106年臺日技術合作計畫

日本專家來臺指導

「智慧機械人才培訓」
執行成效報告

經濟部國際合作處

106年11月

目錄

一、 前言

一國之繁榮維繫於該國的先進生產力，尤其精密工具機產業向為工業之母，亦是國家工業等級與國力強弱領先指標。智慧機械為政府積極推動之產業創新之一，期望加速產業轉型升級，以作為臺灣下世代產業成長的驅動核心。然我國精密機械產業現面臨關稅、關鍵開發技術瓶頸與技術人才不足、產品附加價值遠較德、日、韓等國為低等難題。

本計畫邀請日本東京大學淺間一教授於本(106)年11月2日至5日來臺指導「智慧機械人才培訓」，與勞動部勞動力發展署中彰投分署智慧機械產業相關師資，以及經濟部106年產業種子師資培訓計畫「智慧機械」班來自東南亞及中東歐國家之學員分享日本智慧機械人才培育經驗，並講授「機器人技術於災害預防和社會韌性響應之應用」課程，旨於深耕我國工業基礎與發展關鍵技術，積極培養技術人才各項職能，期望以生產力4.0元素，發展智慧機械，提升臺灣精密機械附加價值與加速產業聚落升級轉型。

二、 技術合作行程安排

起訖時間：106 年 11 月 2 日起至 5 日止

接待人員：經濟部國際合作處 柏國芳 組員

時間	活動內容	
	活動事項	地點
106 年 11 月 2 日(四) 16:00-23:00	日本-臺北-臺中	松山機場-臺中高鐵站
106 年 11 月 3 日(五) 9:00-16:00	授課「機器人技術於災害預防和社會韌性響應之應用」	勞動部 勞動力發展署中彰投分署
106 年 11 月 4 日(六) 10:00-11:20	參觀「2017 臺中工具機展」	大台中國際會展中心
106 年 11 月 4 日(六) 13:30-15:30	臺中-臺北	高鐵站
106 年 11 月 4 日(六) 15:45-18:00	拜會智慧機器人及自動化國際研究中心羅仁權主任	臺灣大學
106 年 11 月 5 日(日) 6:00-12:00	離臺	松山機場

三、 來臺日本專家簡歷

淺間一(Hajime Asama)教授分別於1982、1984和1989年間獲得東京大學工程學士、碩士和博士學位。1986年至2002年在日本國立研究開發法人理化研究所（Institute of Physical and Chemical Research, RIKEN）擔任科學研究員等職。2002年，成為東京大學人工工程研究中心（Research into Artifacts, Center for Engineering , RACE）教授，2009年起任東京大學工程學院教授。並於2013年獲得日本機器人學會(Robotics Society of Japan)傑出服務獎(RSJ Distinguished Service Award)；於2009年獲得日本機械學會(Japan Society of Mechanical Engineers)機電一體化獎(JSME Robotics and Mechatronics Award)。

淺間一教授於2011年至2012年擔任日本機器人學會(Robotics Society of Japan)副主席，2007 至2009年間擔任IEEE機器人與自動化學會(IEEE Robotics and Automation Society)行政委員會成員。自2017年至今獲選為國際自動控制聯合會(International

Federation of Automatic Control, IFAC)總裁，自2014年起擔任國際智能自動化系統學會(International Society for Intelligent Autonomous Systems)會長；機器人與自動化系統學報(Journal of Robotics and Autonomous Systems)、現場機器人學報(Journal of Field Robotics)和控制工程實踐(Control Engineering Practice)等副主編；現任日本科學理事會理事；同時為日本機械學會(Japan Society of Mechanical Engineers, JSME)和日本機器人學會(Robotics Society of Japan, RSJ)院士。

目前為核能損害賠償、廢爐支援機構(Nuclear Damage Compensation and Decommissioning Facilitation Corporation, NDF)燃油清除專家委員會成員，國際核退役研究（International Research Institute for Nuclear Decommissioning ,IRID）技術委員會成員，日本原子能機構(Japan Atomic Energy Agency, JAEA)模型試驗設備技術委員會成員，日本競爭力委員會（Competitiveness-Japan, COCN）機器人災害應對計畫負責人。

其主要研究為自主機器人系統、智能空間、服務工程、認知具體化大腦系統及服務機器人。

四、 技術合作專家指導情形

(一)邀請緣由：

為加強我與友邦國家之經貿關係，協助該等國家發展產業技術，國際合作處於 93 年開始委請勞動部勞動力發展署中彰投分署辦理產業技術種子師資培訓，106 年配合推動五大產業創新邀請新南向國家，以及與我友好之中東歐國家參與「智慧機械」課程，以期推廣我國智慧機械產業並利用我國師資與來自各國技術種子師資齊聚之際，邀請日本專家來臺授課，擴大技術合作之效益。

(二)指導情形：

1. 淺間一教授於本年 11 月 2 日晚間抵達松山機場後，隨即於本處熟諳日語的柏國芳組員陪同下，搭乘高鐵前往台中；3 日上午隨即展開以「機器人技術於災害預防和社會韌性響應之應用」為主題之授課。授課對象為勞動部勞動力發展署中彰投分署智慧機械產業/工具機械相關臺灣師資，以及經濟部 106 年產業種子師資培訓計畫「智慧機械」班來自東南亞包括越南、寮國、印尼、泰國、

及中東歐包括波蘭、捷克、斯洛伐克及保加利亞等國學員，該等學員主要來自上述該等國家高等教育、技術教育職能發展機構、政府單位、公協會及國營事業。

2.教授講授「機器人技術於災害預防和社會韌性響應之應用」課程時，以為人所知的核災事件切入，包括1979年日本三哩島核洩露事故、1986年蘇聯車諾比核子事故、1999年日本東海村JCO臨界意外及2011年日本福島第一核電廠等事件，進而探討機器人技術於核電領域應用之需求，包括冷卻系統的穩定、減少工人的輻射照射、清潔、儀器設置、採樣、材料和設備之運輸、包括圖像、輻射、溫度、濕度、氧氣濃度等數據之監視和測繪等。除核電領域應用，無人力系統針對於火山爆發之應用亦為一大主題，課堂中輔以大量實例照片講說機器人於探勘、建築、去汙等其他領域之應用。

3.針對災難處理，淺間一教授指出機器人技術廣泛應用於受害者之搜索救援、檢查，診斷和修復工廠和設施、監測海面下方水文、繪製受損區域以及災後被疏散者的心理照護等，但現今日本對機器人技術的期待與實際應用上仍有很大落差，因少有機器人和遙控機器擁有

足夠多的功能可用於實際災難現場中，且在日本發展的機器人大多只是研究人員開發的原型，實用產品甚少。

4.淺間一教授表示,未來機器人技術發展需仰賴各國攜手合作，才能在災害預防及應對上共同為人類謀求福祉；亦盼未來能夠與臺灣有更多合作機會。

五、 展覽參訪

(一) 安排緣由：

中部地區精密機械業產值約占我國總產值 80%,為我國精密機械的大本營，整合產業上至下游的供應鏈，在臺灣機械產業扮演重要角色。隨著我國機械技術水準不斷提升，機械產業為製造產業帶來無限商機。近年政府積極推動產業轉型與升級，而臺中被定位為我國「智慧機械之都」。

此次淺間一教授親臨臺中，因為停留時間甚短；僅有 1 日半行程，因此特別安排教授參訪「2017 臺中工具機展」,期望在有限的停留時間內，向該教授展現我國工具機企業發展成果。

(二) 展覽介紹

兩年一度之「2017台中工具機展」於本年11月2至6日於大台中國際會展中心舉行，該展覽協助我國機械製造相關業者，發揚並推廣品質優良之產品及技術，於會場中展示新穎的工具機設備，不僅提升產品競爭力、促進產業交流，更吸引國外買主採購意願。

此次展示主題包括、工具機區、自動車床區、產業機械區、自控檢測區、五金暨配組件區、切削刀具區、倉儲暨搬運設備區及產學合作專區。

（三）參訪情形

此次參訪行程時間緊湊，本處柏組員國芳偕同淺間一教授於3日上午十時抵達展覽會場，並停留1.5小時後隨即搭程高鐵驅車北上前往拜會智慧機器人及自動化國際研究中心羅仁權主任。

淺間一教授於參訪展覽時以表示，此次參觀主題與其學生時代所學相關，能夠親身至臺中參觀業者展覽並端詳臺廠製造機械實屬難得機會，唯此次展覽雖設有產學合作專區並陳列機械手臂，但整體仍偏重傳統精密機械，很遺憾未能瞭解臺灣在智慧化連結、驅動系統及智慧機械技術之發展，實為臺中之行一大遺憾。

