A Robotics Innovation for USAR - ImPACT Tough Robotics Challenge

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2022.5.5 Humanitarian Network and Partnership Weeks
CURSOR Workshop

Kobe, Jan. 1995


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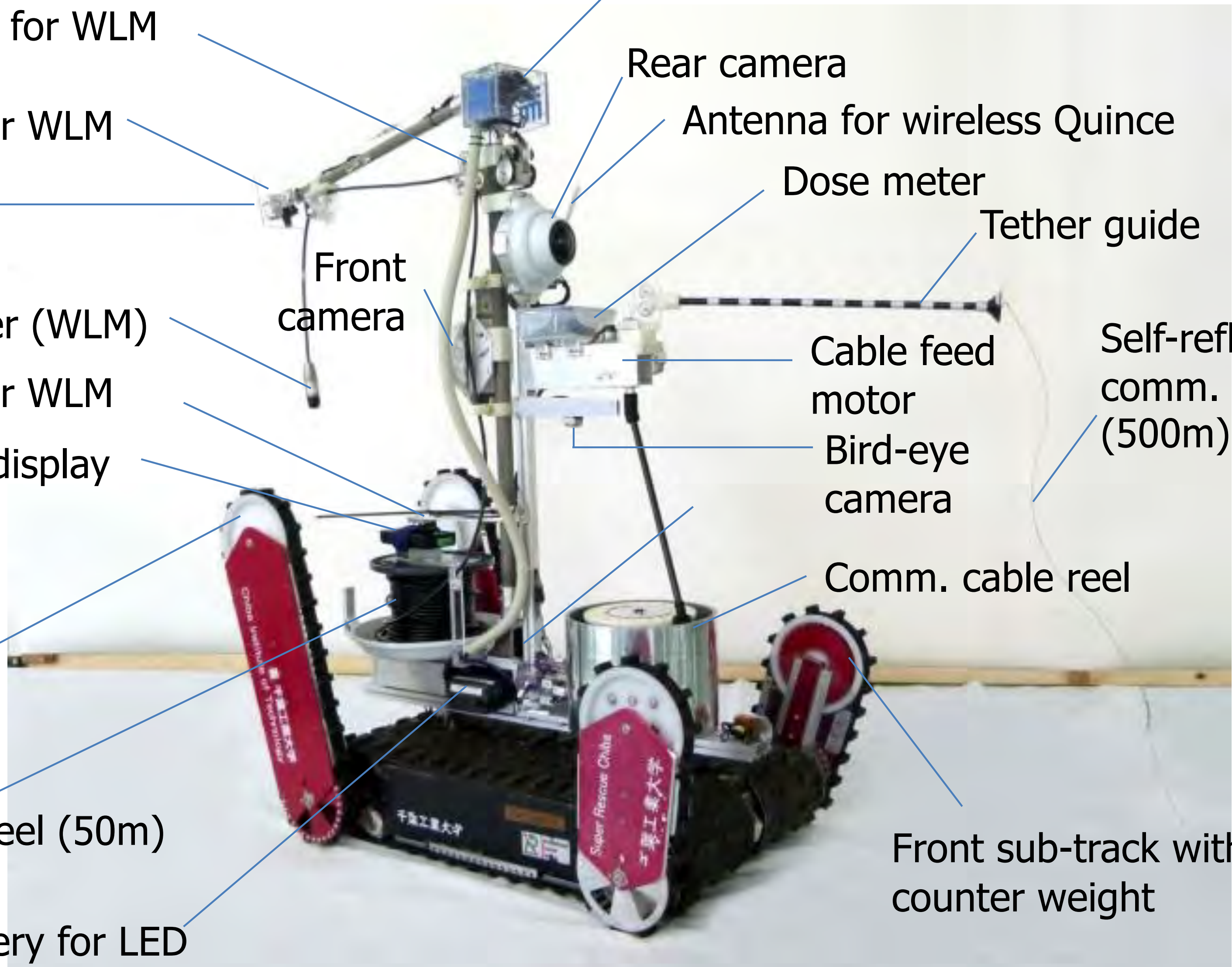
C'mon Sendai !!
Tohoku University
Seriously Damaged Bldg. 28 /588
Bldg. Damage: 448 MUSD
Facility Damage: 324 MUSD

Quince for Fukushima-Daiichi Nuclear Plant



千葉工業大学 Chiba Institute of Technology

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International Rescue System

Roles and Needs of Disaster Robots

What are Expected from Robotics?

Remote/automatic

A) Investigation of situation (e.g. information gathering)

B) Work for reducing damage (e.g. recovery works)

for Substituting human

When is Robotics Needed?

1) Inaccessible for human, such as confined space, high place, water, etc.
2) High (potential) risk of contamination, fire, explosion, etc.
3) Improve quality/accuracy by informatization, such as integration of information of position and data
4) Reduce the cost by remote/automated operation, such as of long-term/global routine works

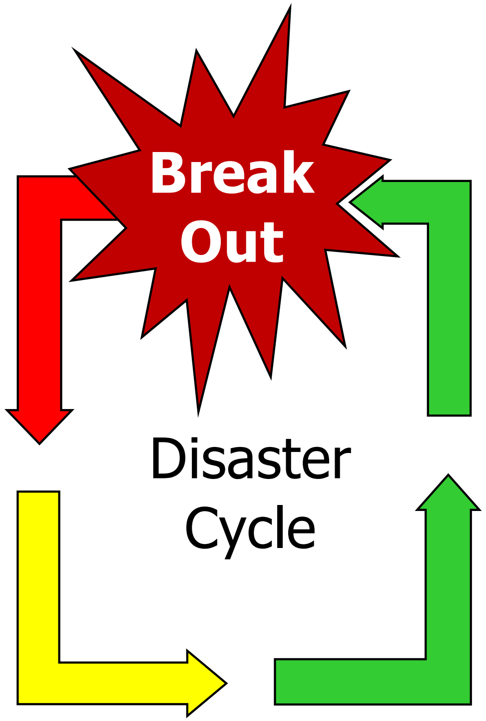
Disaster Cycle and Robot Needs

Calm-down at Acute Emergency

Response (Days)
- Evacuation
- Search & rescue
- Emergency investigation
- Emergency work
- Emergency repair

Reduce Risk

Preparedness (>10 yrs)
- Inspection of facilities
- Aseismic reinforcement
- Coastal levee maintenance
- Maintenance of aged infrastructures and factories



Recovery (Months)
- Damage investigation
- Remedial work
- Repair work

Recovery from Damage

Revival (Years)
- Daily life
- Economy, labor

Return to Normal

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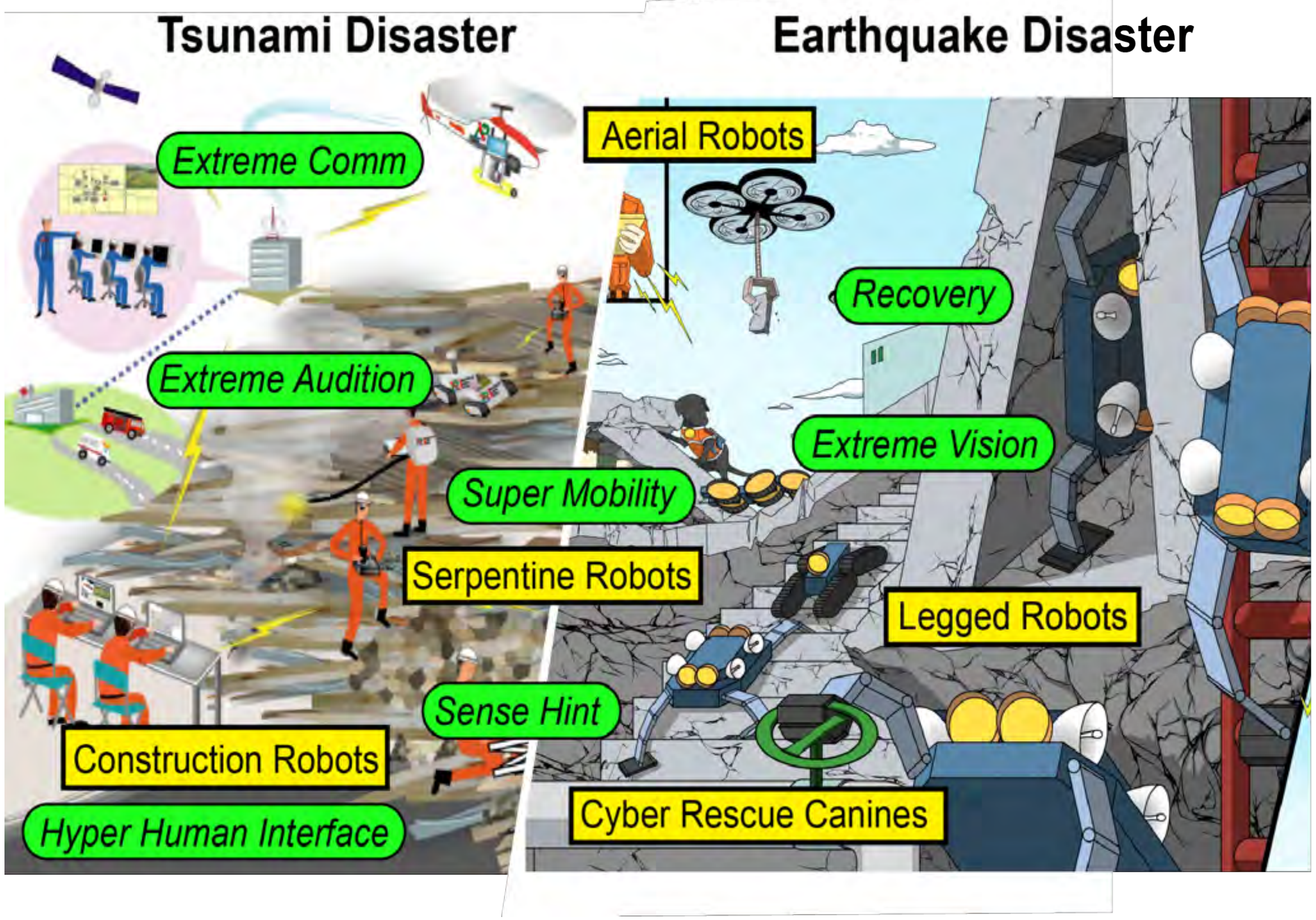
- **Frequent natural/man-made disaster – Robotics for Effective Solution**
  - Preparedness, Response and Recovery, Search and Rescue
  - Impossible for Human, High Risk for Human, Rapid/Efficient Task Execution
- **Tough Robust Robots** ← Fragile Technologies



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**

Kumamoto-EQ
ImPACT-TRC
Investigation

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

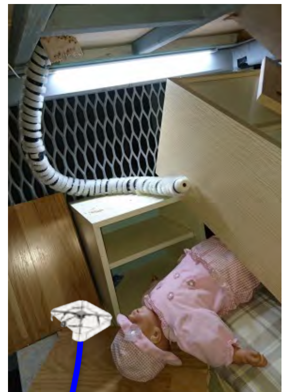
Firefighters
Police, Military
Ressue Dogs

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.

