Robust Roboticss ←←←← Fragile Technologies**



Tough & Robust

- ✓ Accessibility in extreme conditions
- ✓ Sensing in adverse conditions (hearing, watching and touching)
- ✓ Recovery from failure
- ✓ Compatibility with disaster environment

Robot Needs: Response to Earthquake

Disaster Mission	Insufficiency	ImPACT-TRC Solution
Surveillance Gather info from sky OSSOC Firefighters Police, Military	**Drones** but Risk of crash Wind & rain	**Mini-Surveyor** Robust in strong wind/rain Lower risk
S&R Find victims in rubble Firefighters Police, Military Ressue Dogs	**Rescue Dog** but Where run? Why barked?	**Cyber Resc. Dog** Cyber suit for remote monitoring and guidance
	Scopes but Mobility Where?	**Serpentine R. (Thin)** Penetrate into rubbles to search and comm.
Const-ruction Remote work Const. Company Local Gov.	**Remote C.** but Low mobility Low efficiency	**Construction R.** Dual arms with high power & precision for tasks & mobility




Kumamoto-EQ
ImPACT-TRC
Investigation

飛行ロボット

Aerial Platform for Disaster Survey

[Nonami, ACSL]

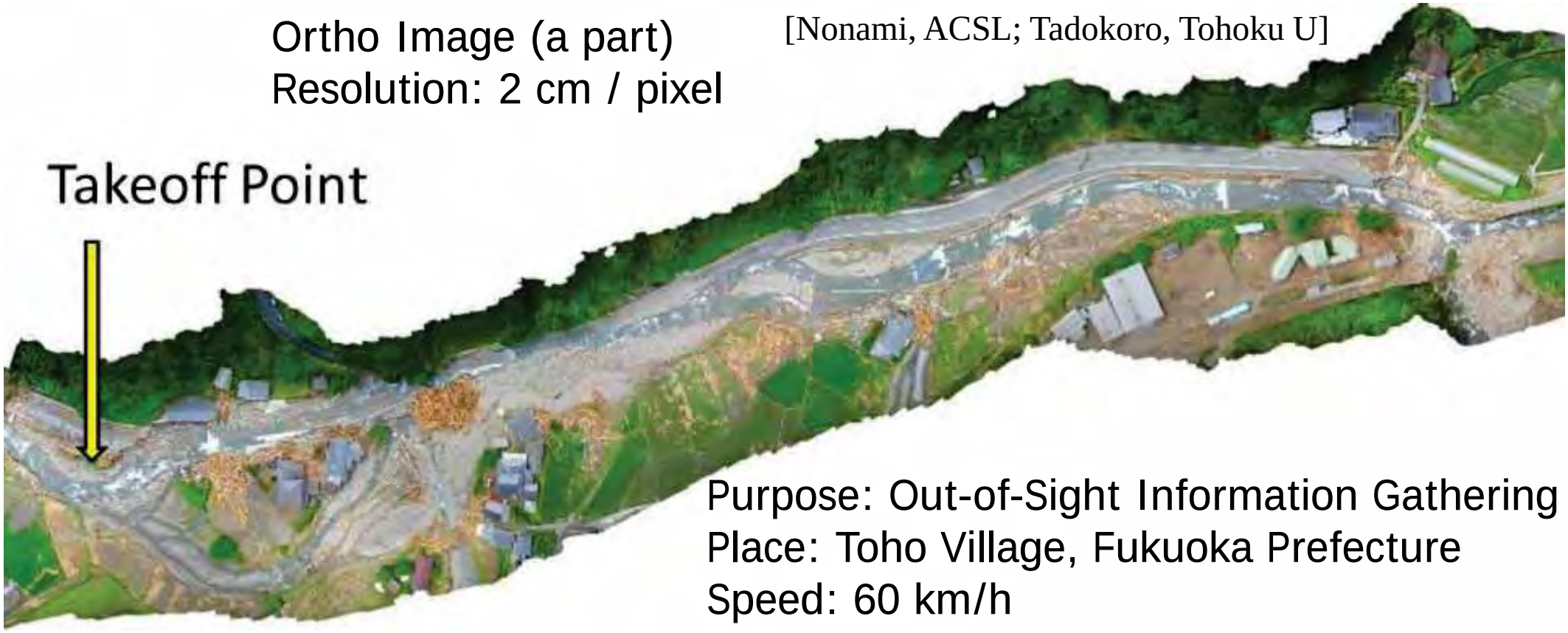
Length	1,173mm
Hight	483mm
Weight	7.7kg
Dry weight	5kg
Flying speed	20m/s
Gust wind	10m/s
Water protection	IPX3
Four eye camera Resolution	20 megapixcel
Shutter speed	8fps(2fps/camera)

Northern Kyushu Heavy Rain Flood

Northern Kyushu Heavy Rain Flood

Ortho Image (a part)
Resolution: 2 cm / pixel

[Nonami, ACSL; Tadokoro, Tohoku U]



Purpose: Out-of-Sight Information Gathering
Place: Toho Village, Fukuoka Prefecture
Speed: 60 km/h
Flight Time: 7 min

<Achievement>

- Information was gathered by aerial robot
- Data were give to FDMA, CAO, Fukuoka Pref., etc.
- The data quality and the robot specification were enough for the needs.
- Various lessons were learned
  (out-of-sight flight, position sharing, map of electric cables,
  support system, local information sharing system)

Remote Sound Source Exploration

[Nakadai, TITECH; Kumon, Kumamoto U; Okuno, Waseda U]

Drone with a remote robot-audition technology to detect/identify human voice under significant noise, which provides an efficient method to search survivors in need of help.

Multirotor helicopter with a microphone array

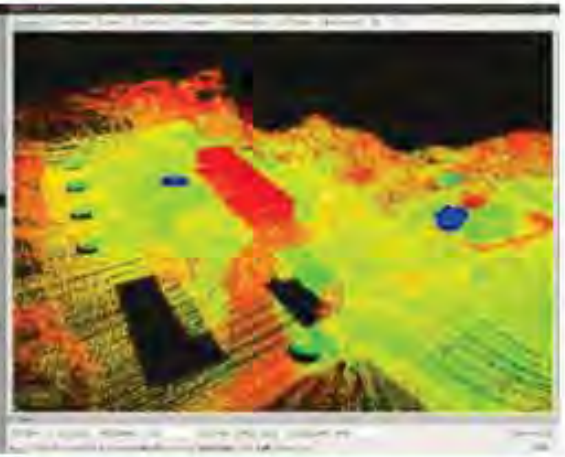
HARK
Honda Research Institute Japan Audition for Robots with Kyoto University

Keytechnology:

- Integration of sound source localization/separation and sound source identification using deep learning techniques
- Embedded acoustic signal processing system; (Embedded HARK)
- Robust wide-range 3D localization

udio-signal processing board ; RASP-MX

16ch Microphone-array with an embedded audio signal processing system (RASP-MX)



Sound sources on the ground are localized and displayed on a pointcloud map in realtime (blue dots show the positions of targets).
Sensory information is transmitted via ToughWireless technology to GCS.

索状ロボット

Overview: ImPACT Thin Serpentine Robot Project

Missions

- Rapid search and rescue for victims trapped in collapsed building
- Inspections in a narrow space in plants and infrastructures for daily use

[Konyo, Tadokoro, Tohoku U]

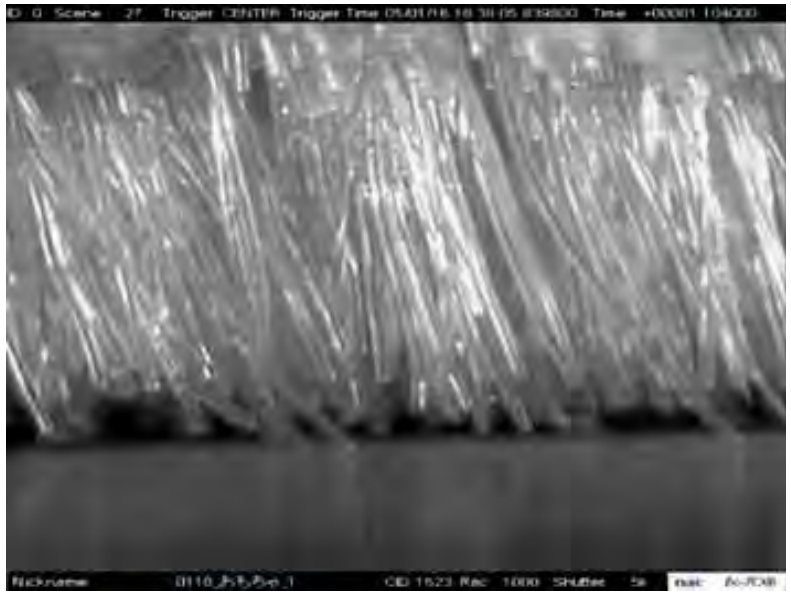
Our conventional approach:

Active Scope Camera （ASC）

- Self-propelled video scope [IROS 07]

Mechanism [JRM 0]

Ciliary vibration drive



The ASC can propel forward with the ciliary vibration drive, which generates propulsion force by vibrating tilted cilia wrapped around the flexible robot.