六、學者交流

（一）交流事項：

淺間一教授於11月4日拜會羅仁權教授，參觀智慧型機器人暨自動化實驗室（Intelligent Robot and Automation Lab; IRA Lab），並與其所帶領之研究團隊討論以下系列研討會及論壇之相關規劃：

（1）106年12月11日至14日舉辦之「2017 IEEE／SICE系統整合國際研討會」(2017 IEEE/SICE International Symposium on System Integration)

（2）106年12月11日 8:50-12:30 舉辦之「2017 IEEE工業論壇I機器人與AI：技術趨勢及其工業應用」(2017 IEEE Industry Forum I on Ribotics and AI: Technology Trends and Its Industrial Applications)

（3）106年12月11日 13:30-17:10舉辦之「2017IEEE國際產業論壇II智能自動化與製造」(2017 IEEE International Industry Forum II on Intelligent Automation and Manufacturing)

（二）學者簡介：

智慧機器人及自動化國際研究中心羅仁權主任為德國柏林工業大學電機工程博士，現任臺大電機系何宜慈講座暨終身特聘教授及臺灣研發管理經理人協會理事長，經歷豐富，包括：1.國立中正大學校長(2001-2007)；國立中正大學講座教授 2.國立中正大學工學院院長 3.美國北卡州立大學系統智慧型機器人研究中心主任 4.日本東京大學講座教授 5.美國北卡州立大學電機電腦工程系終身職教授 6.美國北卡州立大學電機電腦工程系助理教授 7.美國伊利諾大學助理教授 8.IEEE 國際工業電子學會總裁(係我國第一位擔任此國際學術團體職位者） 9.IEEE/ASME 國際機電整合期刊總主編（Editor-in-Chief）10.IEEE 國際工業電子工程師學會首席執行副總裁 11.IEEE 國際機器人及自動化學會執行委員會及科技委員會主席 12.IEEE 國際工業電子學會主管刊物出版的副總裁 13.IEEE 國際工業電子學會主管科技的副總裁 14.中華民國自動化科技學會理事長(1999-2003) 15.中華民國斐陶斐榮譽學會理事長(2003-2005) 16.中華民國中小企業育成協會理事長(2005-2007) 17.彰雲嘉十六所大學院校聯盟

創會理事長(2003-2006) 18.行政院國家科學委員會自動化學門召集人(1999-2002) 19.行政院國家科學委員會傑出研究獎決審委員 20.行政院國家科學委員會傑出科技人才獎決審委員 21.行政院國家科學委員會諮議委員會諮議委員--工程處自動化學門 22.行政院國家科學委員會諮議委員會諮議委員--工程處電機及控制學門 23.受邀擔任多次國際大型國家型研究計畫評審，包括美國、加拿大、日本、澳洲、香港、新加坡等國。 24.臺灣機器人學會理事長。

渠學術與研究專長為智慧型感測控制機器人理論及應用、光機電整合系統、微奈米技術、電腦視覺、快速原型系統及先進製造自動化;並於以上學術專業領域發表 300 餘篇學術科技論文在國際著名學術期刊、國際會議、專書，擁有多項國內外專利。

(三)智慧型機器人暨自動化實驗室簡介

智慧型機器人暨自動化實驗室（Intelligent Robot and Automation Lab; IRA Lab）隸屬於國立臺灣大學電機工程學系暨研究所，由羅仁權教授擔任實驗

室之專任指導教授。該實驗室以積極培育學術卓越與技術創新之人才為宗旨，其研究範圍包括有：

1.智慧型機器人(雙足機器人、保全機器人、機器人視覺及遠端診斷與維修)

2.自動化運用(智慧型嵌入式、系統智慧型大樓、電子商務應用及醫療自動化)

3.微感測器製造(多重感測器訊號融合、多重感測機械系統製作及矩陣式感測器)

4.快速成型與快速原型(速原型直接切層、快速模具製作、熱擠疊層式快速原型機之研究及智慧型模具)

（四）IEEE/SICE 系統整合國際研討會簡介

IEEE／SICE 系統整合國際研討會為展現系統整合的最新技術及未來前景之系列活動，相關領域專家，研究員和學者聚集於此，分享關於前端技術、突破、創新解決方案及其應用之想法和經驗。

2017 年 IEEE ／ SICE 系統整合國際研討會（SII 2017）為第 10 屆系統整合研討會。系統整合為重要關鍵技術，硬體和軟體整合對於解決新世代的工業或社會系統問題尤為重要。本年此研討會側重於系統整

合的新研究和產業化應用，並討論提高系統整合有效方法。

七、 檢討與建議

（一）邀訪期程應避開教務繁忙期間：淺間一教授為日本機械及機器人科技領域之翹楚，此次能夠於教學繁忙中撥冗來臺指導，實屬難得，也因教授平日教務繁忙，僅能於週四至週日間赴臺指導。未來，若有機會邀請日本著名學者，建議行程可安排在暑假(平日)之際，以便能夠藉此種難得機會與教授就其專精領域更深入交流。

（二）針對教授所學領域，更妥適安排行程：

（1） 此次原擬安排教授拜會本部智慧機械推動辦公室及桃園祥儀機器人夢工場，然礙於教授訪臺期間短暫並跨及假日，僅得順道匆匆參訪「2017 台中工具機展」，然該展覽主題與教授學術研究主題仍有落差，未來在安排行程上，應避免此情形發生。

(2) 除與公家機關交流外，未來可考慮利用日籍教授難得來臺之際，與大專院校相關學系共同安排校園演講，以擴大邀請教授來臺指導效益。

（三）建議增加雙向溝通交流機會,而非教授單方面授課：淺間教授上課時間為一整日，較無與學員互動機會與時間，未來授課前可安排學生自我介紹，並考慮安排上午上課，下午至勞動力發展署中彰投分署工廠設備實作區與學員互動，強化實作經驗、師生交流並增強學習效果。

八、 結語

此次透過106年臺日技術合作計畫邀請東京大學淺間一教授來臺講述「機器人技術於災害預防和社會韌性響應之應用」，並就機器人技術及智慧機械領域為主題與勞動部勞動力發展署中彰投分署機械產業相關師資交流，與會人員咸感收穫良多，亦盼臺灣未來在機器人技術及智慧機械技術應用規劃與發展方面，能夠在既有的良好基礎上汲取日方寶貴經驗，持續發展。

九、 活動剪影

授課情形

參訪台中工具機展

十、參考資料

（一）臺灣大學智慧機器人及自動化國際研究中心

http://www.iceira.ntu.edu.tw/faculty/eecs/185-2013-10-27-14-14-10

（二）臺灣大學智慧型機器人暨自動化實驗室

https://sites.google.com/a/ira.ee.ntu.edu.tw/iralab/shi-yan-shi-jian-jie-1

（三）2017 IEEE// SICE II

http://www.sii2017.org/

附件：日本專家簡報節錄

Smart machinery industry personnel training, MOEA, Taiwan
Taichung, Nov. 3, 2017

Societal Dissemination of Robot Technology for Disaster Prevention and Response

Hajime ASAMA
Dept. of Precision Engineering, The University of Tokyo, Japan

Japanese Government and TEPCO: Council for the Decommissioning of TEPCO's Fukushima Daiichi NPS, member
Nuclear Damage Compensation & Decommissioning Facilitation Corp. (NDF), Expert Committee on Fuel Removal member
International Research Institute for Nuclear Decommissioning (IRID), TC member
Japan Atomic Energy Agency(JAEA): Working Committee on Remote Control Equipment and Device Development Facility (Mock-up facility), Chair

THE UNIVERSITY OF TOKYO

Hajime Asama
Dept. of Precision Engineering
The University of Tokyo

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Service Robotics Laboratory

http://www.robot.t.u-tokyo.ac.jp

Make research on service robotics to meet the social needs by solving societal problems such as aging, safety, etc. and to create new value.

Keywords: Robotics, Human Interface, Embodied-Brain Systems, Service Engineering

Main subjects:

Fundamental Research (for knowing human)

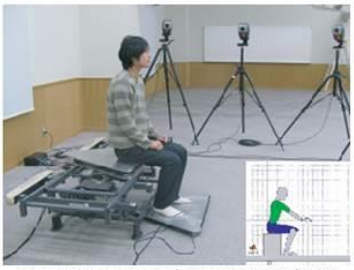
Motion measurement, modeling of embodied-brain system modeling, sense of agency, etc.