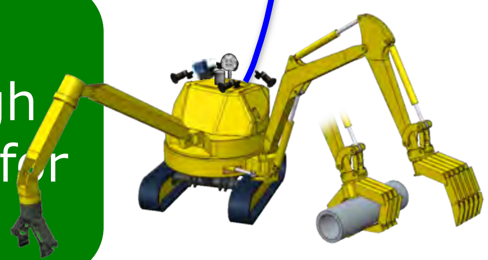


Const-ruction
Remote work

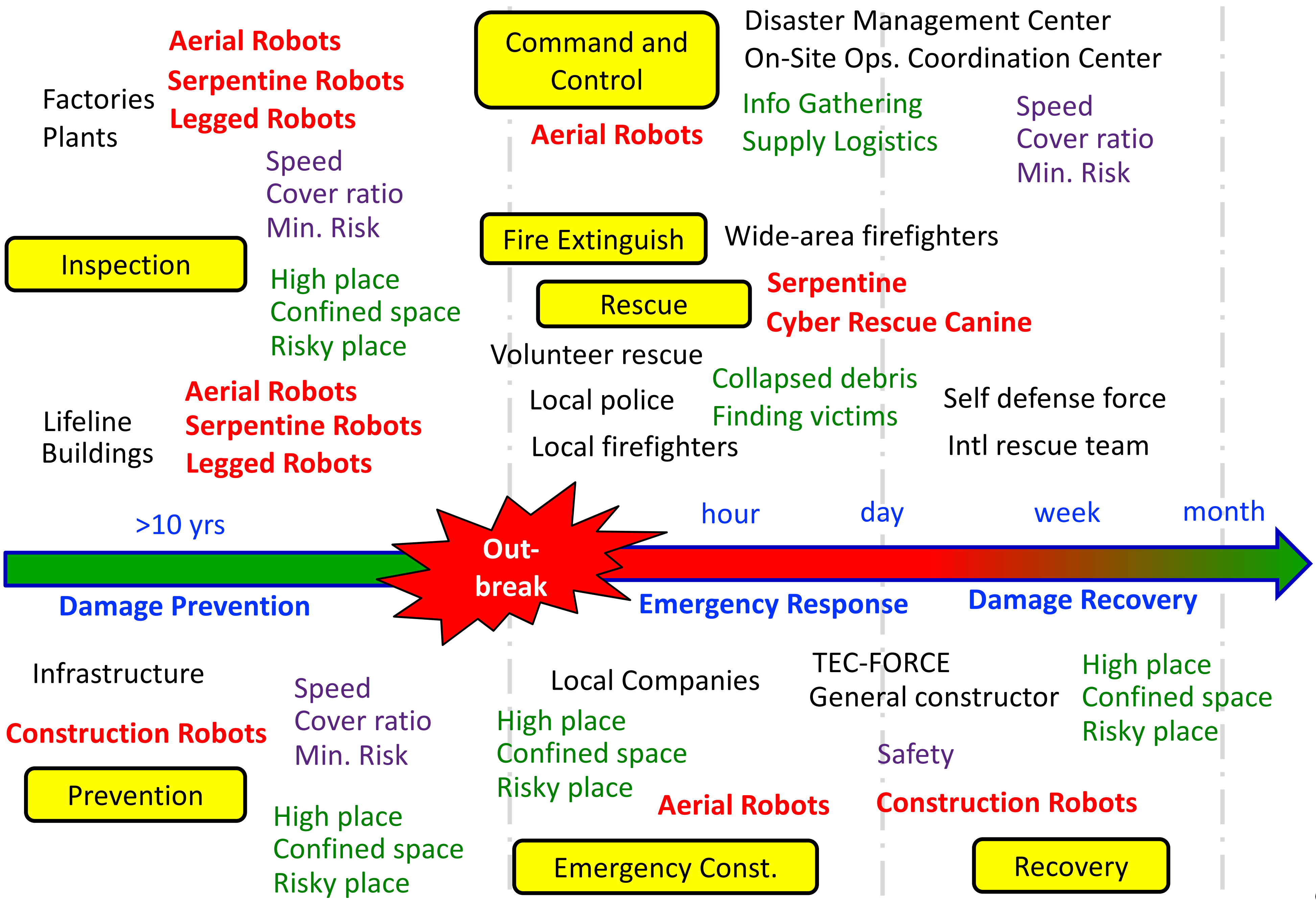
Const. Company
Local Gov.

Remote C.
but
Low mobility
Low efficiency

Construction R.
Dual arms with high power & precision for tasks & mobility



Robotics Scenario for Disaster Mitigation



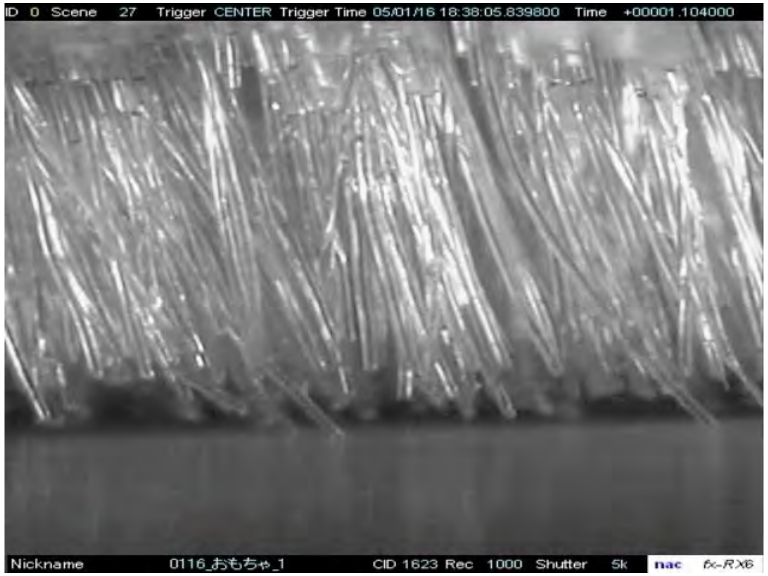
Active Scope Camera, A Serpentine Robot

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]

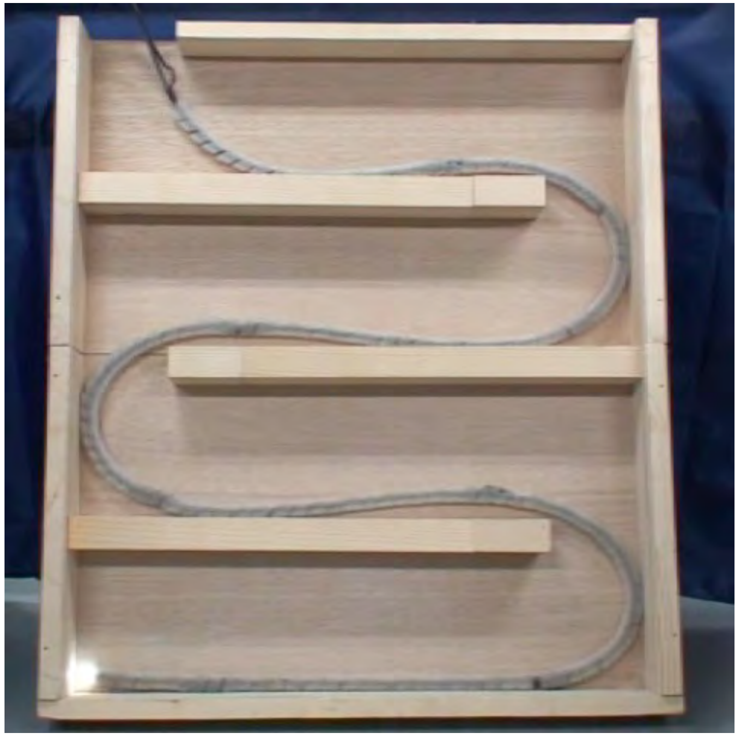
Advantages of ASC (1)

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]

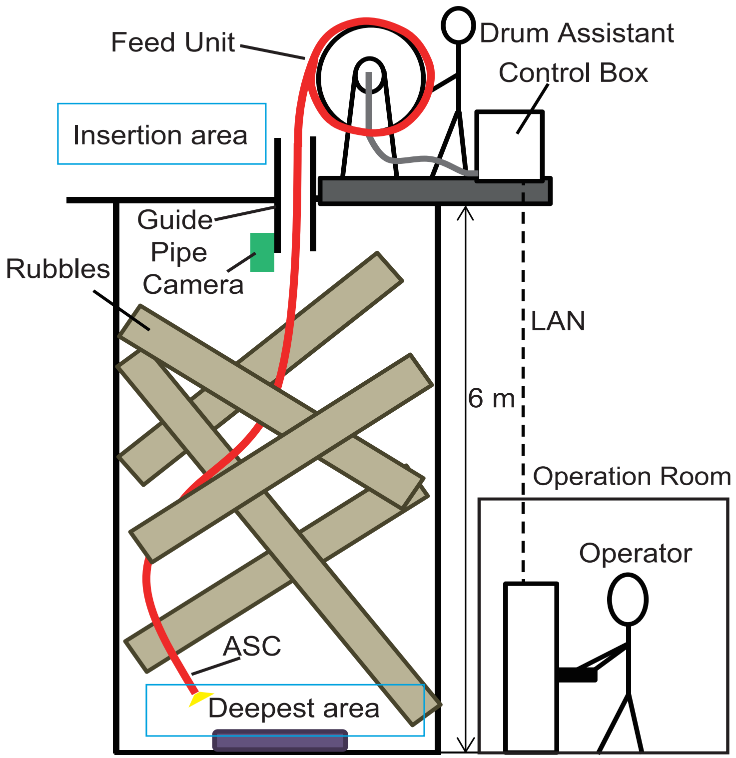
Advantages of ASC (2)

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

CRASAR-IRS Deployment to Cologne Historic Archive Collapse

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Cologne, Germany, March 6-8, 2009

- Search for 2 victims
- Standby for 3 days
- Operation from rubble pile 30 m high was too risky.