[Konyo, Tadokoro, Tohoku U]

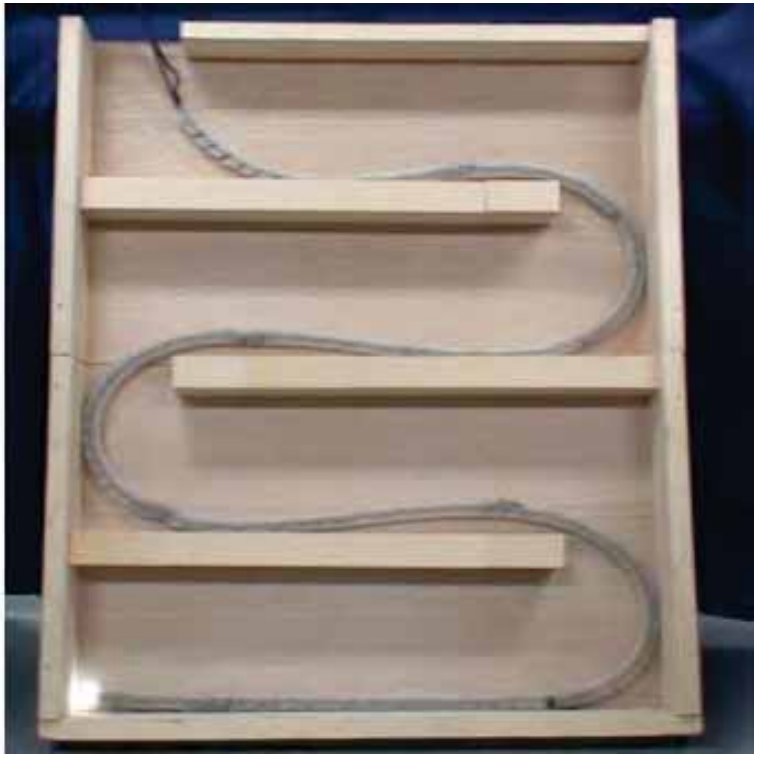
Advantages of ASC (1)

Whole contacted surface generates driving force

Lager contact area generates larger propelling force by distributed drive

Big advantage for inspection in a narrow confined space

Standard industrial video scope (x3)



Active Scope Camera (x3)

[Konyo, Tadokoro, Tohoku U.]

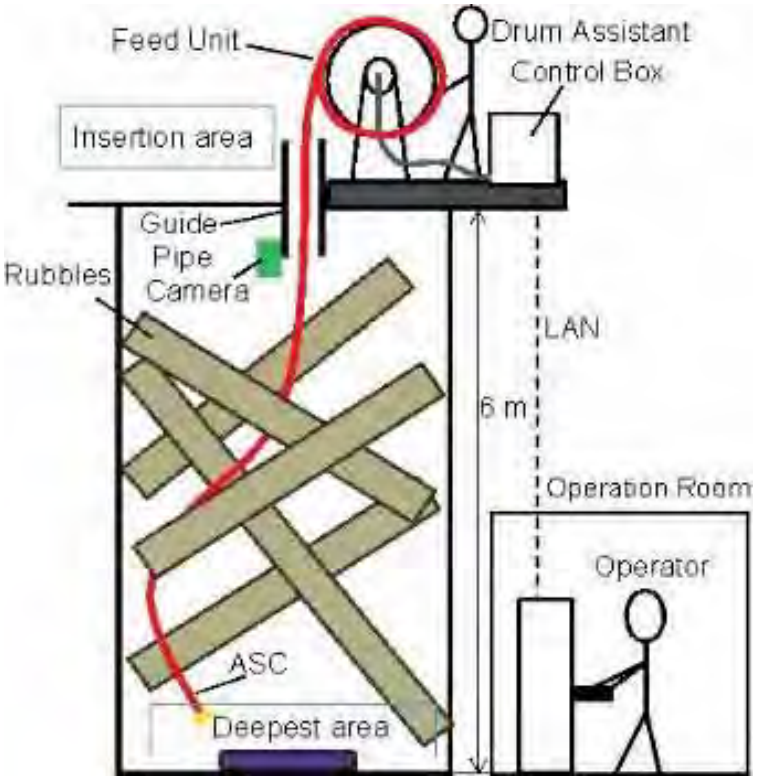
Advantages of ASC (2)

Light flexible continuum body

- **Robustness in rubble**
- **Durability**

[Konyo, Tadokoro, Tohoku U]

Vertical Exploration with Tube-type ASC [IROS2014]



×8.0

×1.0

Active Scope Camera Deployment to Construction Accident in Jacksonville

[Tadokoro, Tohoku U
Murphy, USF]

- Jan. 4-5, 2008 @ Jacksonville, FL
- Gathered evidence info. 7 m deep
  - Shape & direction of RC cracks
  - Shape & cross section of flakes
  - Image of spaces inside
- Impossible by other equipment
  - size, mobility, controllability

TOHOKU

International Rescue System

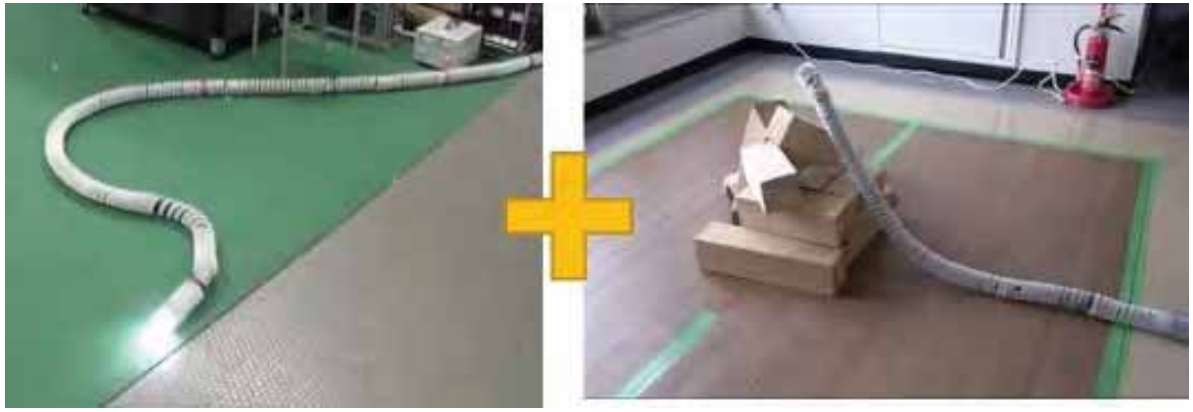
Project Topics and Groups

Insufficient Capabilities in Real Missions

- Mobility (rubbles, gaps, turning, speed, ...)
- Sensing (for Search and Navigation)
- Usability (for quick easy operation)

Mobility

Hyper mobility by Jet injections
Tadokoro, Konyo (Tohoku Univ.)



Ciliary vibration drive　　Air-jet floating

Vision

Visual SLAM
Okatani (Tohoku Univ.)

Image Recognition
Yamazaki (Shinshu Univ.)