Development Research (for interacting with human): Robotics and ubiquitous systems

Motivation induction with dynamic interaction, emergence of cooperative behavior of robots, etc.

Application Research (for use by human): Health-care and assist, rescue, security, etc.

Elderly assist & rehabilitation, decommissioning, disaster response, inspection, skill education, etc.



Measurement and synergy analysis of standing-up motion by motion capture, force plate and EMG

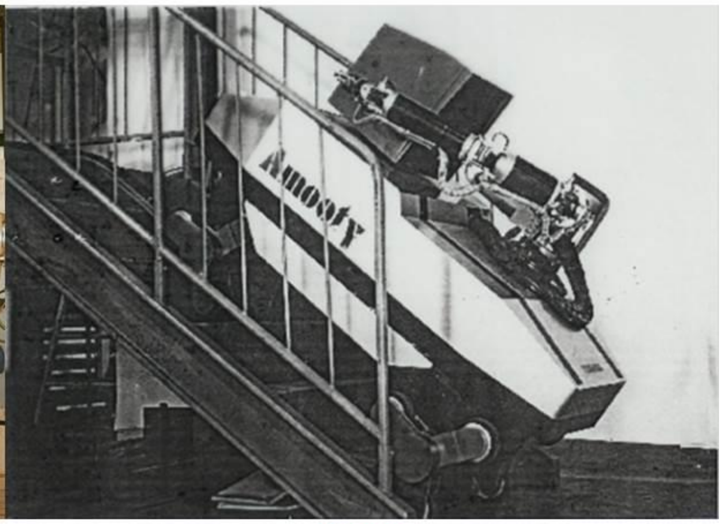
Motion detection and guidance of walking persons by camera and pan-tilt projector

Safe motion control of mobile robots interacting with persons in human-robot co-existing environment

Maintenance Robot for Nuclear Power Plants

(1980, Toshiba Corp. and Univ. of Tokyo)

9 DoF
Metamorphic Manipulator



AMooty
Maintenance Robot for NPP

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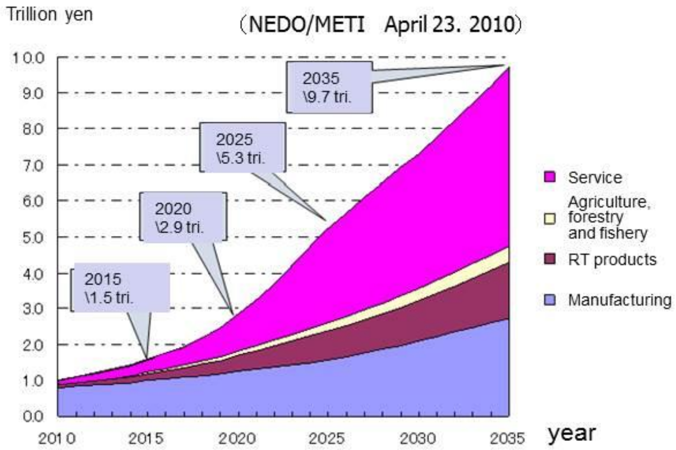
Market forecast in the future of robot industry for 2035



Personal Services

- Medicine (for surgery, therapy)
- QoL Assist (for elderly, disabled, handicapped)
- Security,
- Home services,
- Guidance,
- Education,
- Amusement and Entertainment, etc

Public Services

- Maintenance of facilities
- Disaster response
- Construction
- Agriculture, forestry, fishery
- Demining, etc

The market in 2035 can expand up to 9.7 trillion yen by the spread of the robot to a new field including the service field in addition to the growth of the manufacturing field where the market is formed now .

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RT (Robot Technology)

Technology that includes
sensing system, intelligent control system, and driving system
(METI, Japan)

IT (Information Technology)	RT (Robot Technology)
Technology on information processing and communication in information (virtual) world	Synthetic Technology on detection, measurement, recognition, control, motion, task in physical (real) world

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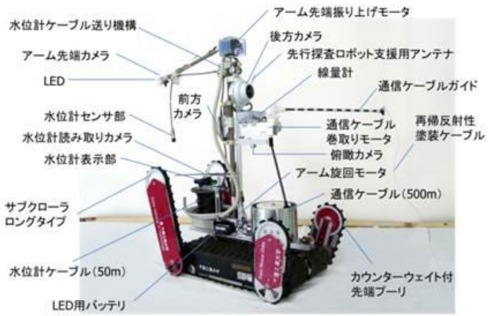
Robot vs RT(Robot Technology)

Robot
- Machine that moves

RT (Robot Technology)
- System integration (not components)
- Synthesis and design according to requirements
- Solution derivation



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RT as technological infrastructure of mechanical systems

Robots

Industrial robots

Service Robots

Transportation vehicles

Automobiles

Medical & assistive devices

Prosthesis

Industrial devices

Sushi machine

Robot Technology(RT): Technological infrastructure)

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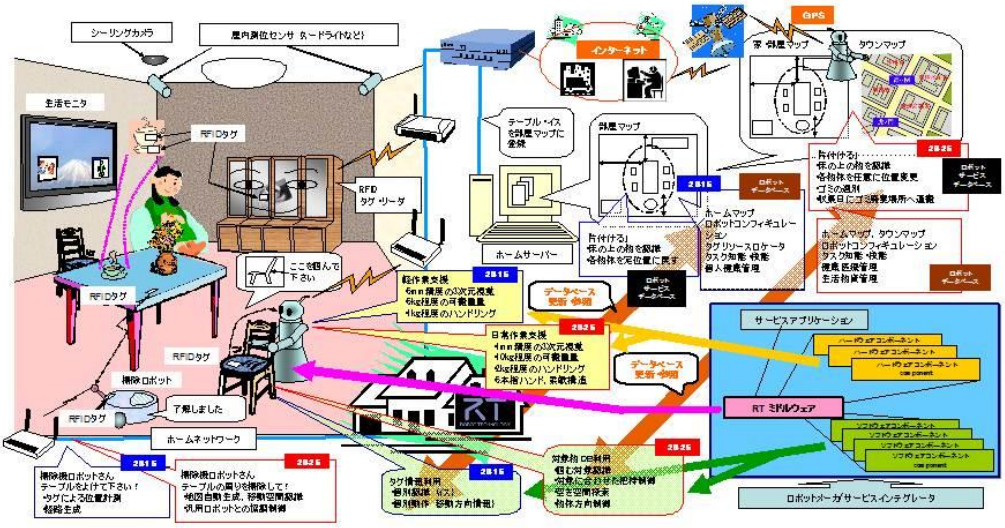
METI Roadmap of Robot Technology, Roadmap of Technological Strategy, 2005

Life Support Robot/Environment



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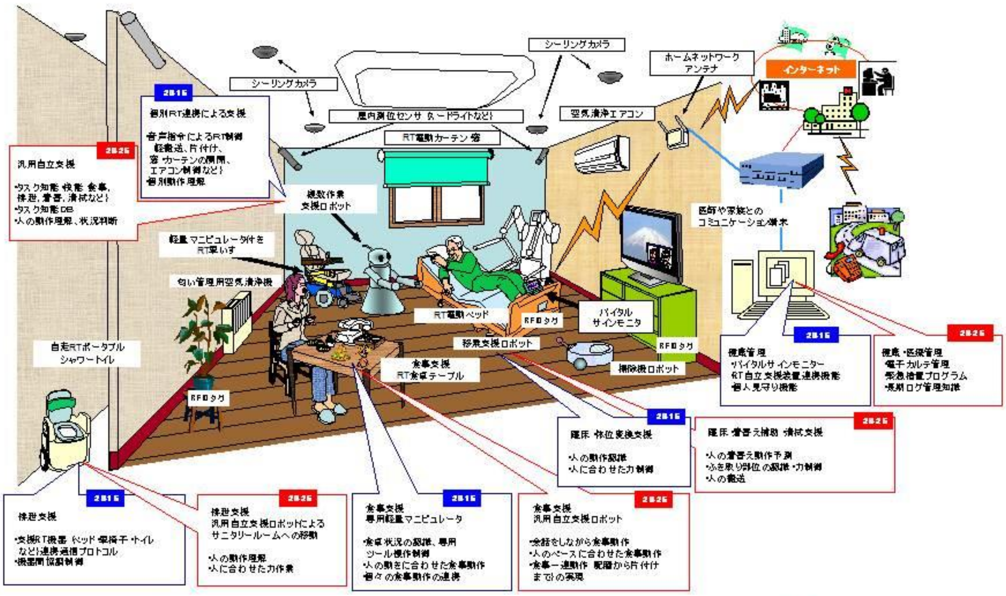
METI Roadmap of Robot Technology, Roadmap of Technological Strategy, 2005