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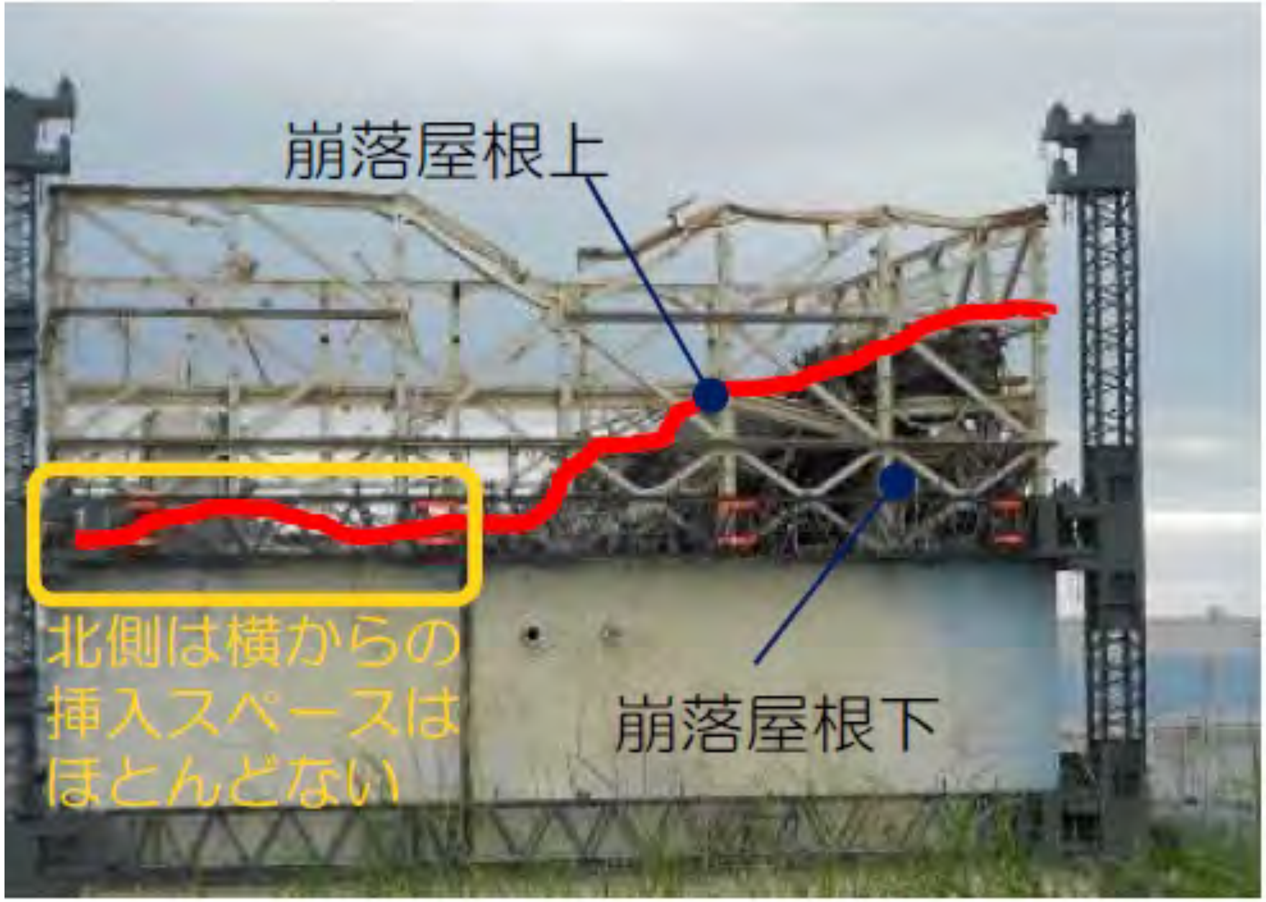
Tadlab [Tadokoro, Tohoku U; Murphy, TAMU]

Fukushima-Daiichi 1st Unit



建屋カバー建設中の状況写真(2011年)

- 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.

International Rescue System Institute SHIMIZU CORPORATION SHMZ [Konyo, Tadokoro, Tohoku U]

Our Solution for Investigation

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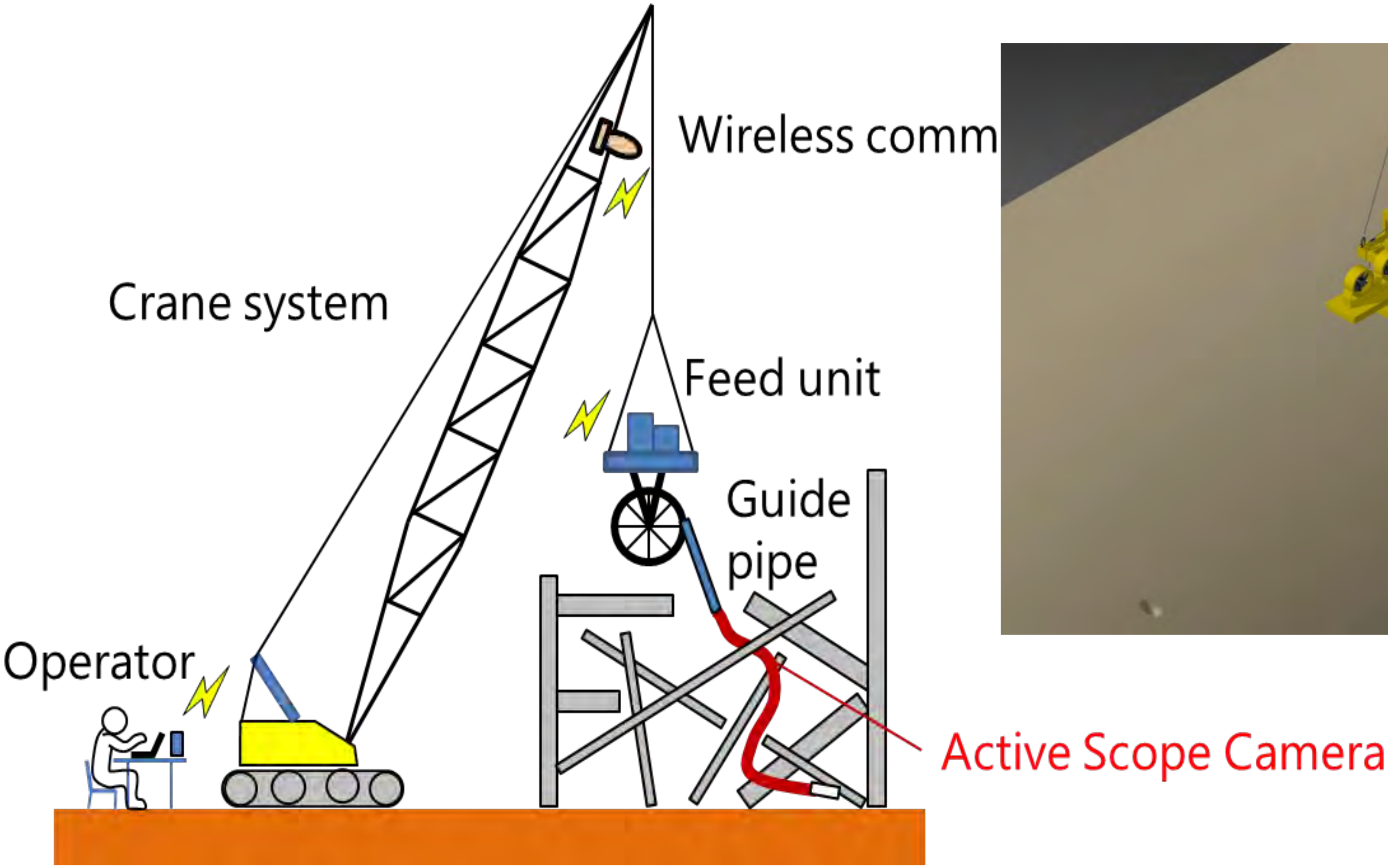

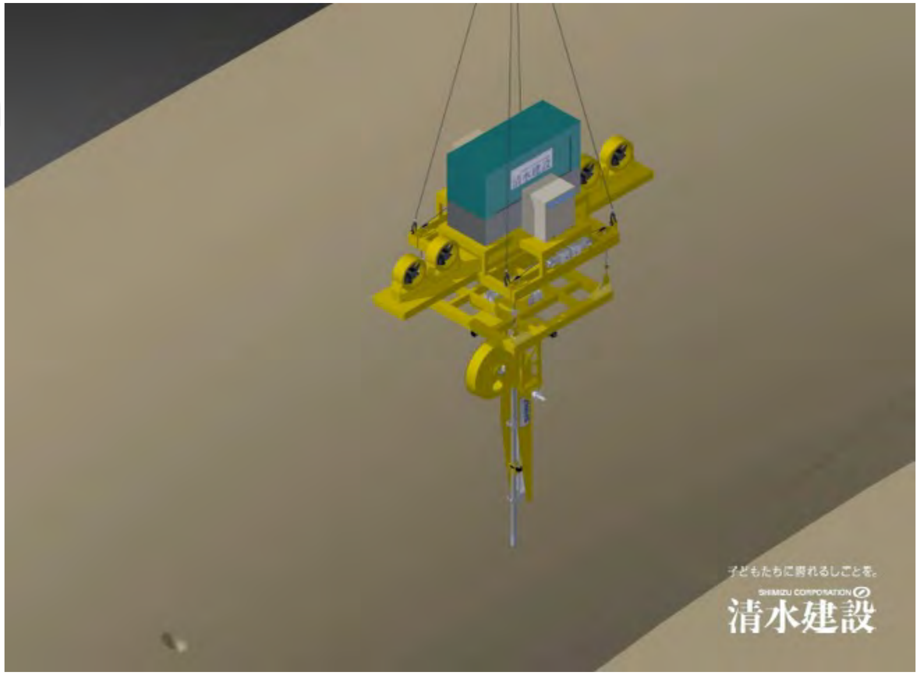

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SHIMIZU CORPORATION SHMZ

[Konyo, Tadokoro, Tohoku U]