Auditory

Realtime speech enhancement Posture estimation
Okuno, Bando (Waseda Univ., AIST)

Offline speech enhancement
Saruwatari (Univ. Tokyo)

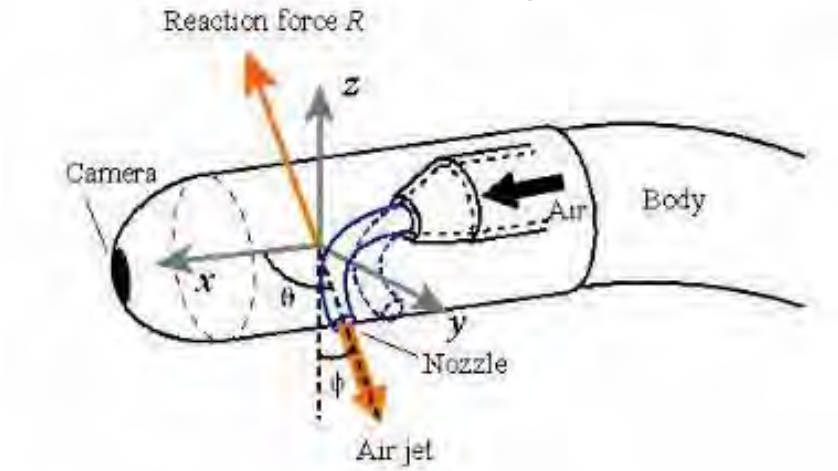
Tactile

Contact Sensing
Konyo (Tohoku Univ.)

[Konyo, Tadokoro, Tohoku U]

Advanced Mobility by Air-jet

Head Floating by Air-jet



Key issue:

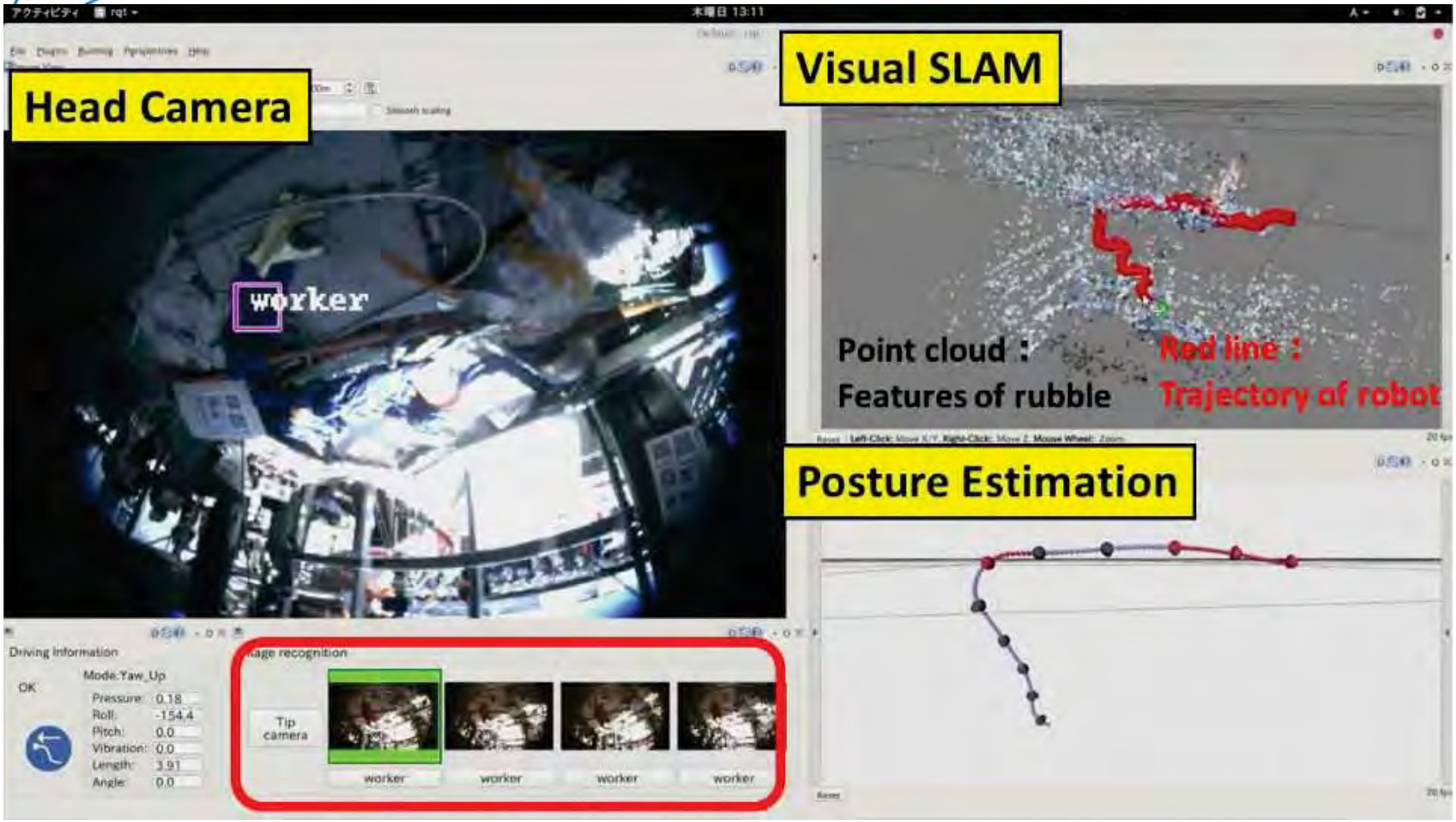
Achieving stability of the lightweight flexible cable in the air

Demonstration in wooden rubble

Running on concrete rubble

[Ambe, Konyo, Tadokoro, Tohoku U]

Sensory Integration



Detection of Pre-Registered Targets

[Konyo, Tadokoro, Tohoku U]

Visual Support for Victim Search

[Yamazaki, Shinshu U]

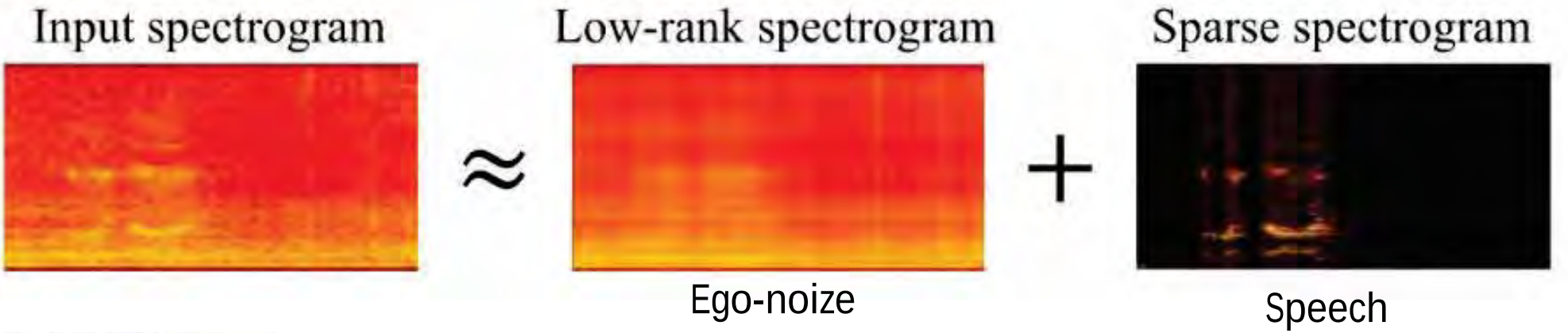
- **Image recognition and categorizing rubble**
  - Analyzing objects in video → Extracting possible objects

Input Image | Image segmentation | Detection of target

Unsupervised Learning
Categorize without prior knowledge using NN (Convolutional Autoencoder) and automatically updated.