Independence Support Robot/Environment



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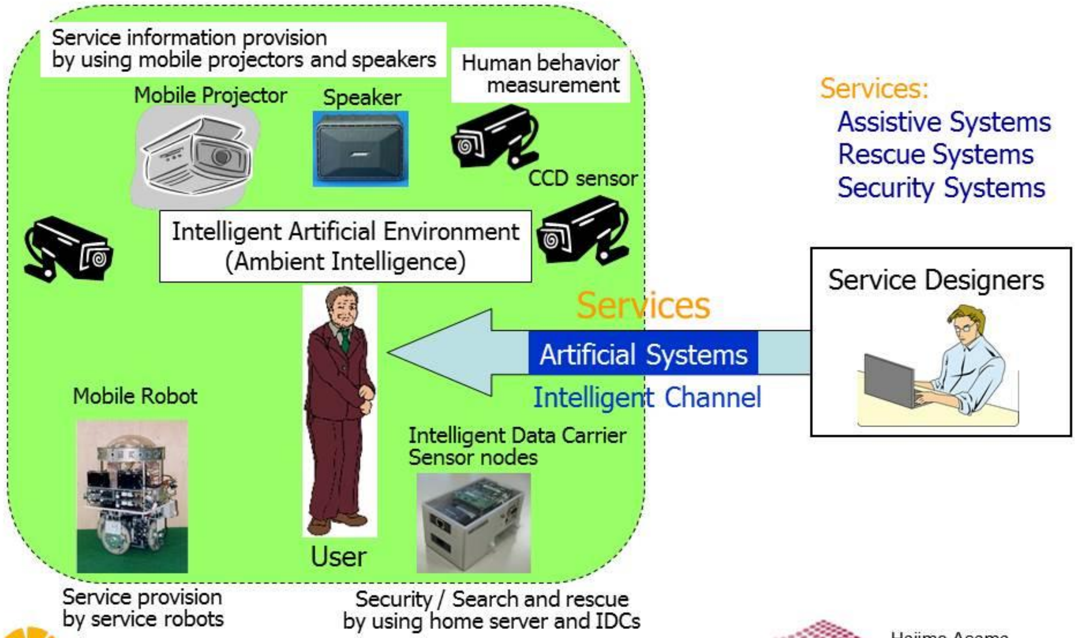
Concept of Service Media



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The Great Eastern Japan Earthquake and the Tsunami

Earthquake
- 14:46, Mar 11, 2011
- Magnitude: M9.0
- Maximum Seismic Intensity Scale: 7

Tsunami
- 30-60 min later
- Maximum Wave Height: 40.5[m]

Tsu nami

津 波

Port Wave

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Accident of Fukushima Daiichi Nuclear Power Plant

- Earthquake (14:47)
- Loss of Power Supply
- Activation of Emergency Diesel Generator
- SCRAM
  Stop Reactors
- Tsunami
- Damage of Fuel Tanks and Generators
- SBO (Situation Black Out) (15:39)
- Failure of Cooling System of Reactors and Fuel Storage Pool
- Loss of Cooling Water
- Melt down
- Hydrogen Explosion (Mar. 12-15, Unit 1, 3, 4)

Fukushima Daiichi Nuclear Power Plant

Seismic Center

By Janet Loehrke, USA TODAY

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Major Accidents of Nuclear Facilities

- Three Mile Island
  - Mar. 28, 1979
  - Level 5 (Accident of coolant loss)

- Chernobyl
  - Apr. 26, 1986
  - Level 7
- Tokai
  - Sep. 30, 1999
  - Level 4 (Criticality accident in fuel processing)
- Fukushima
  - Mar. 12-15, 2011
  - Level 7

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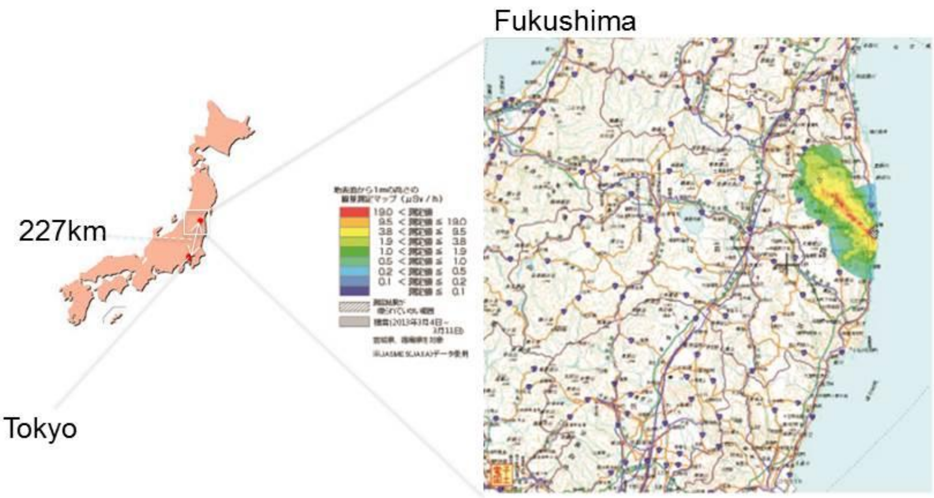
Location of Fukushima NPP



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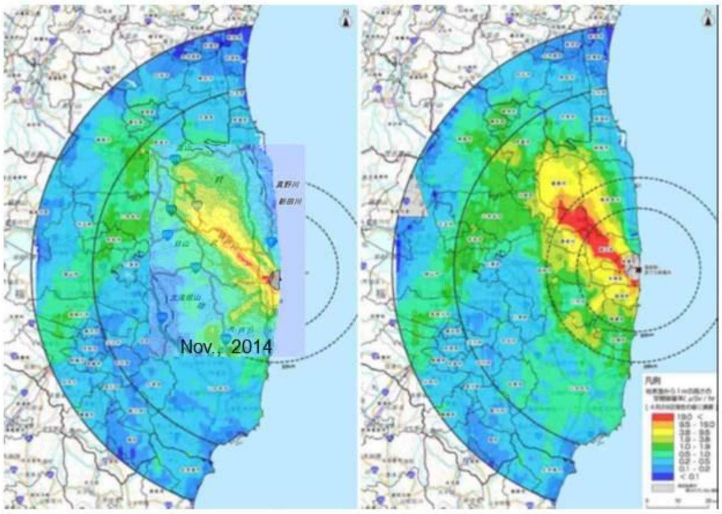
Radiation level



(MEXT)

July, 2011 April, 2011

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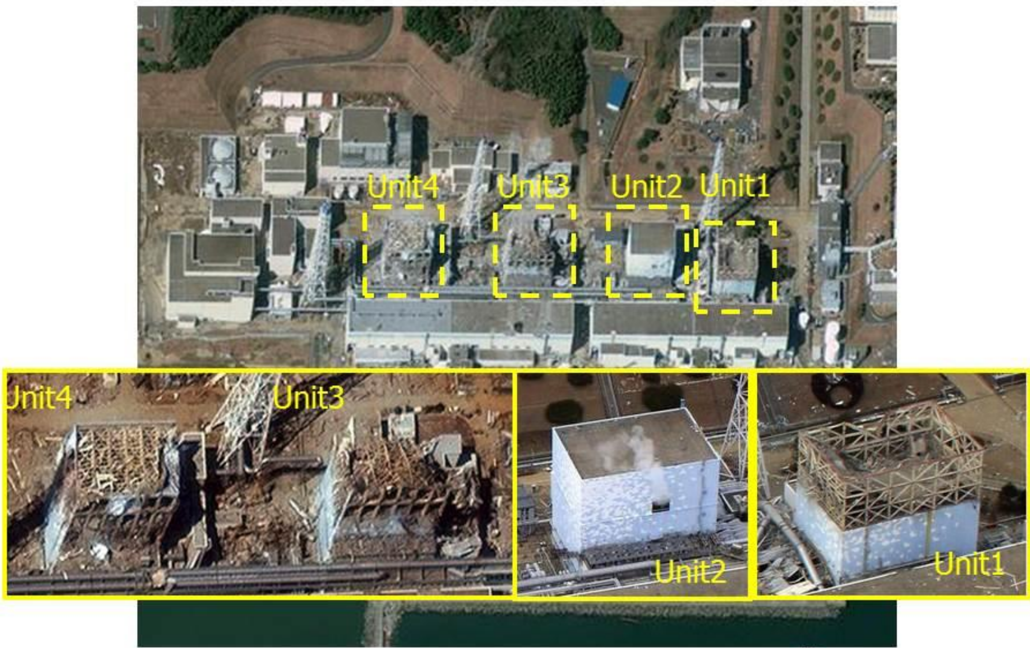
Explosion of the Reactor Building