Experiment in Simulated Space (2013)

x8

[Konyo, Tadokoro, Tohoku U]

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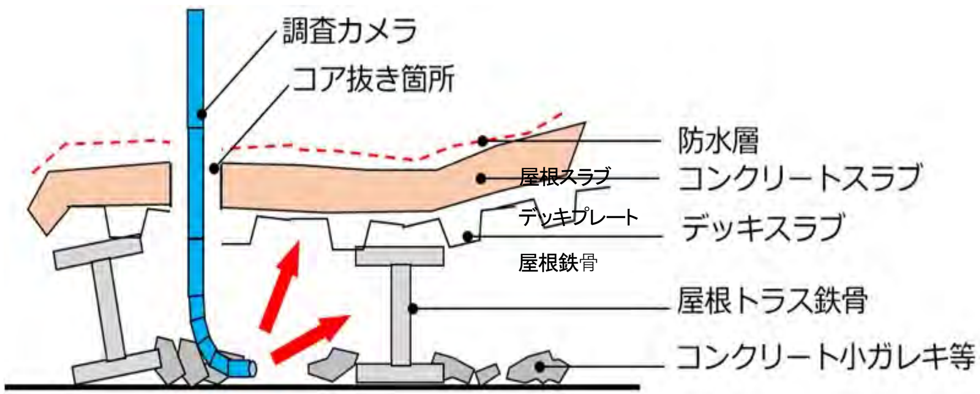
Mission at Fukushima-Daiichi (April 2016)

(C) TEPCO

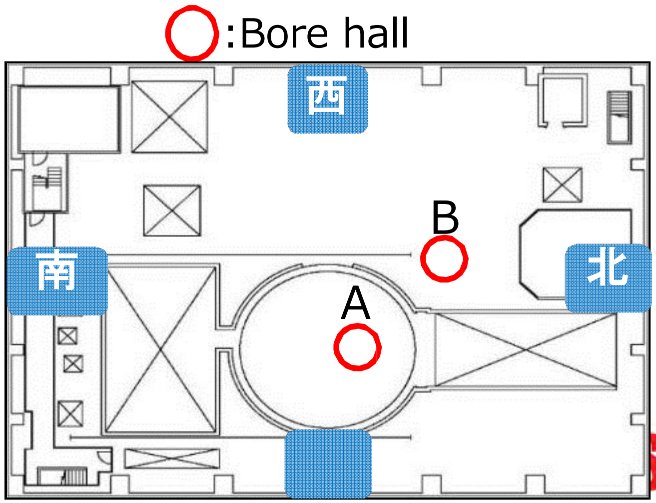
[Konyo, Tadokoro, Tohoku U]

Structural Investigation (Dec 2016 – Feb 2017)

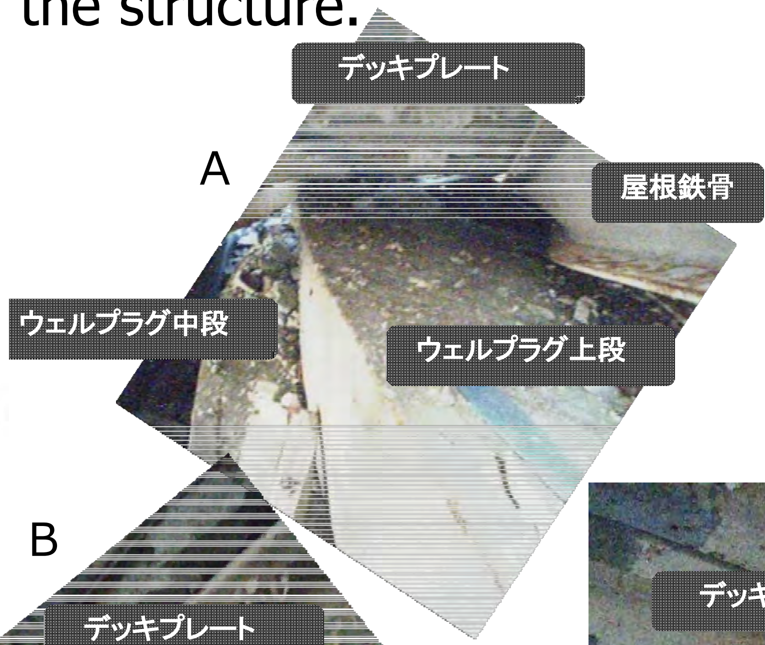
- Investigation of roof structure of the op. floor in the 1st Unit under debris
- Findings:
  - Roof iron framework has its original shape.
  - It can be removed by cutting the structure.



Usage of Active Scope Camera (ASC)



Op Floor



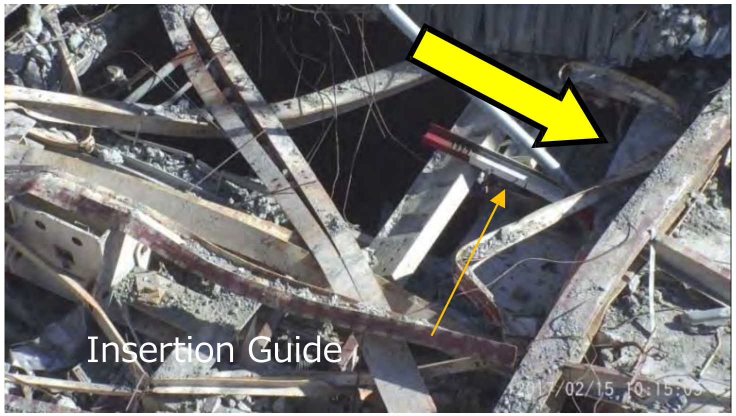
(C) TEPCO

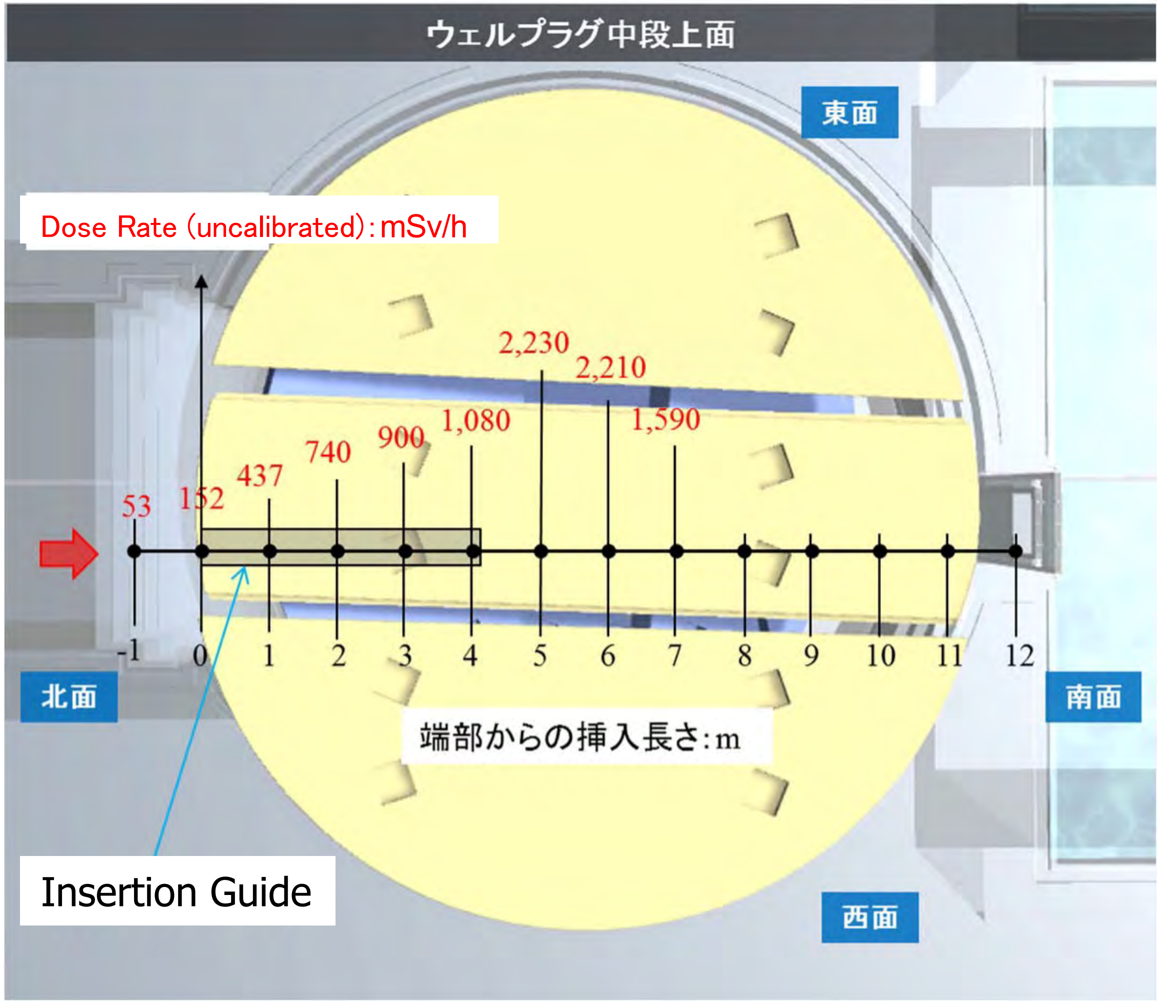
[Konyo, Tadokoro, Tohoku U]

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

[Konyo, Tadokoro, Tohoku U]

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





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Thin Serpentine Robot - Project Topics and Groups

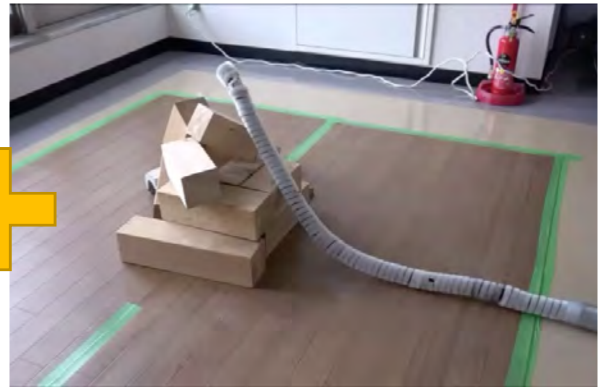
Insufficient Capabilities in Real Missions

- 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)

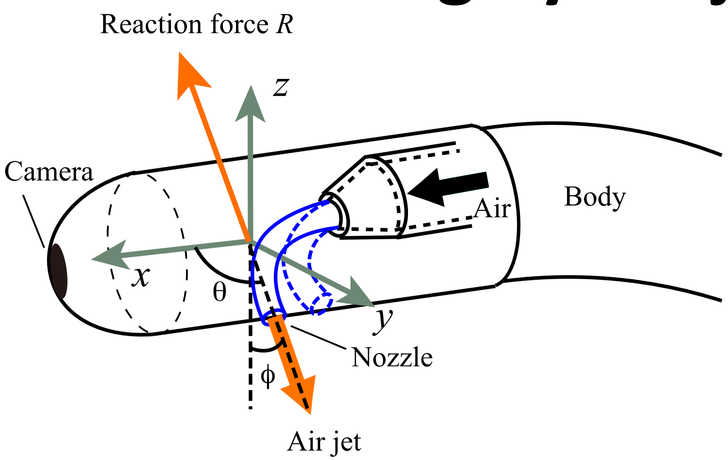
Tactile

Contact Sensing
Konyo (Tohoku Univ.)