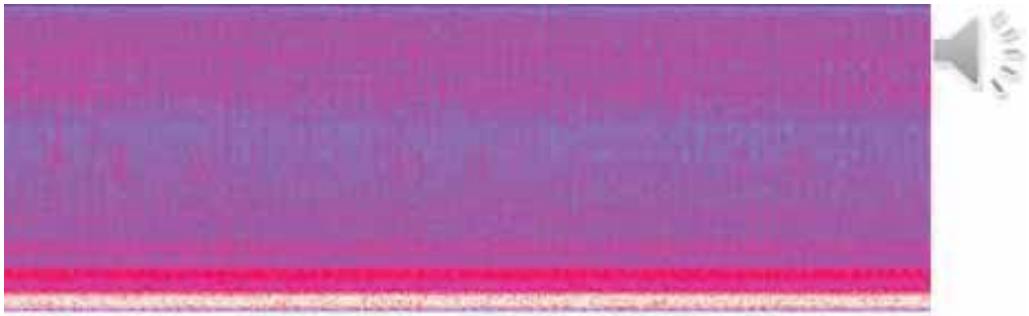
Blind Speech Enhancement

[Bando, Kyoto U; Okuno, Waseda U]

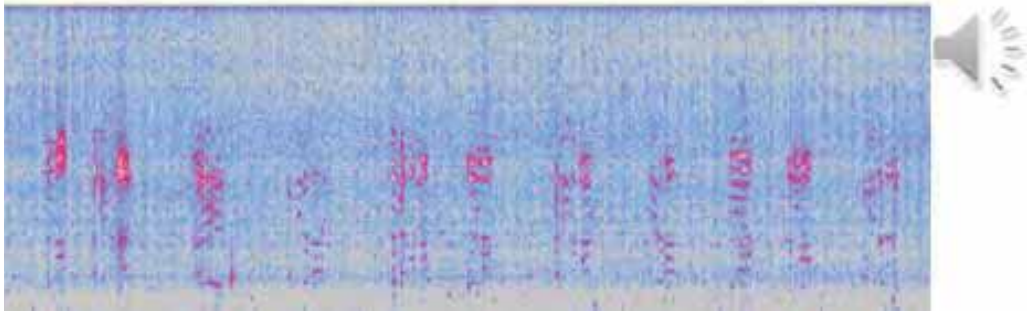


Evaluation in the simulated collapsed house

Input Spectrogram



Spectrogram of Enhanced Speech

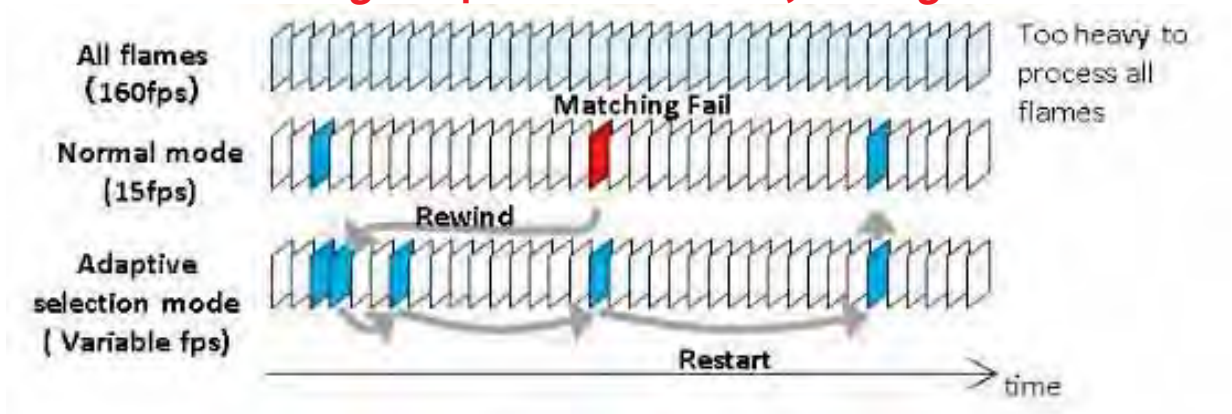


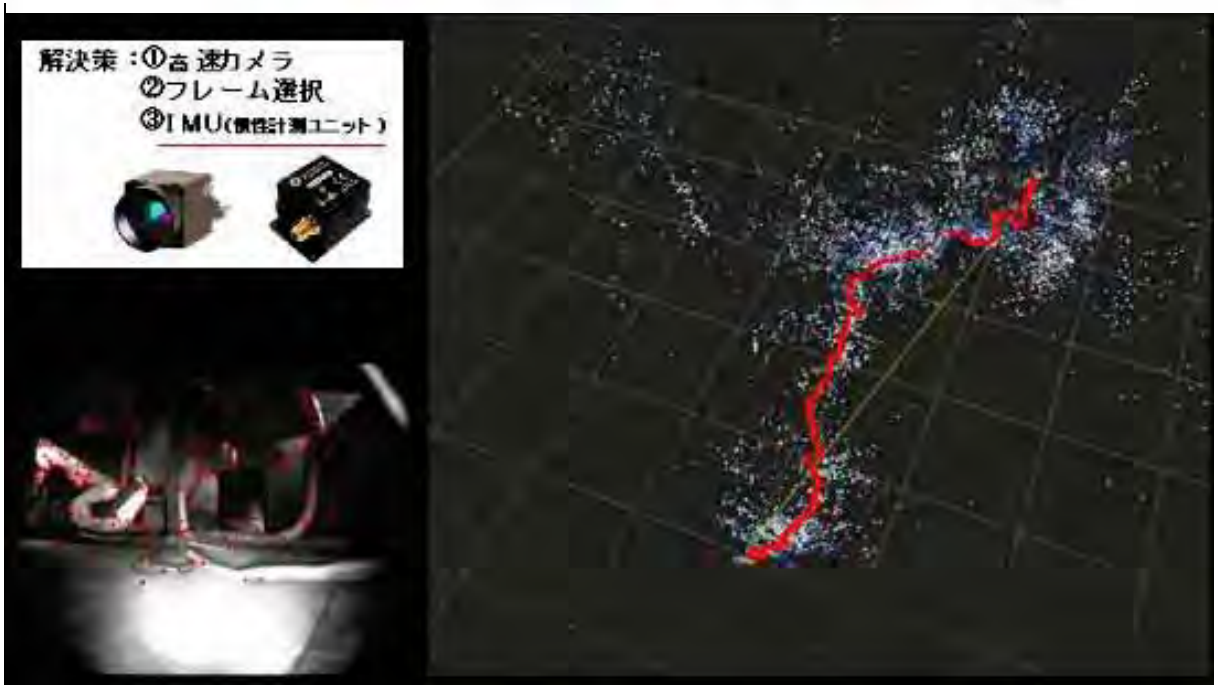
Visual SLAM

[Okatani, Tohoku U]

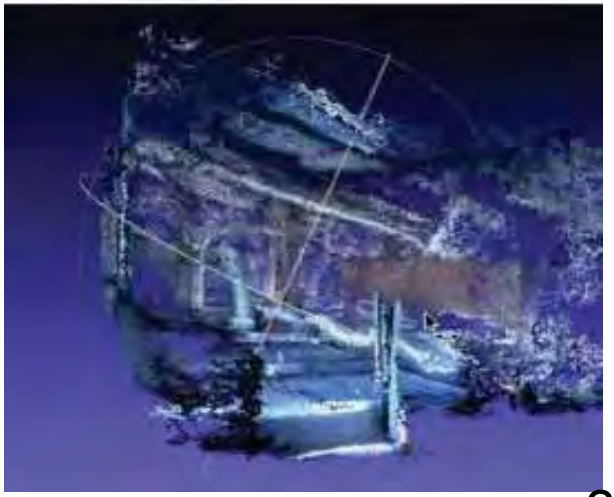
Bottleneck: Confined Space (Distance to objects, Tracking failure by rapid movement)

Solutions: Adaptive selection of flames from high-speed camera, Integration with IMU





Visual Improvement (off-line)



Posture Estimation by IMU and Acoustic Sensors

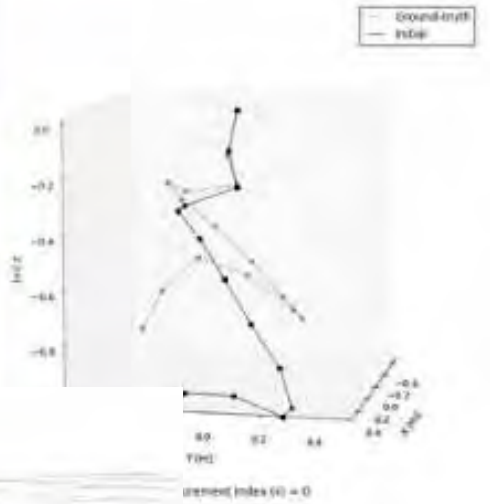
[Bando, Kyoto U; Okuno, Waseda U]

Difficulty: High acceleration by collision in debris

Solution: IMU + MultiSpeakers + Microphones

- **Sound arrival time differences → Estimate the posture**
- **Kalman filter (UKF) for integrating IMU and acoustic estimation**
- **Error < 0.2m for the ASC 3m long**