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Recent View

Japan News: 福島第一原発3号機 原子炉真下の足場なくなる(2017.7.19)
https://www.youtube.com/watch?v=dmvFur8C4DM

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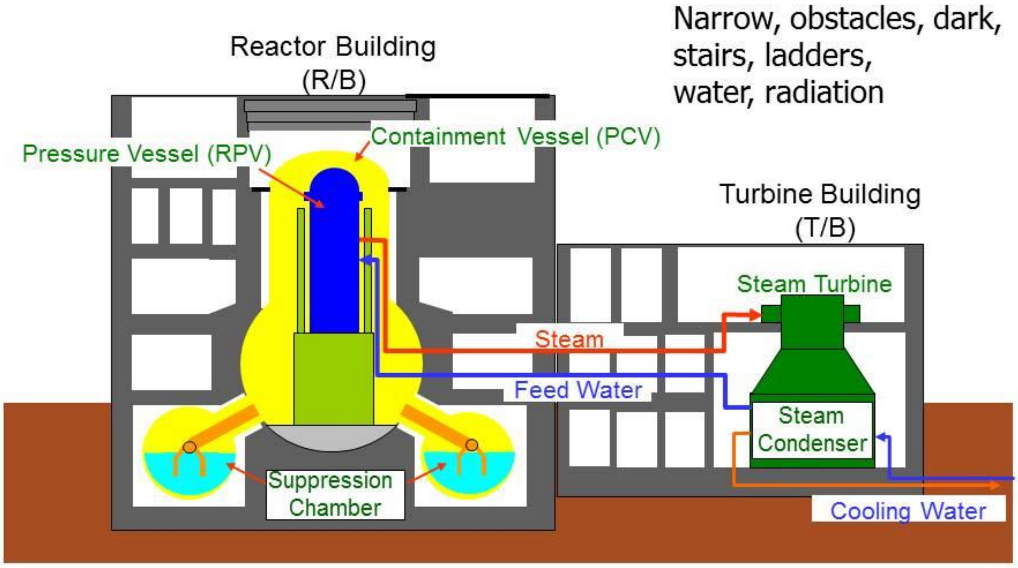
Overview Image of BWR-4

Narrow, obstacles, dark,
stairs, ladders,
water, radiation



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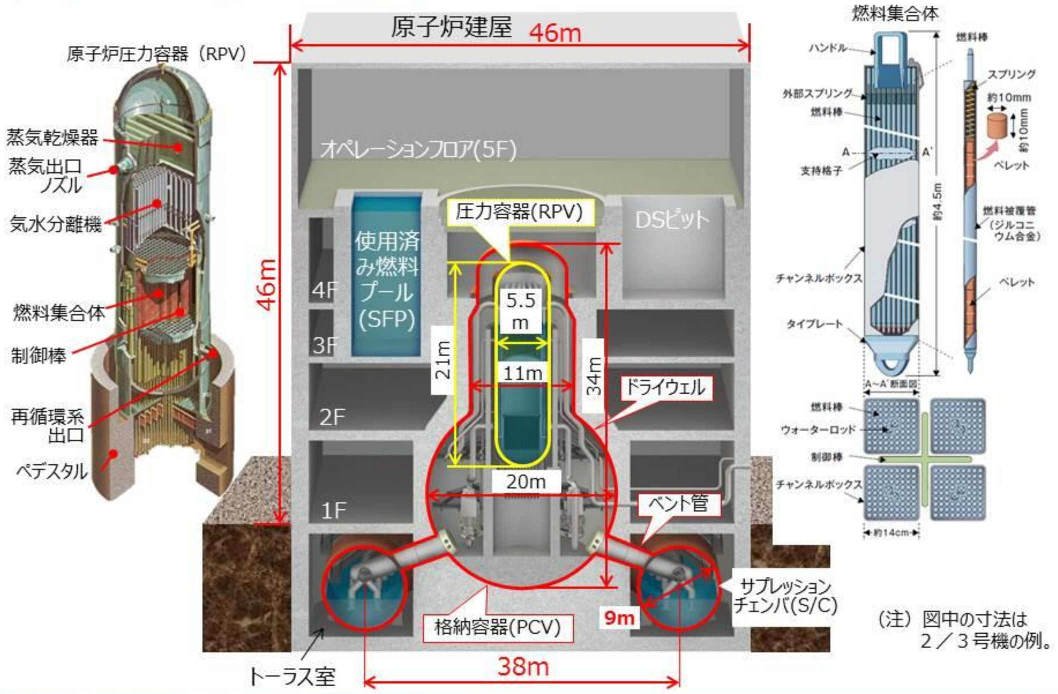
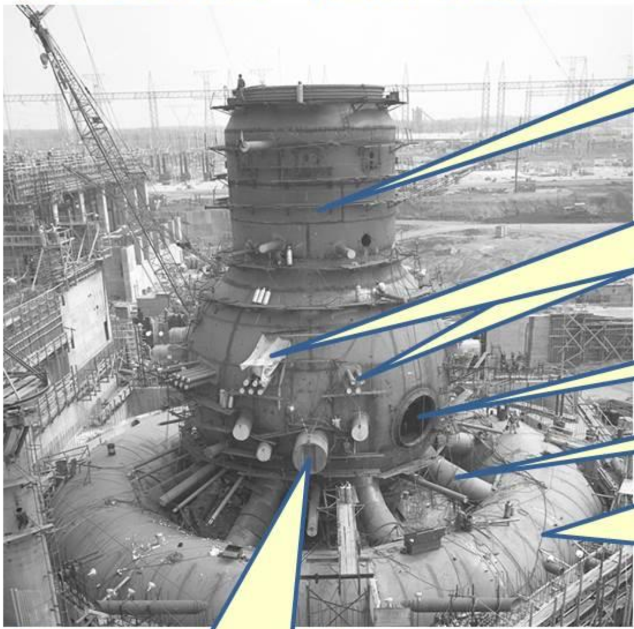
原子力発電所の構造



（注）図中の寸法は
２／３号機の例。

PCVの外観（建設写真）



「ドライウェル（D/W）」：S/Cより上部のPCV

「PCV貫通部」：配管貫通部、電気配線貫通部等
1号機　約150か所
2号機　約200か所
3号機　約190か所

「機器ハッチ」：大型機器の搬出入口

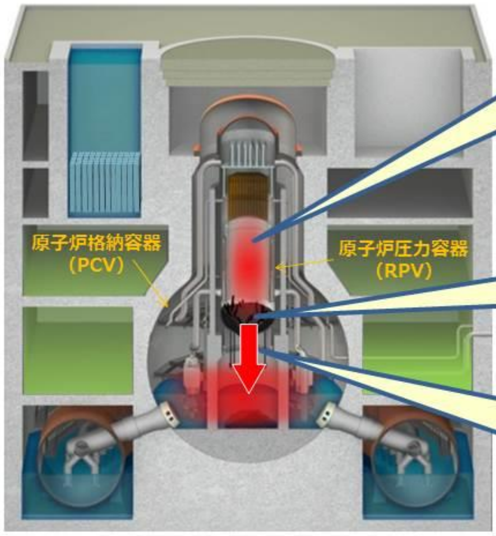
「ベント管」：D/WとS/Cの連絡配管

「サプレッションチェンバ（S/C）」：事故が起きた時に発生した蒸気をS/C内の水で凝縮し、PCVの圧力の上昇を抑える。

「エアロック」：人の出入口

「Browns Ferry Unit 1 under construction　1966.Sep.」
Tennessee Valley Authority – TVA's 75th Anniversary webpage