[Konyo, Tadokoro, Tohoku U]

Advanced Mobility by Air-jet

■ Head Floating by Air-jet




Demonstration in wooden rubble


Running on concrete rubble

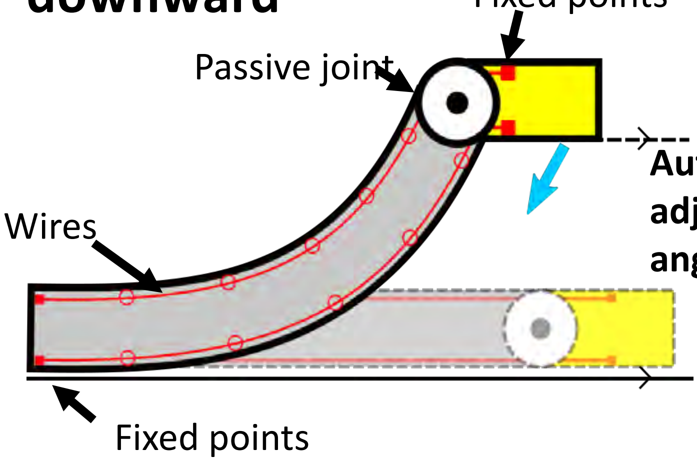
Key issue:

Achieving stability of the lightweight flexible cable in the air

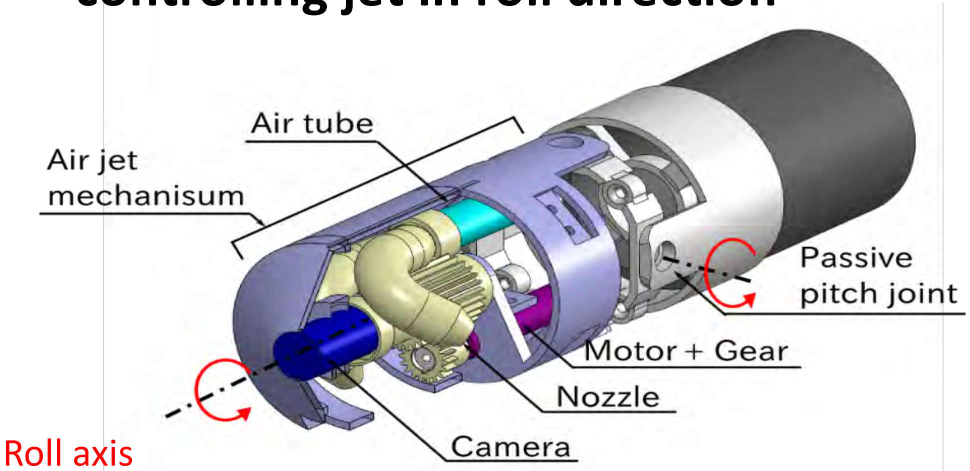
[Ambe, Konyo, Tadokoro, Tohoku U]

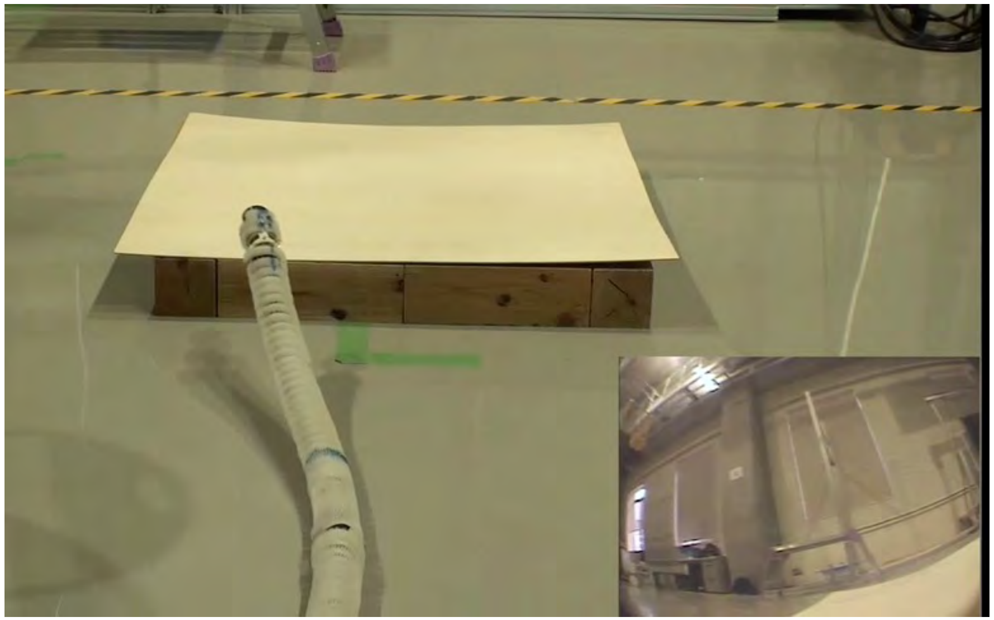
Stable Floating and Head Direction Control

- Stable floating by keeping the jet downward



- Rapid head direction change by controlling jet in roll direction





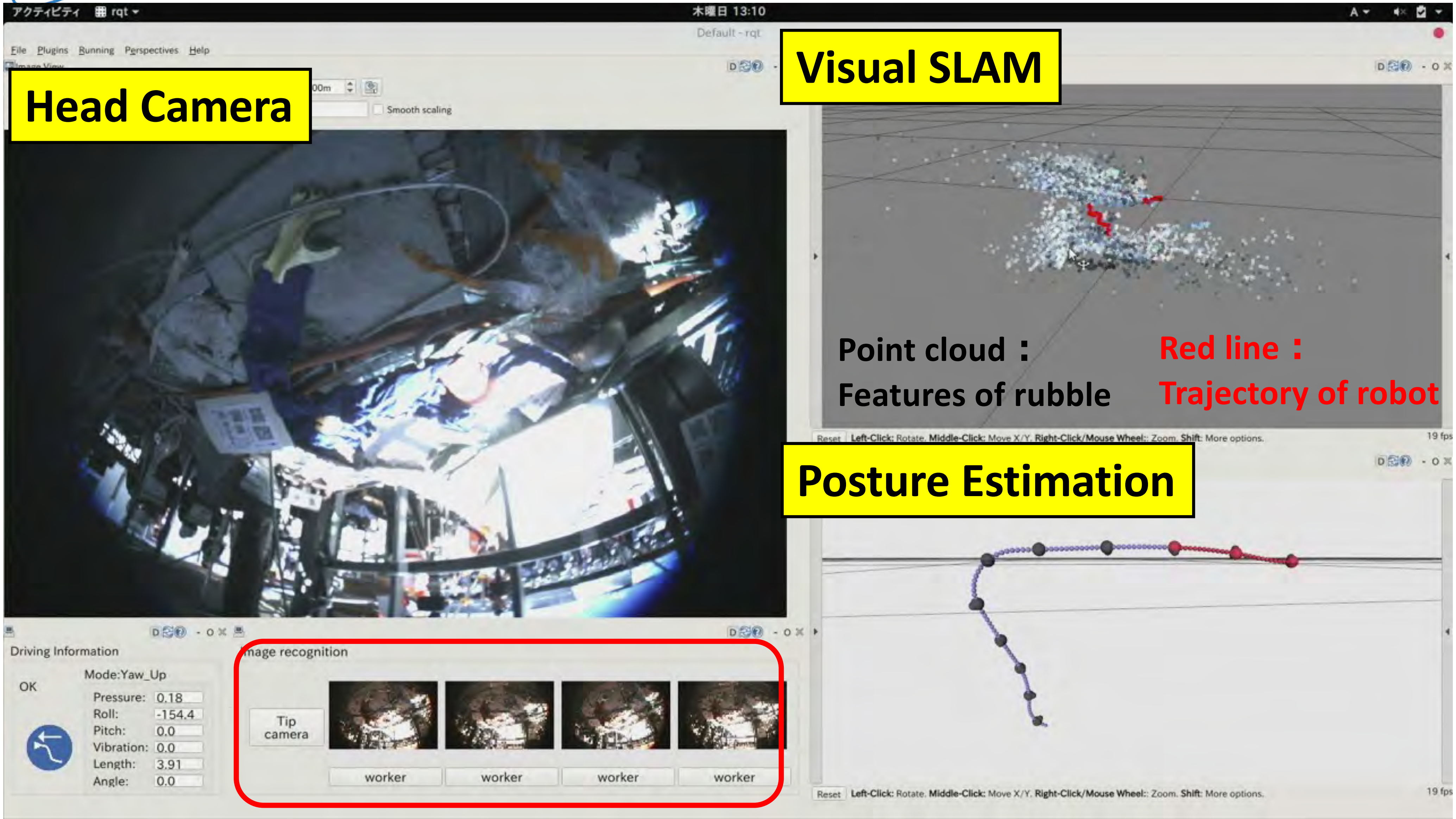
[Ambe, Konyo, Tadokoro, Tohoku U]