[Bando et al., Advanced Robotics, 2015, IROS2016]
Advanced Robotics Best Paper Award



Experimental Result at Hyogo Fire Tra

Contact Estimation and Visio-Haptic Display

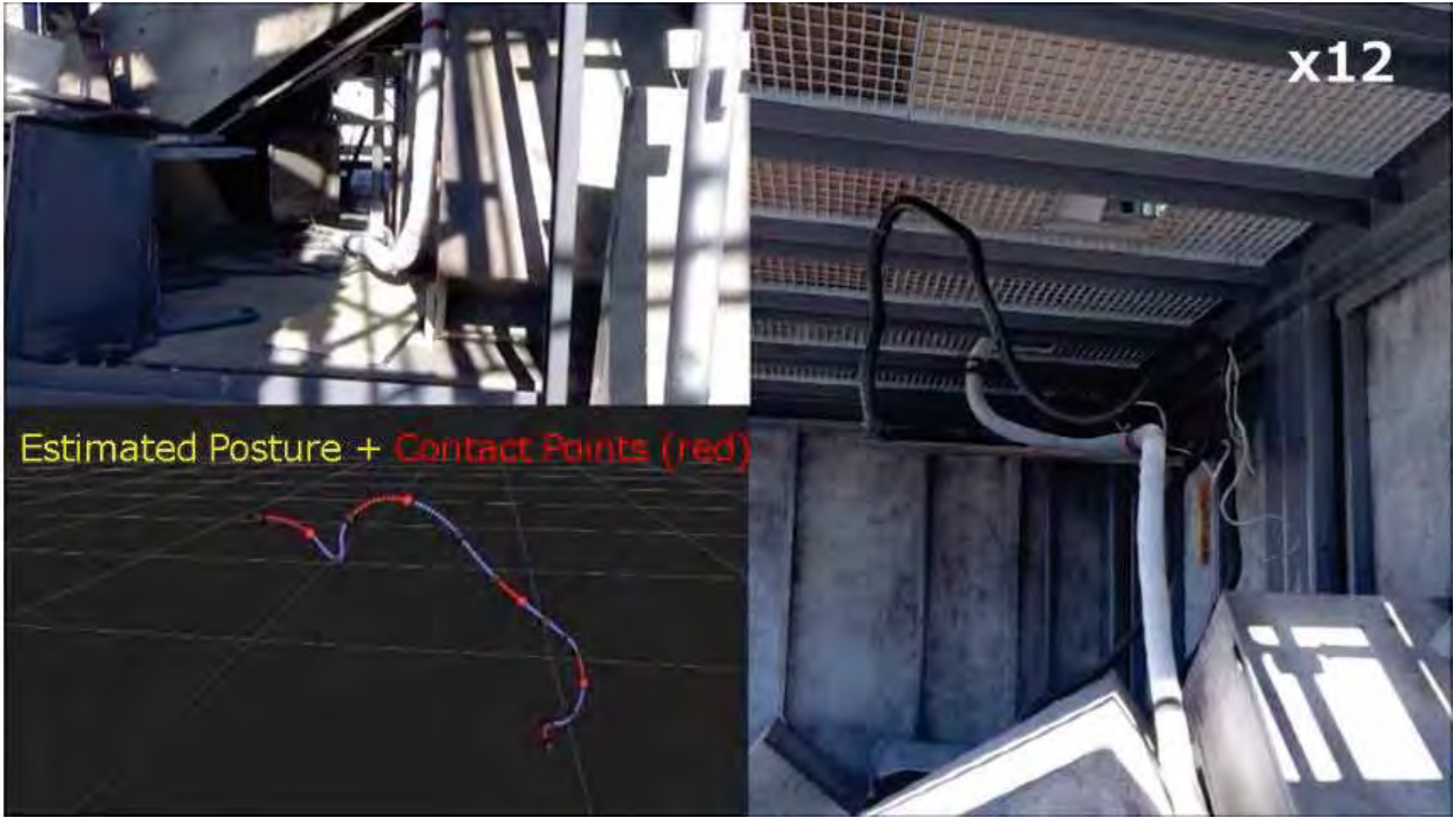
[Konyo, Tohoku U; Bando, Kyoto U; Okuno, Waseda U]

Contact Information for Navigation

- Detection of deadlock by local contacts
- Keeping contact area for stable drive

Estimation by Distributed Vibration Sensors

- Vibration motor for excitation
- Machine learning for recognizing the change of vibration

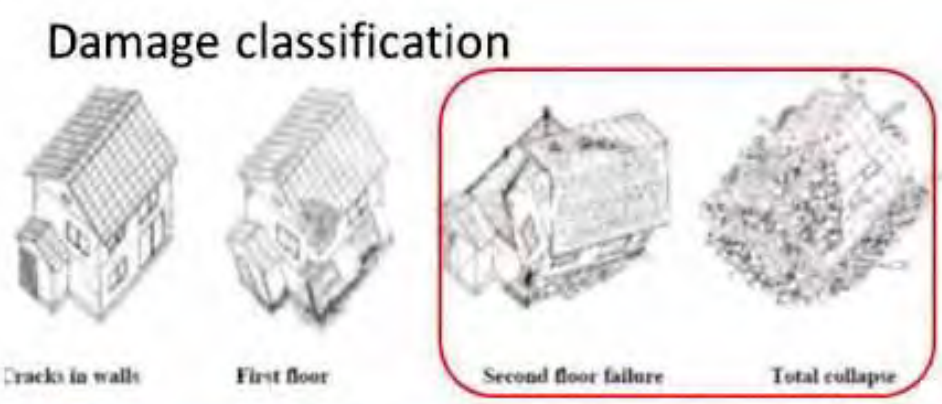


Inspection of collapsed house by landslide

Okayama, Western Japan Heavy Rain [July.25-26, 2018]

- Target: Two-story wooden house collapsed by a landslide due to heavy rain

[Konyo, Tadokoro, Tohoku U]



Inserted through 3-m pipe from the east side

Inspection of collapsed house by landslide

Okayama, West Japan Heavy Rain [July.25-26, 2018]

Passive type air-jet floating ASC was applied

Insertion depth: approx. 3 m (x2)

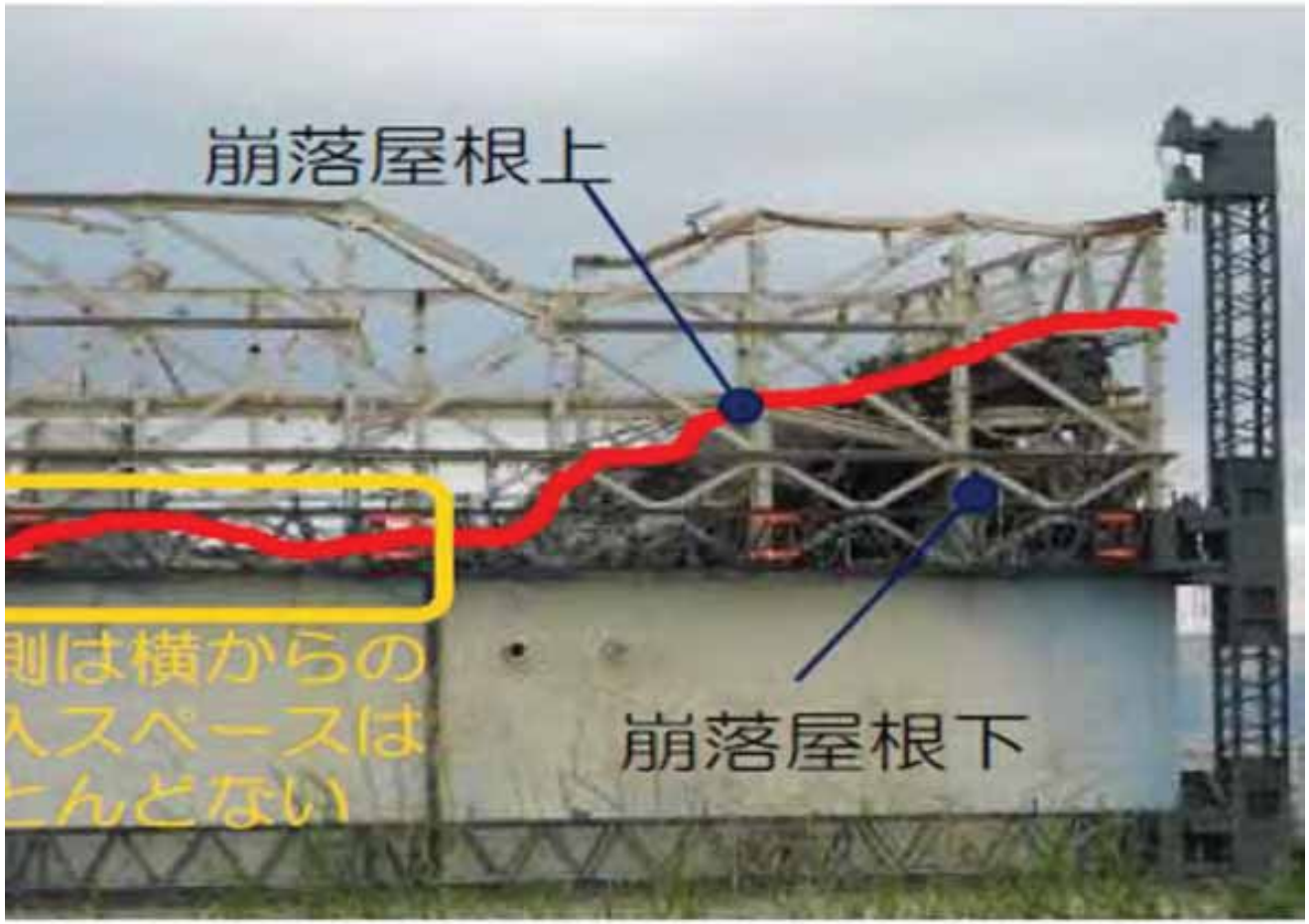
Insertion depth: approx. 5 m (x2)