炉心溶融、メルトダウン、メルトスルーの意味は？



原子炉建屋（R/B）断面図

「炉心溶融」：炉心の冷却機能が失われ、核燃料の過熱により炉心を構成している燃料集合体や炉心支持構造物が高温で融解すること。

「メルトダウン」：炉心溶融が進み、溶融した燃料デブリが炉心から落下して圧力容器の底に溜まること。

「メルトスルー」：圧力容器の底に溜まった高温の燃料デブリがさらに圧力容器の底まで溶かし、圧力容器の外に流れ出ること。

※ 必ずしも「炉心溶融＝メルトダウン」ではない。
区別して使われることがある。

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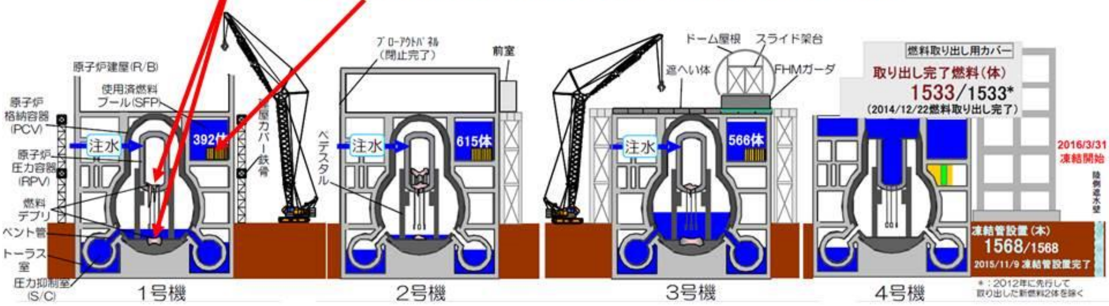
Current Situation of 4 Units

Fuel Debris (Melt-down Fuel)

Spent Fuel and New Fuel in Spent Fuel Pool



47th meeting of Japanese Government and TEPCO: Council for the Decommissioning of TEPCO's Fukushima Daiichi NPS

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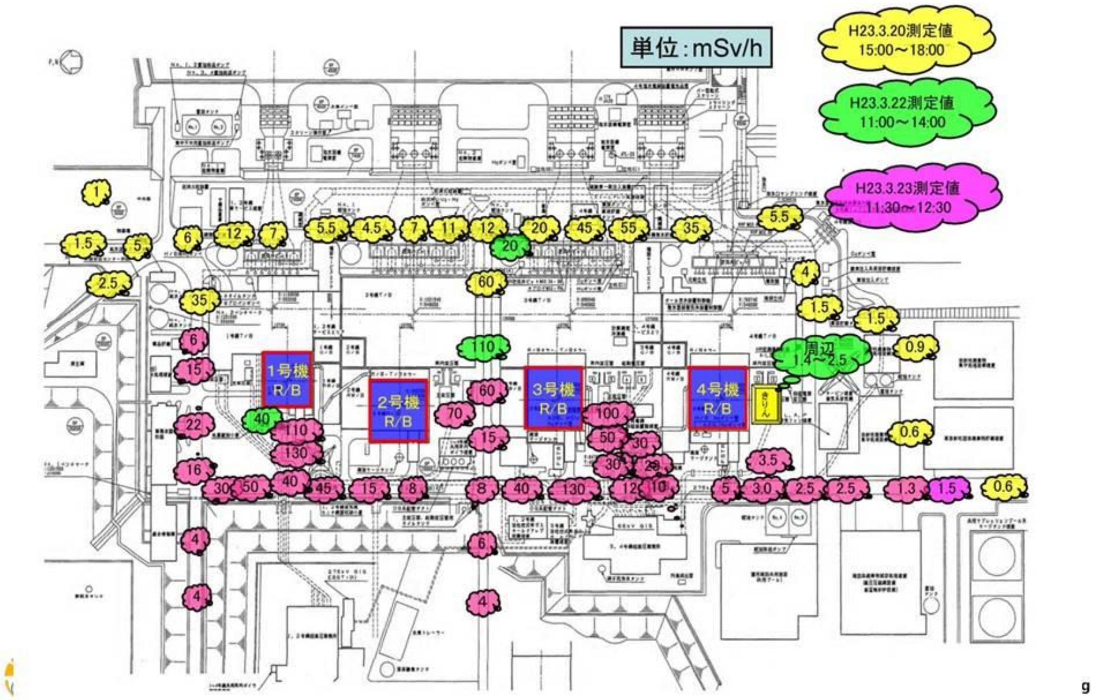
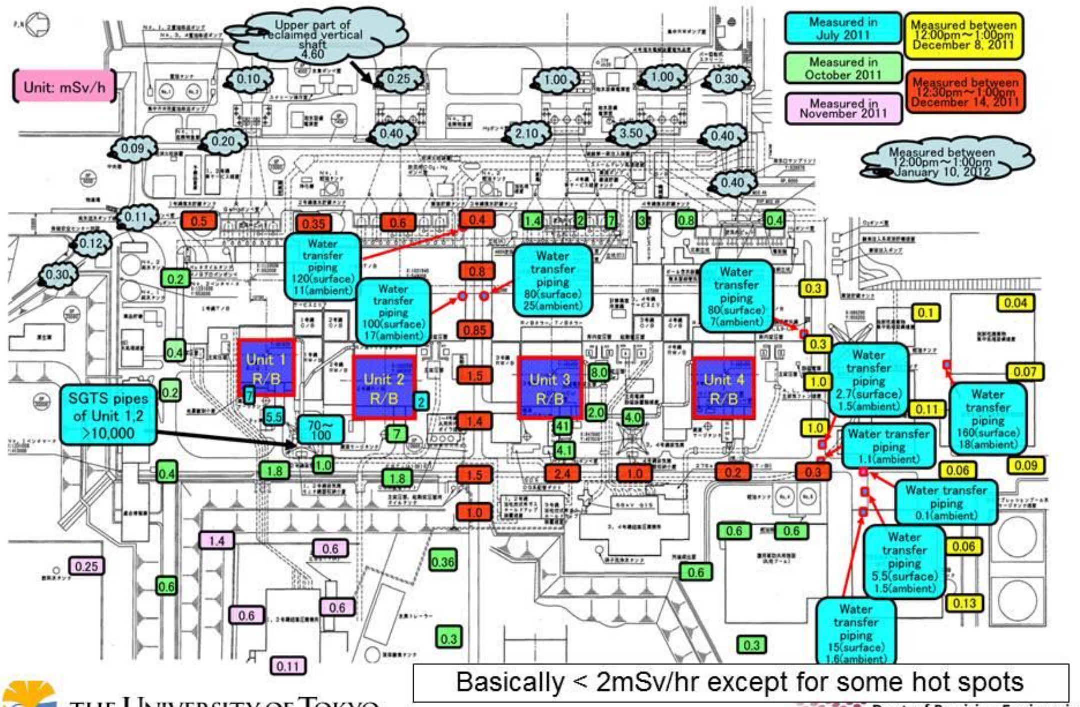
Survey Map (2011.3.23)



Dose Rate Map of Fukushima Daiichi Site (As of 5:00PM Jan.10, 2012)

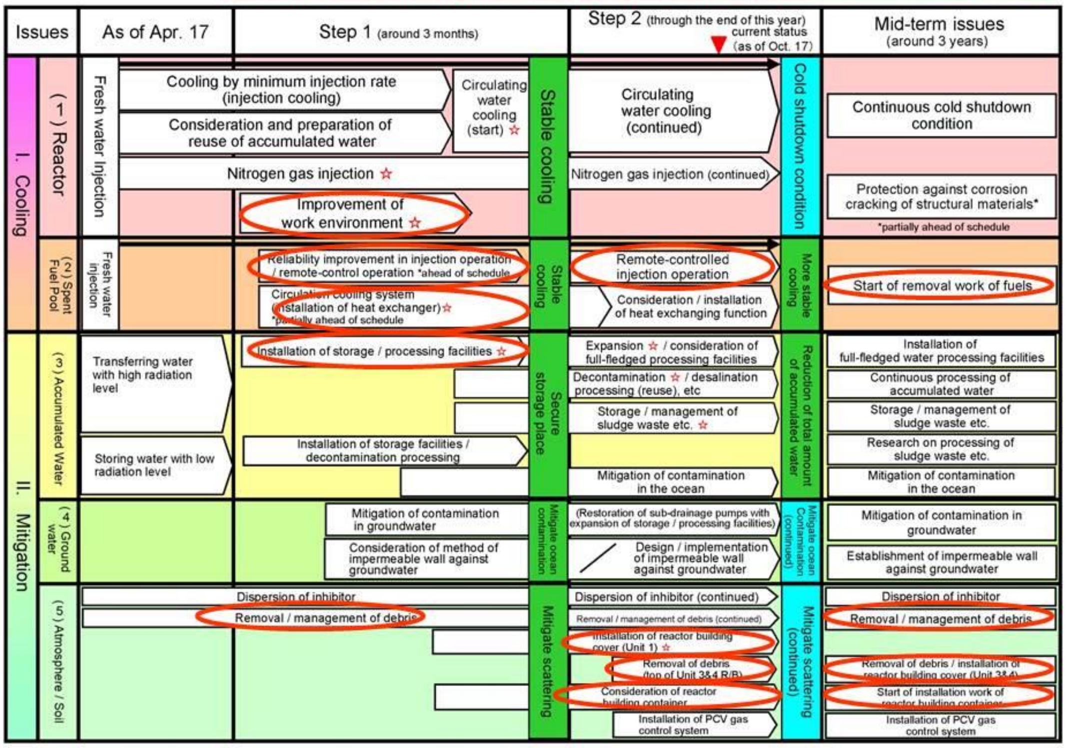


Appendix 3

Current Status of "Roadmap towards Restoration from the Accident at Fukushima Daiichi Nuclear Power Station, TEPCO" (Revised edition)