Biaxial Active Nozzle with Flexible Flow Channel

[A. Ishii, et al. IROS 2018]

[Ambe, Konyo, Tadokoro, Tohoku U]

Sensory Integration



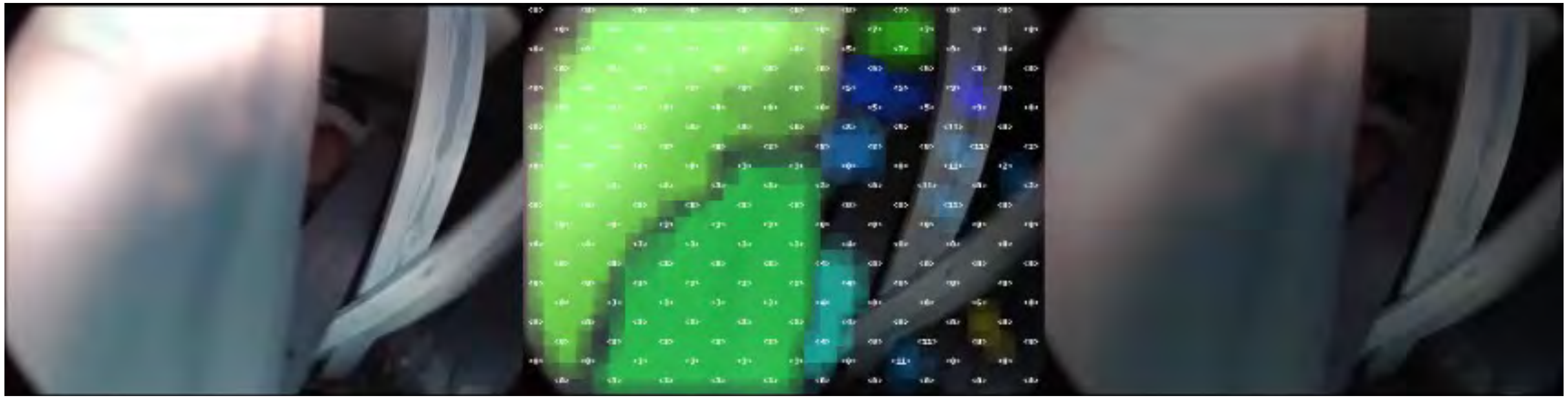
Detection of Pre-Registered Targets

[Konyo, Tadokoro, Tohoku U]

Visual Support for Victim Search

[Yamazaki, Shinshu U]

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

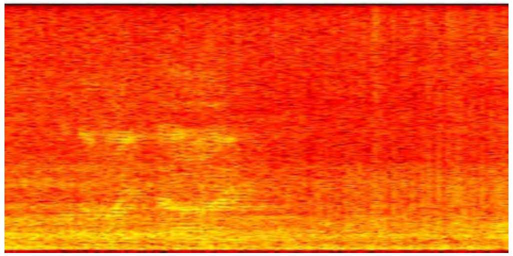
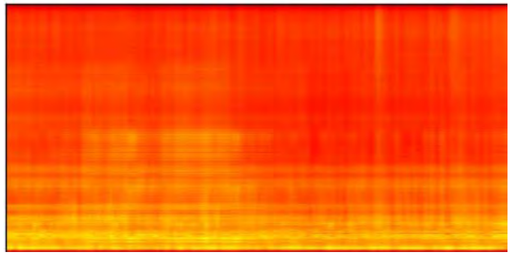
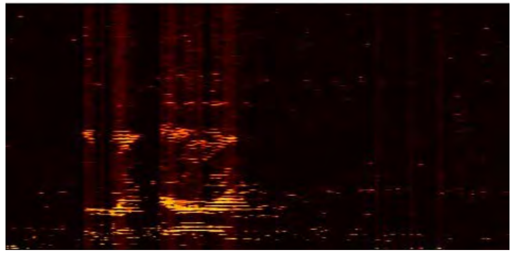


Input Image　　Image segmentation　　Detection of target

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

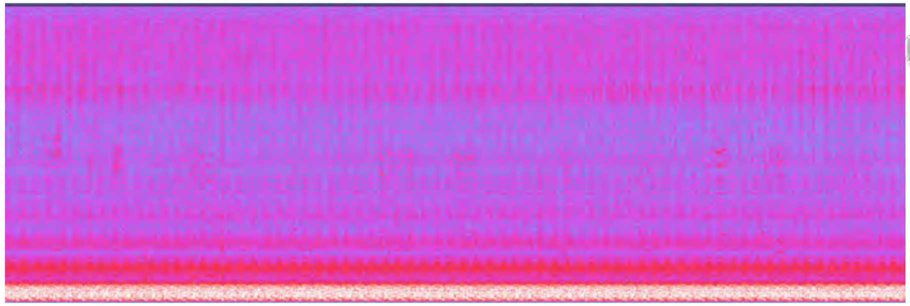
Blind Speech Enhancement

[Bando, Kyoto U; Okuno, Waseda U]

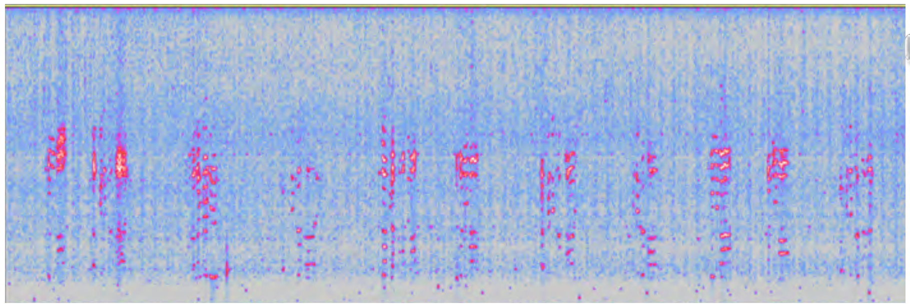
Input spectrogram		Low-rank spectrogram		Sparse spectrogram
	≈		+	
		Ego-noize		Speech

Evaluation in the simulated collapsed house

Input Spectrogram



Spectrogram of Enhanced Speech

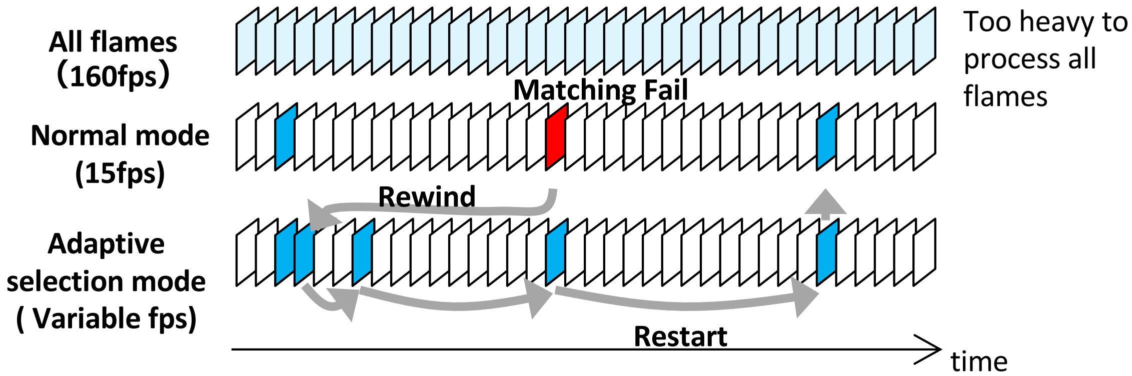


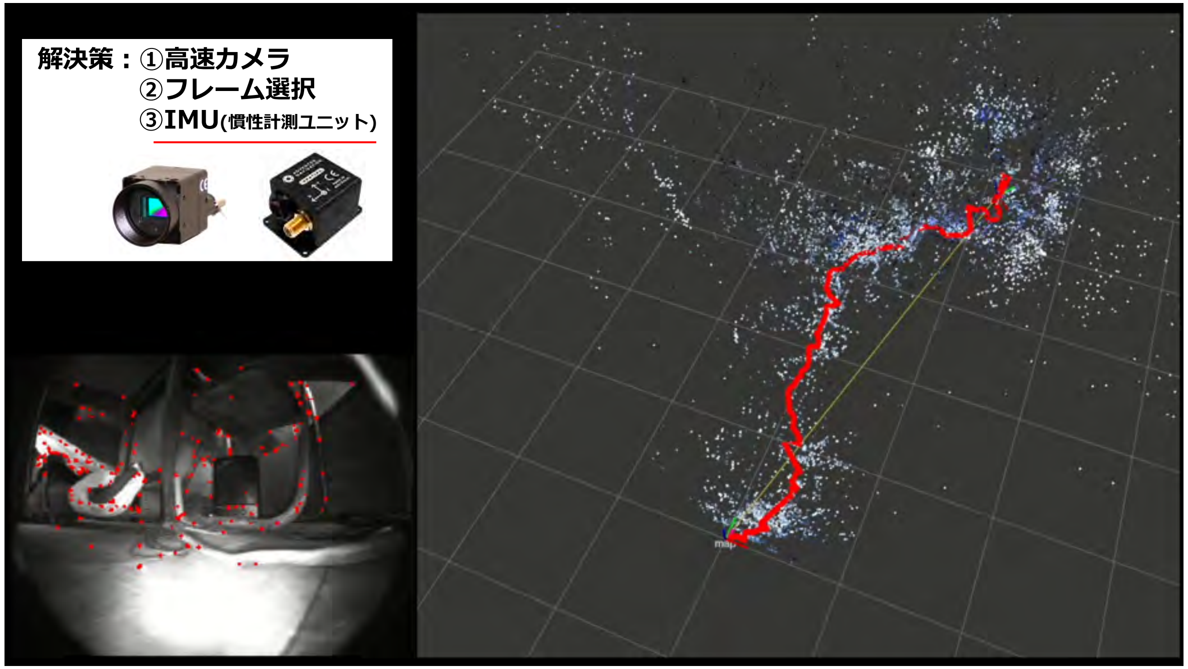
Visual SLAM

[Okatani, Tohoku U]