- **Successfully inserted in 5 m max. through a narrow path**
- **Air-jet floating could surmount rubble with large steps and gaps**
- **Sensing system is necessary to localize the position**

Other problems：Durability and Operability

[Konyo, Tadokoro, Tohoku U]

Fukushima-Daiichi 1st Unit

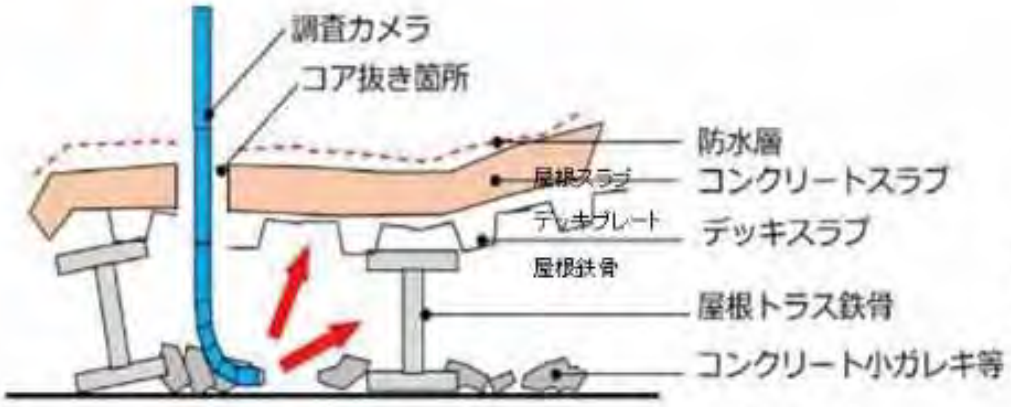


建屋カバー建設中の状況写真(201

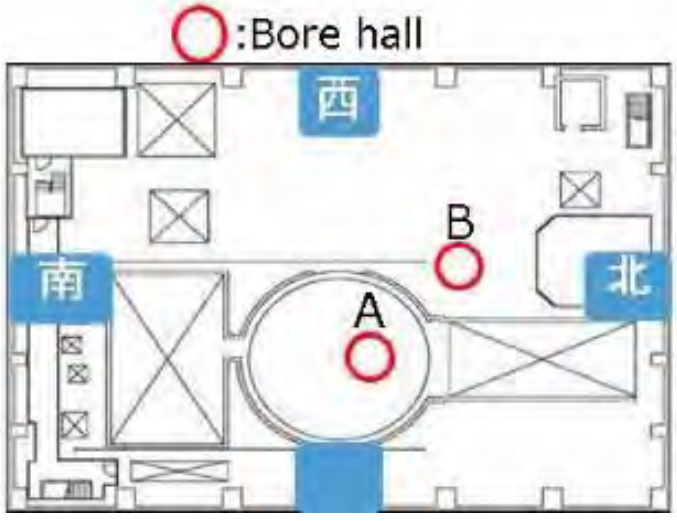
- Investigation of the operating floor (5F) under the dropped roof in order to extract used fuel rods
- A cover has been constructed to prevent leakage of radiation.
- Balloon in the building has captured image from the hatch.
- Pole camera from the cover had limited accessibility.
- No solution for heavily crushed area.

Structural Investigation (Dec 2016 – Feb 2017)

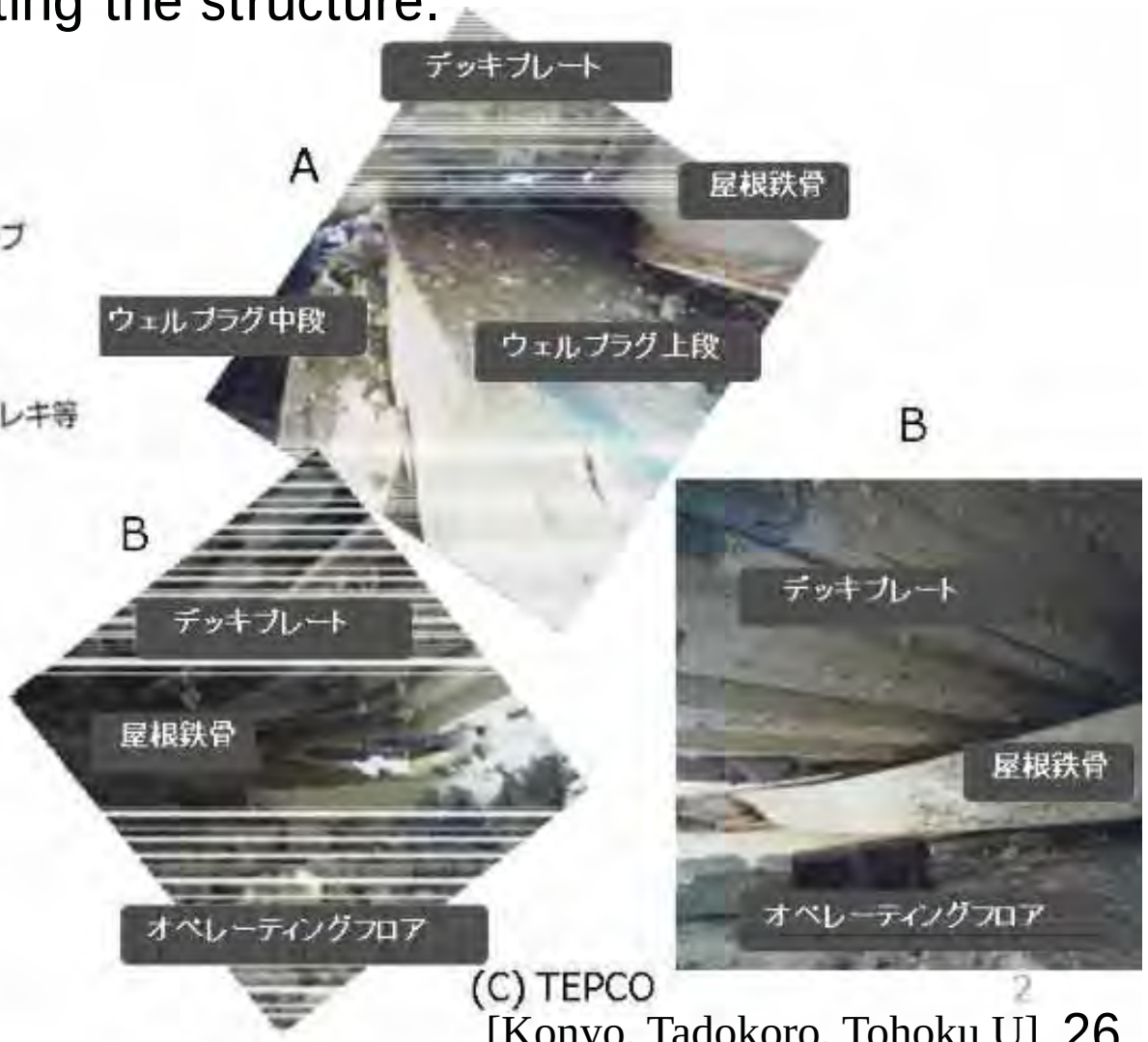
- Investigation of roof structure of the op. floor in the 1st Unit under debris
- Findings:
  - Roof iron framework has its original shape.
  - It can be removed by cutting the structure.