October 17, 2011
Nuclear Emergency Response Headquarters
Government-TEPCO Integrated Response Office

Red colored letter: newly added to the previous version, ☆: already reported to the government, Green colored shading: achieved target

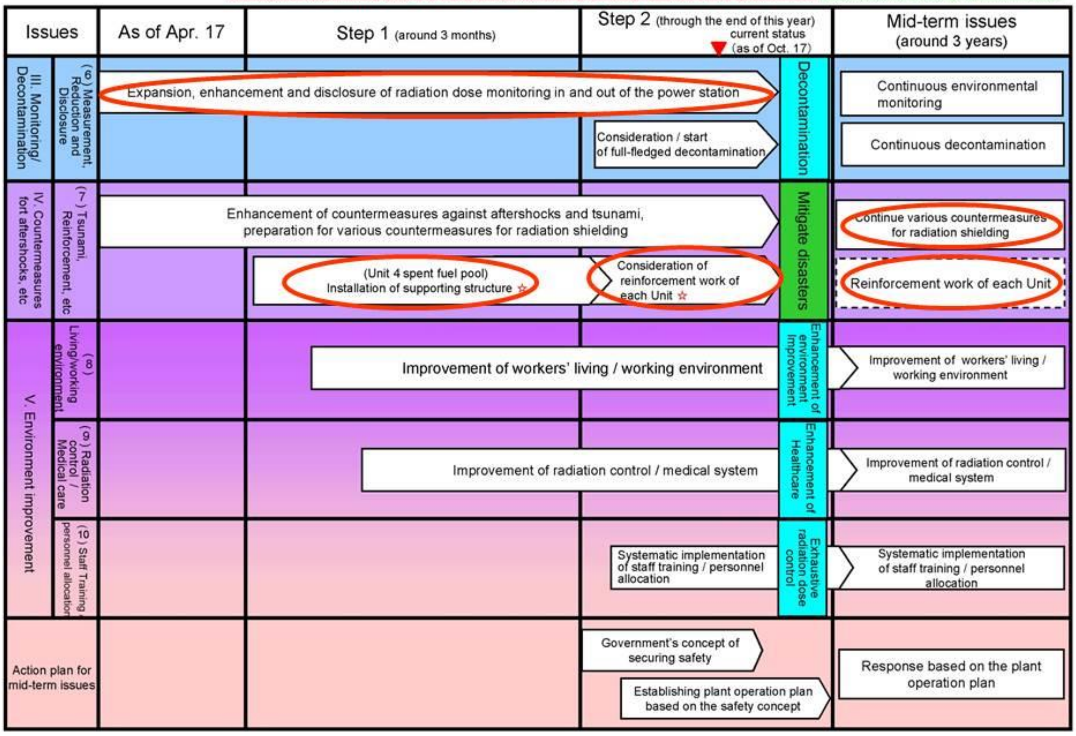


ii

Current Status of "Roadmap towards Restoration from the Accident at Fukushima Daiichi Nuclear Power Station, TEPCO" (Revised edition)

October 17, 2011
Nuclear Emergency Response Headquarters
Government-TEPCO Integrated Response Office

Red colored letter: newly added to the previous version, ☆: already reported to the government, Green colored shading: achieved object



Special Project Teams (Japanese Gov. and TEPCO)

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Mid-and-long-Term Roadmap Summary (TEPCO)

Present (Completion of Step 2)	Within 2 Years	Within 10 Years	After 30-40 Years
Step 1, 2	**Phase 1**	**Phase 2**	**Phase 3**
<Achieved Stable Conditions>	**Period to the start of fuel removal from the spent fuel pool (Within 2 years)**	**Period to the start of fuel debris removal (Within 10 years)**	**Period to the end of decommissioning (After 30-40 years)**
-Condition equivalent to cold shutdown -Significant Suppression of Emissions	-Commence the removal of fuels from the spent fuel pools (Unit 4 in 2 years) -Reduce the radiation impact due to additional emissions from the whole site and radioactive waste generated after the accident (secondary waste materials via water processing and debris etc.) Thus maintain an effective radiation dose of less than 1 mSv/yr at the site boundaries caused by the aforementioned. -Maintain stable reactor cooling and accumulated water processing and improve their credibility. -Commence R&D and decontamination towards the removal of fuel debris -Commence R&D of radioactive waste processing and disposal	-Complete the fuel removal from the spent fuel pools at all Units -Complete preparations for the removal of fuel debris such as decontaminating the insides of the buildings, restoring the PCVs and filling the PCVs with water Then commence the removal of fuel debris (Target: within 10 years) -Continue stable reactor cooling -Complete the processing of accumulated water -Continue R&D on radioactive waste processing and disposal, and commence R&D on the reactor facilities decommission	-Complete the fuel debris removal (in 20-25 years) -Complete the decommission (in 30-40 years) -Implement radioactive waste processing and disposal

Actions towards systematic staff training and allocation, improving motivation, and securing worker safety will be continuously implemented.

ring

Needs for Robots

- For Operation in Nuclear Power Plants
  - Missions
    - Stabilization of the cooling systems
    - Containment (Coverage of Reactor Buildings)
    - Decommission (Extraction of fuel debris (melt-down fuels))
    - Reduction of radiation exposure of workers
  - Tasks
    - Debris removal
    - Surveillance and mapping outside and inside of the buildings (Images, radiation, temperature, humidity, oxygen concentration, etc.)
    - Instruments setup, sampling
    - Shield and decontamination
    - Handling, removal, construction, transportation of materials and equipments, etc.

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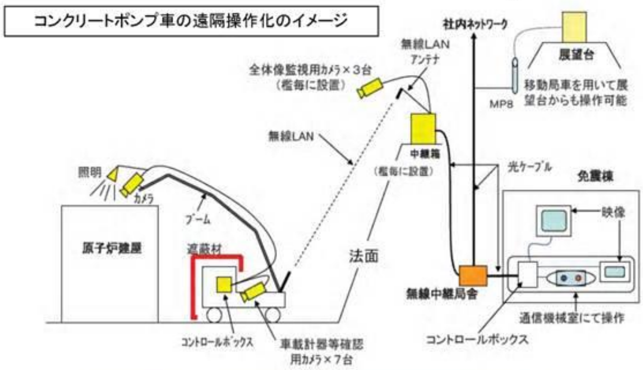
Automated watering by concrete pumping truck

From Mar. 22, 2011

(TEPCO)



ブーム先端へのカメラ等の設置

4号機 "ぞうさん2号"による注水状況

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Remotely controlled Unmanned Construction System for Debris Clearing-up
From Apr. 6, 2011

TEPCO

処理前

コンテナ１個分の処理後

ガレキ積ﾌ

コンテナふた

Crawler dumps

仮置き

ナ周辺約 2.5mSv/h)

Backhoes & Iron Forks

積み込み時配置

完了時配置

遠隔操作重機によるガレキ撤去作業

（コンテナ：3.2×1.6×1.1m、約4m^3）

1号　原子炉建屋周辺

（撤去前）

（撤去後）

（仮置の瓦礫収集コンテナ）

（東京電力提供）

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Unmanned Construction System

Used in response against explosion of volcano (Unzen-Fugen Mt.), in 1991
- Pyroclastic flow (Flow of heated rocks and volcanic ash)
- Avalanche of earth and rocks (Flow of debris)

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Unmanned Aerial Vehicles T-Hawk (Remotely controlled)
From Apr. 10, 2011