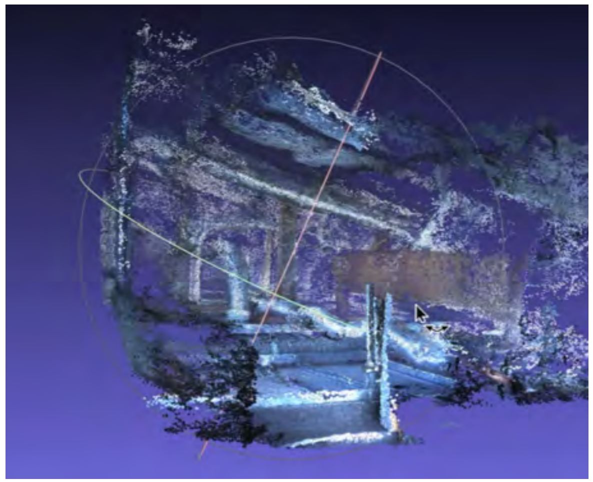
Bottleneck: Confined Space (Distance to objects, Tracking failure by rapid movement)

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





Visual Improvement (off-line)



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

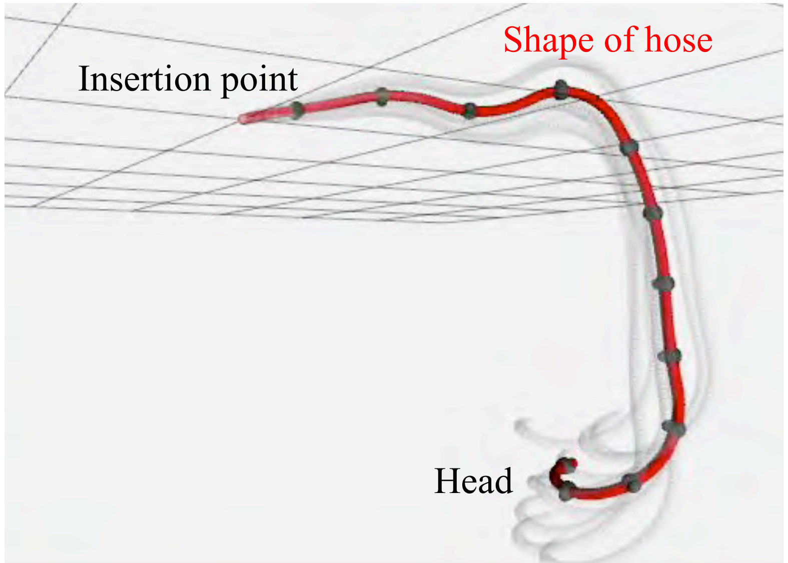
- Vibration motor for excitation
- Machine learning for recognizing the change of vibration

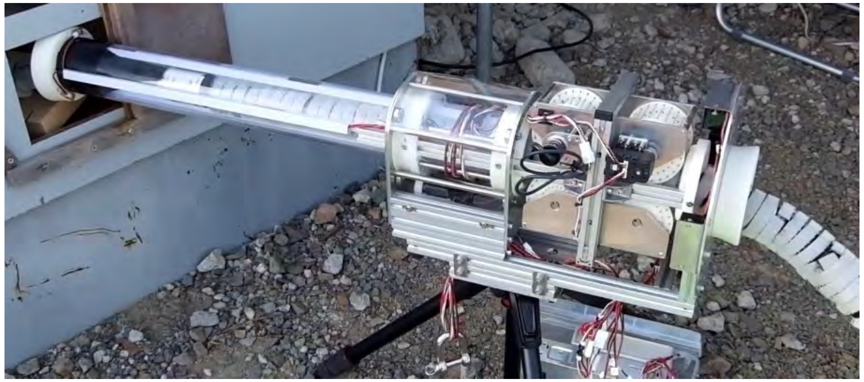
Autonomous Motion in Rubble

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

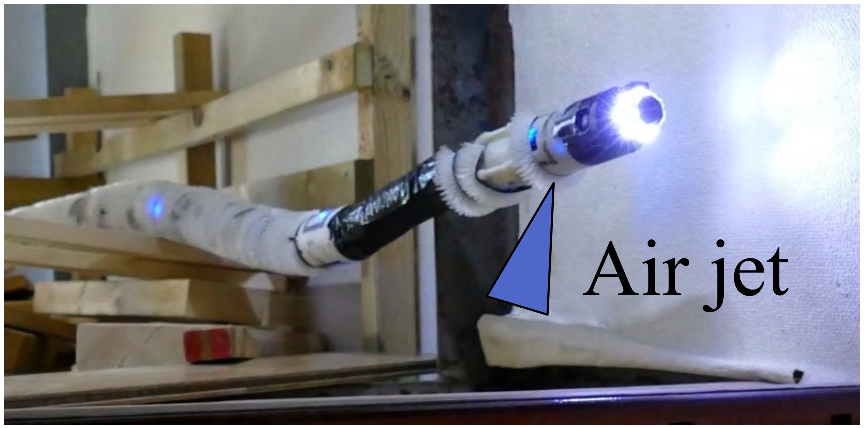
Estimated Position & Posture of ASC

Speed & Twist of Insertion Direction of Air Jet





Automatic Inserter
[IEEE/ASME AIM2018 Best Paper Award]



Air-Jet Active Scope Camera for First Responders

[Konyo, Tadokoro, Tohoku U]

- Portability by using air from air tank of firefighters
  (6 min/tank for continuous jet = 20 min regular operation)
- Lightweight meal nozzle by wrought Al-Mg alloy → better durability
- Lightweight design by limiting sensors (microphone, speaker, IMU)

Evaluation by Kobe FD (March, 2019)

[Konyo, Tadokoro, Tohoku U]

- Kobe Super-Eagle Hyper Rescue 14 firefighters
- Questionnaires for usability for future deployment

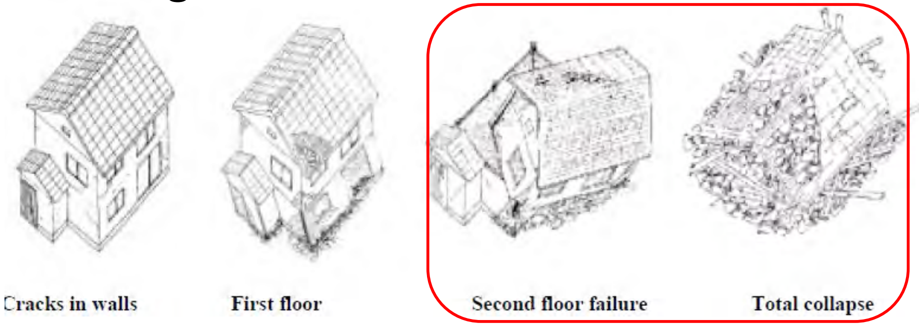
- Pros
  - High mobility for entering small gaps where pushing operation does not work
  - Higher mobility at obstacles
  - Communication with victims
  - Applicable to duct fires, oxygen-shortage accidents in manholes and ships
- Cons
  - Higher mobility is desired
  - Autonomy is expected for easier operation
  - Dust by air jet affects victims
  - Insufficient situation awareness
  - Appropriate training program to learn the basic operation is necessary

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

Damage classification [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]

Cyber Rescue Canine

Cyber-enhanced Rescue Canine (CRC)

New method for searching victims [Ohno, Tohoku U]

by fusion of human, dog, and robot technologies

Dog (Excellent olfactive & mobility)
Human （Excellent judgment）

✖

Robot technology：
Sensing, Recognition, Control

Search & rescue dog

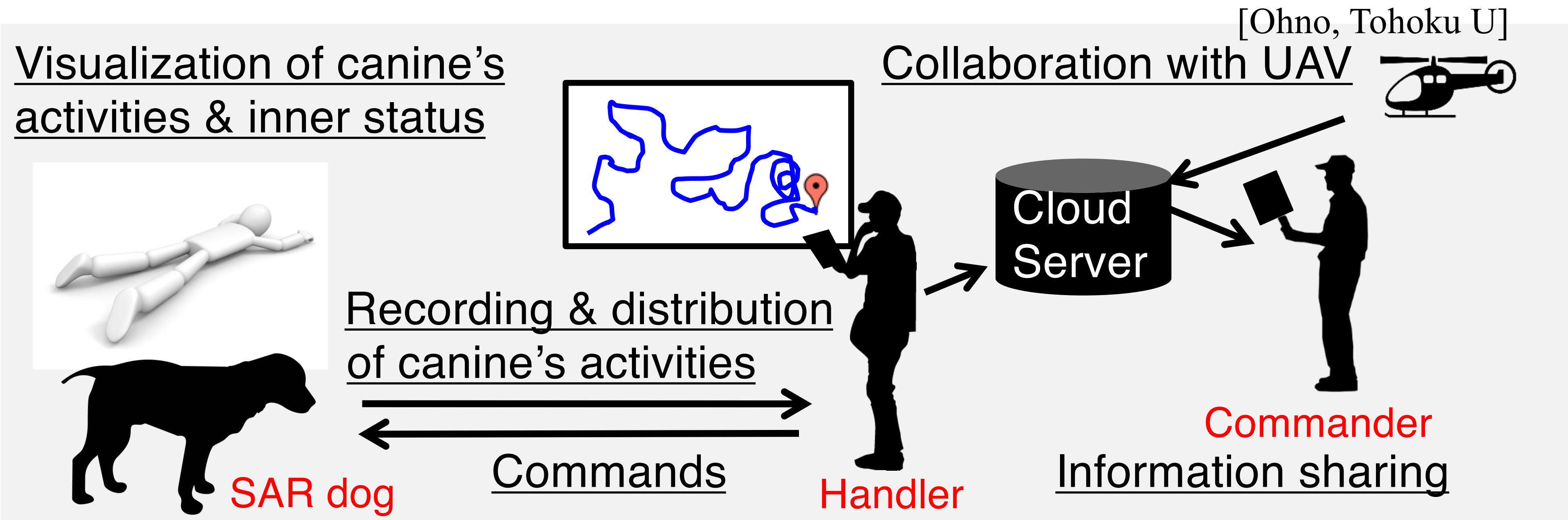
✖

Disaster response robots

Supplement to ability of SAR dogs with disaster response robotics

Cyber-enhanced Canine

System of Cyber-enhanced Rescue Canine (CRC)