Usage of Active Scope Camera (ASC)



Op Floor

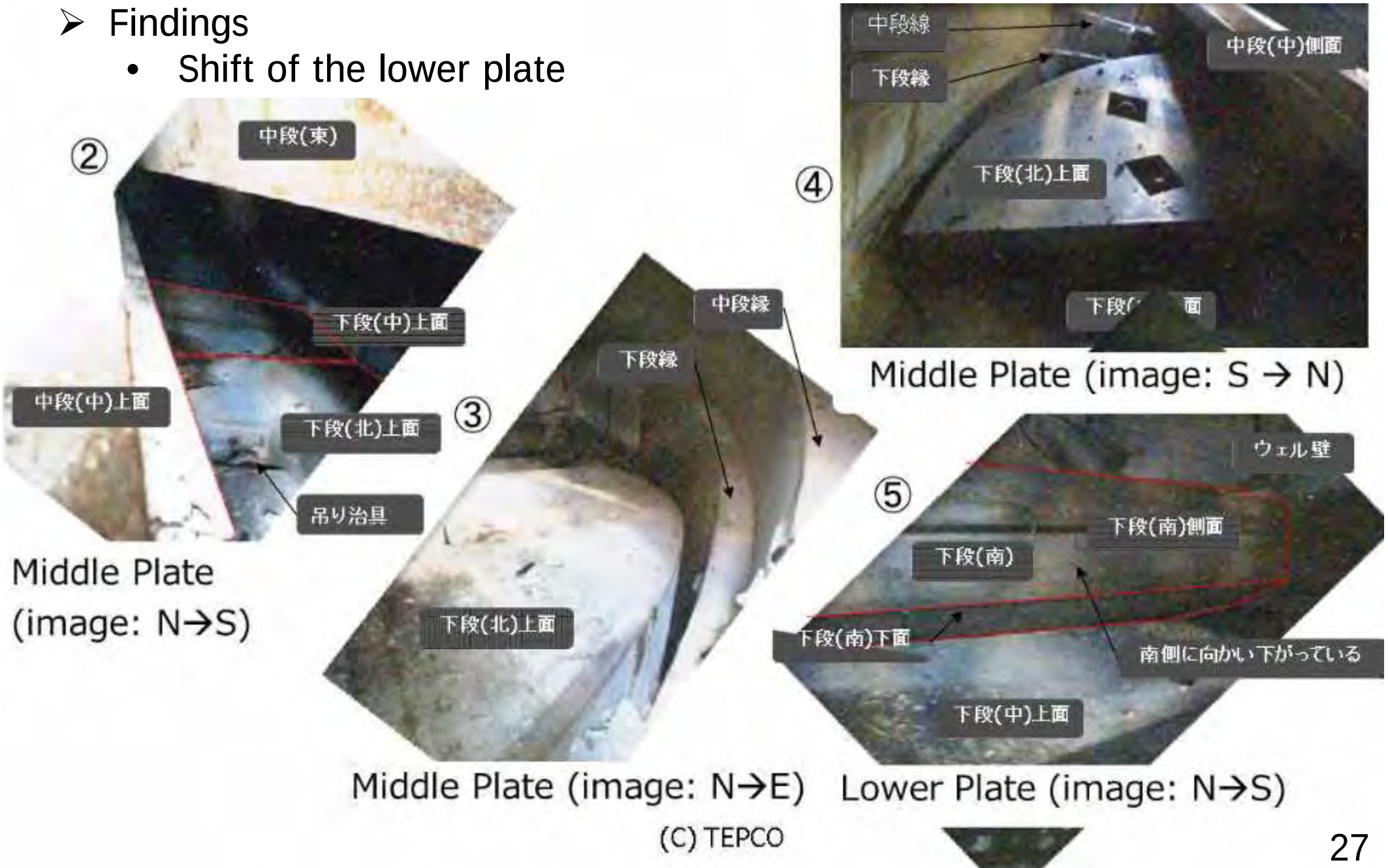


(C) TEPCO

Well Plug of PCV (Dec 2016 – Feb 2017)

[Konyo, Tadokoro, Tohoku U]

- Findings
  - Shift of the lower plate



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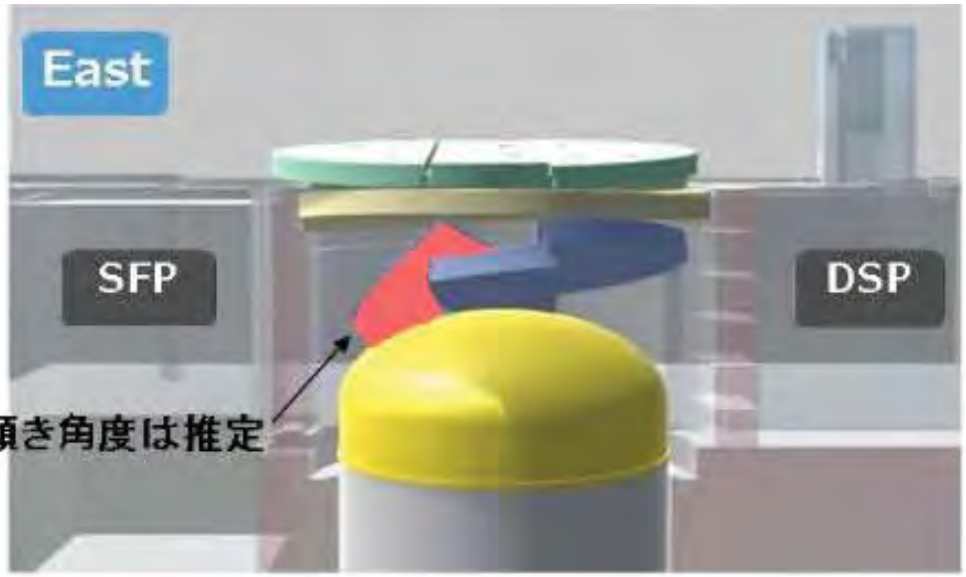
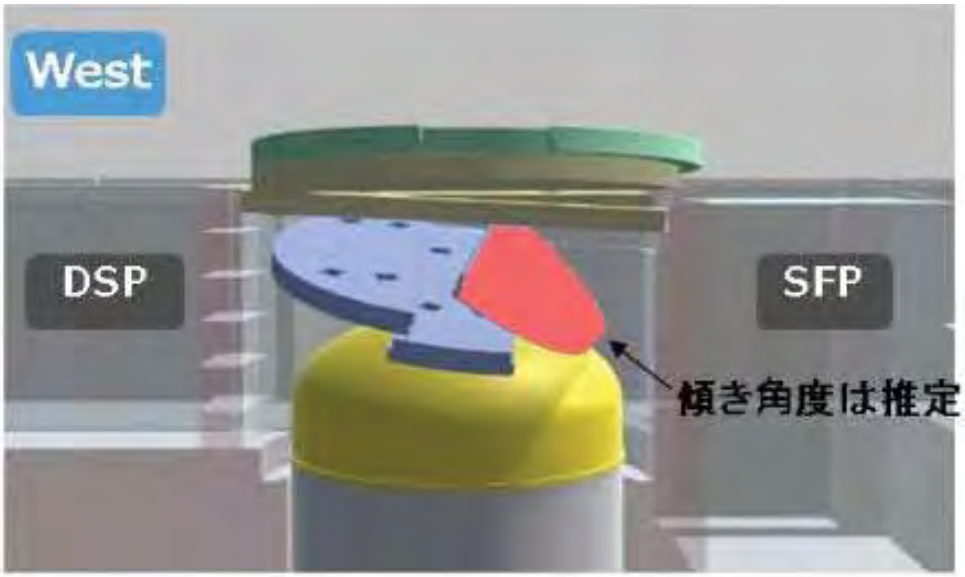
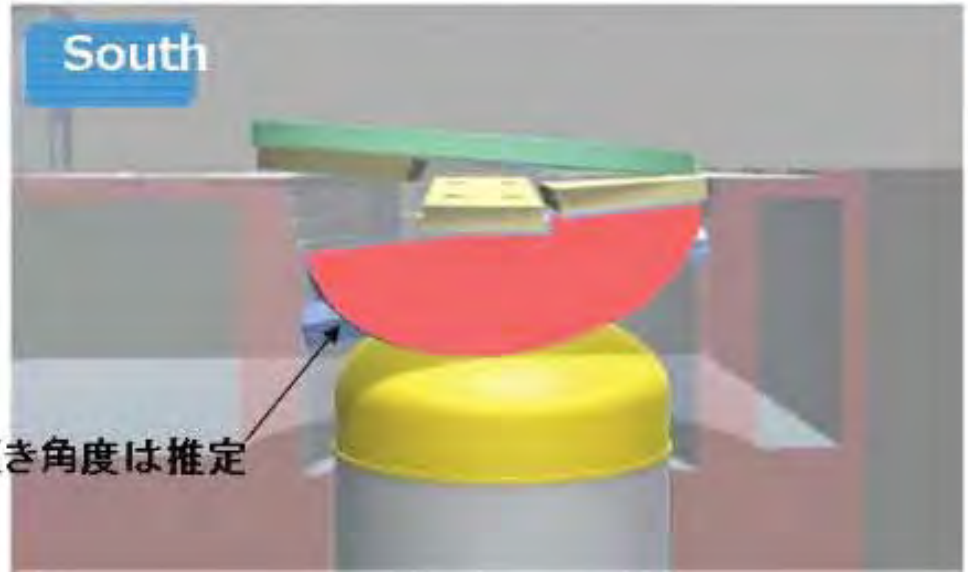
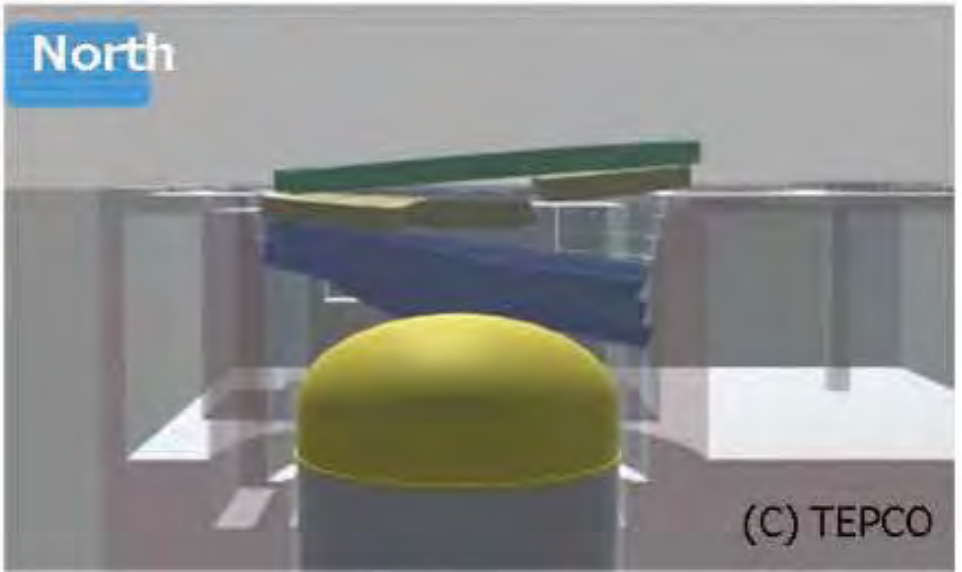




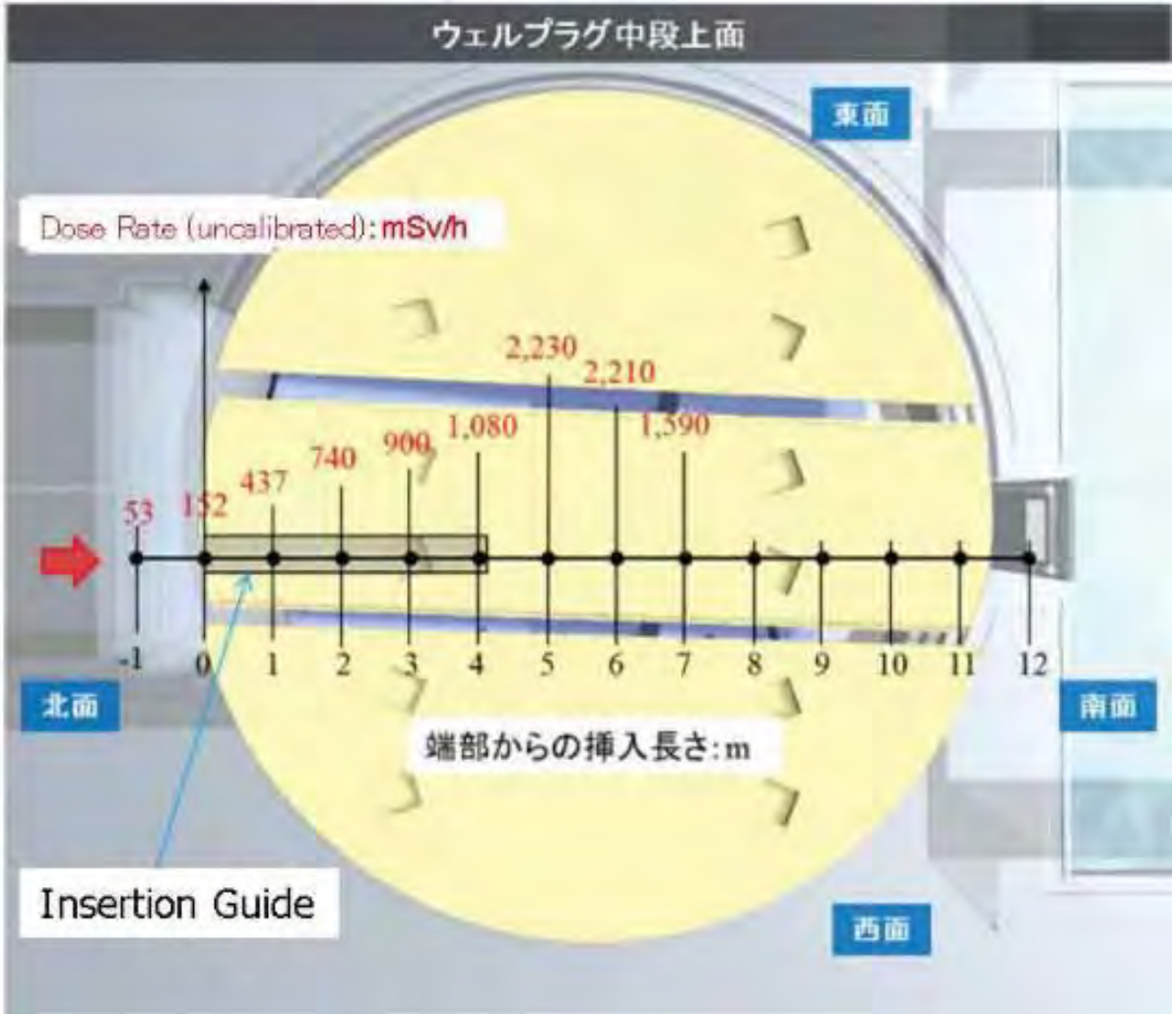




Dose Rate in Well Plug (Dec 2016 – Feb 2017)

[Konyo, Tadokoro, Tohoku U]

- Findings:
  - The center of well plug has higher dose rate



(C) TEPCO

Air-Jet Active Scope Camera for First Responders

- Portability by using air from air tank of firefighters (6 m in/tank for continuous jet = 20 m in regular operation) [Konyo, Tadokoro, Tohoku U]
- Lightweight metal nozzle by wrought Al-Mg alloy → better durability
- Lightweight design by limiting sensors (microphone, speaker, IMU)