Tough technologies for Cyber Rescue Canine suits

1) Remote monitoring of canines' motion, watching image, sound (Ohno G)
2) Lightweight Cyber Rescue Canine suits (Ohno G)
3) Retrospective image search for belongings left by victims (Yamazaki G)
4) Estimation of canine's emotions from its heart rate variation (Kikusui G)
5) Estimation of canine's behaviors from an IMU sensor (Shinohara G)
6) Estimation of canine's trajectory using visual SLAM (Okatani G)
7) Motion control of canine using light sources (Ohno G)

GUI for Dog Handler

Mapping of motion and behavior (run, walk, sniff, found victim)

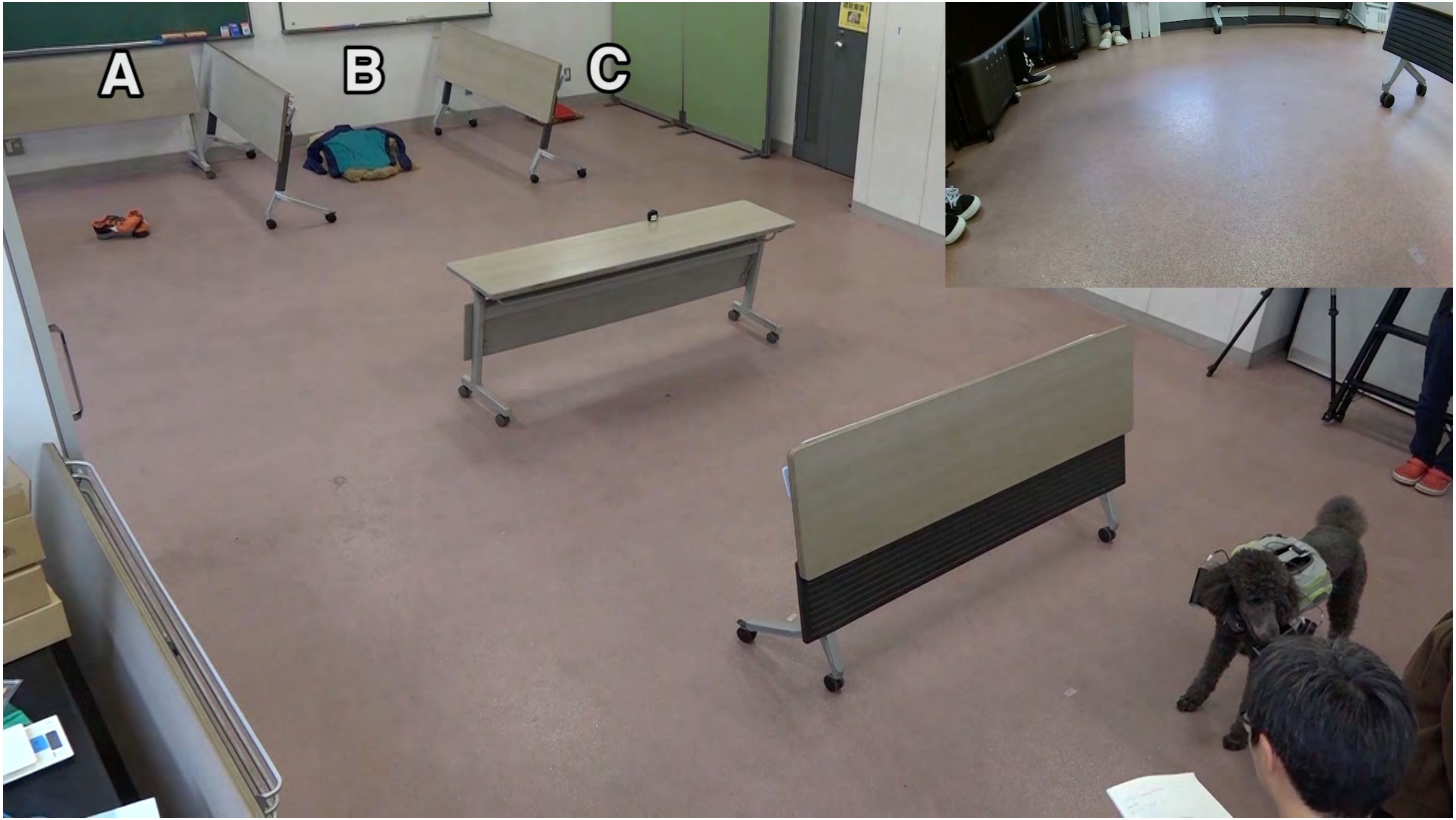
[Ohno, Tohoku U; Dawn; Murphy, TAMU]

ImPACT TRC Field Test

Emotion of Dog during Training

[Kikusui, Azabu U; Ikeda, NAIST; Ohno, Tohoku U]

Dog Navigation using Laser Beams



[Kikusui, Azabu U; Ohno, Tohoku U]

Dog Navigation using Laser Beams

[Kikusui, Azabu U; Ohno, Tohoku U]

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TCPAi
Tough Cyberphysical AI Research Center
Tohoku University

CURSOR
Accelerating Search and Rescue operations

A Collaborative Project on Robotic Equipment for Search and Rescue Jointly Funded by HORIZON2020 (EU) and JST (Japan)

Satoshi Tadokoro, Tohoku University

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 832790, and from the Japan Science and Technology Agency's SICORP framework under grant No. JPMJSC1810.

CURSOR Research Goals

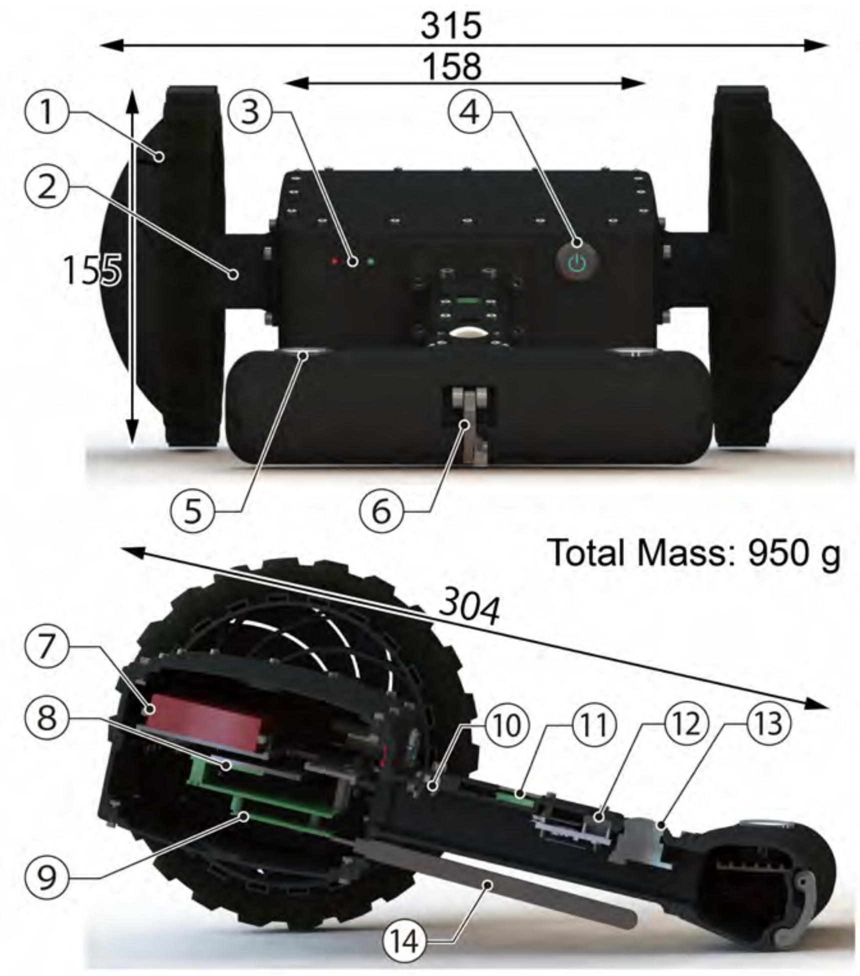
- *CURSOR SaR Kit for advanced search and rescue in debris cones*
- *Swarm of soft miniaturised robots SMURFs w/ advanced VOC sensors Sniffer*
- *Mothership Drones w/ ground penetrating radars*
- *Transfer Drone for robots*
- *Integration and reasoning of sensory information for common operational picture and incident management*

CURSOR
Accelerating Search and Rescue operations

TCPAI
Tough Cyberphysical AI Research Center
Tohoku University

SMURF V1.0.3

SMURF
Soft Miniaturised Underground Robotic Finders



① Wheel	Dia. 155 mm, Elastic structure.
② Geared motor	1 W x 2, 33 rpm, 1:1000.
③ LED indicator	Green for Wi-Fi, Red for other purpose.
④ Power switch	Push type, LED for remained battery capacity.
⑤ LED lighting	3W x 2, 180-200 lm.
⑥ Hook	Passively store by a torsion spring.
⑦ Battery	LiPo. 7.4 V, 3300 mAh.
⑧ Main Board	Raspberry Pi Zero, 1GHz, 512 MB.
⑨ IMU	Accel. x 3 / Gyro x 3 / Mag. x 3 / Temp.
⑩ Speaker	0.7 W.
⑪ Microphone	SN ratio 65 dB.
⑫ Thermal camera	80x60 pixel, Longwave infrared, 8 μm to 14 μm.
⑬ Visual camera	3280x2464 pixel, Viewing angle 220°.
⑭ Antenna	2.4 GHz and 5 GHz.
Beacon	To be installed
Sniffer	To be installed

SMURFV1 Field Test Overview @ Hyogo Pref. EM & Training Center


Fig.1 Climb up the inclined concrete culvert


Fig.2 Climb up the inclined concrete culvert (another angle)


Fig.3 Enter the duct pipe


Fig.4 Enter the rollover car


Fig.5 Run on the mesh fence


Fig.6 Run on the grating

SMURF V1.0.5 Field Test Overview in SSFT1.2 @ Camps Couderc, Brignoles, France


Fig.1 Enter narrow spaces


Fig.2 Enter a concrete pipe


Fig.3 Drop on rubbles


Fig.4 Run on mud


Fig.5 Run on woods


Fig.6 Run on porcelain and brick tiles

Thank you for listening !!

ImPACT YouTube Video

- ImPACT-TRC R&D Achievement (17 min)

https://youtu.be/lj3pQP_DzsI

ImPACT Book:

https://www.springer.com/gp/book/9783030053208