TEPCO

T-Hawk (Honeywell)

Landing

Operation Room

Top View of R/B Unit 1

Top View of R/B Unit 3

Top View of R/B Unit 4

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Mobile Robots (Remotely controlled)
From Apr. 17, 2011

TEPCO

Packbot

Entering from the doors

Near Doors

1st floor of R/B Unit 1

1st floor of R/B Unit 2

1st floor of R/B Unit 3

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Operation Vehicle (TEAM NIPPON)

JAEA (Japan Atomic Energy Agency)

- Radiation measurement and robot teleoperation
- Operation box shielded by iron plate of 80mm thickness
- Equipped with Gamma camera, monitoring camera, lightening devices, tele-operated survey meter
- Localization of radiation source by the Gamma Camera
- Confirmation of safety by measuring radiation level

(↑)ロボット操作車の外観

(←)ロボット操作車の装備

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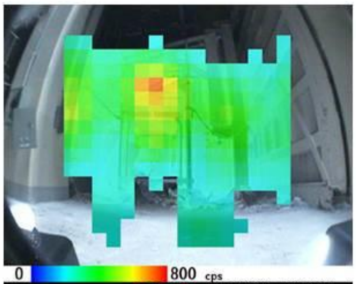
Localization of radiation source and measurement of radiation level by the Gamma Camera

May 22, 2011

(TEPCO)



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Debris Removal inside of Reactor Building Unit 3

May 10-June, 2011

Talon (QinetiQ)

Brokk-90 (Brokk)

Bob Cat (QinetiQ)

Brokk-330 (Brokk)

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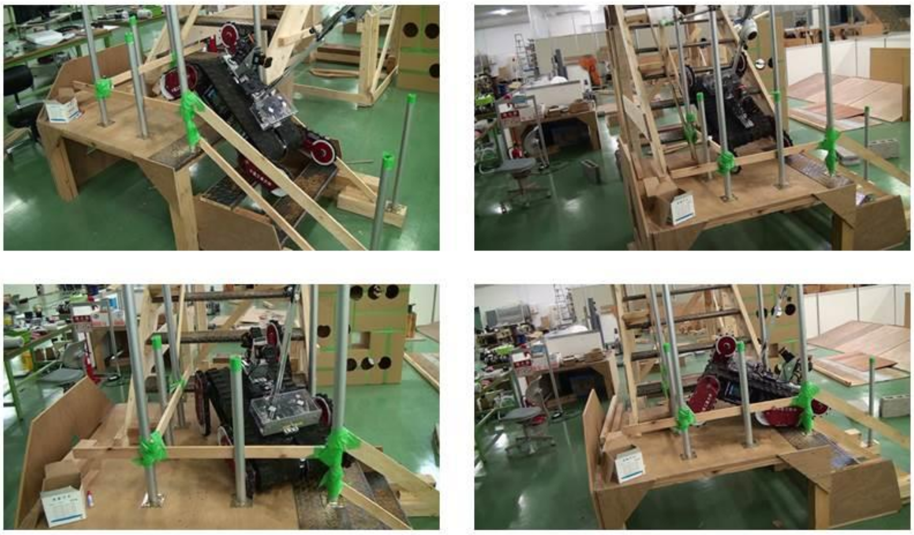
Sampling of contaminated water and setting up of water level gauge by Quince from June 24, 2011

Modified Quince

Operator Training of Narrow Stair Climbing by Quince



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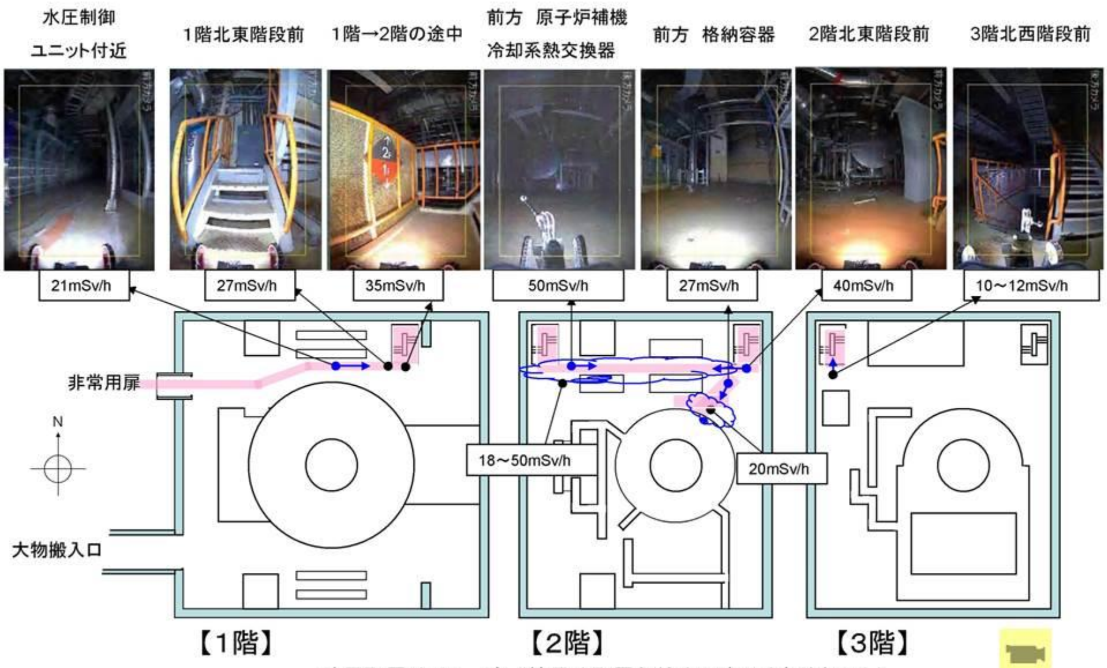
Investigation inside R/B unit 2 on July 8 by Quince

ロボットの移動経路
カメラの方向

TEPCO
July 11, 2011



建屋配置はイメージ（縮尺や配置などは正確ではありません）

Investigation of 1st-5th floor inside Unit 2 R/B on Oct. 20, 2011 by Quince

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Cleaning inside of reactor building unit 3 using the Warrior

July 2, 2011 TEPCO

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Inspection of Soundness of CS System by Packbot and Quince

July 22, 26, 2011

- Soundness of CS system was checked.
- It made it possible to cool down the core directly from inside of the pressure vessel

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Inspection inside of Reactor Building Unit 3 (2 Packbots and 1 Warrior)

Nov. 16, 2011

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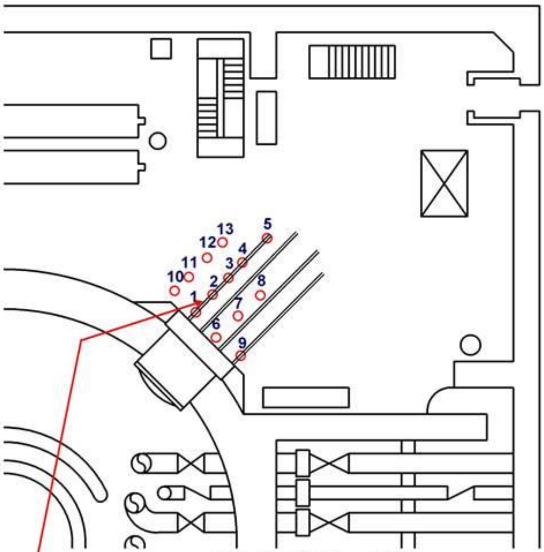
Results of Radiation Measurement at 1st floor of Unit 3

TEPCO
Nov. 16, 2011



北東エリア（機器ハッチ前）

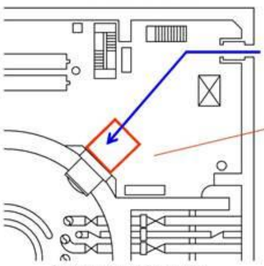
※レール溝内の水有無確認作業時に北側レール表面近傍において約1,300mSv/hを確認

測定点	測定高[m]		
	0.4	1.2	1.7
1	870	370	255
2	800	415	290
3	750	420	280
4	650	410	270
5	380	200	130
6	180	190	180
7	170	190	180
8	145	180	180
9	120	105	105
10	180	200	200
11	180	220	210
12	190	210	205
13	170	190	185

雰囲気線量測定結果[mSv/h]

Wiping Floor by a Robot

ロボット進入経路



機器ハッチ前エリア

機器ハッチレール

表面がスラッジ状

レール溝　拭き取り前

拭取り

水面が露出

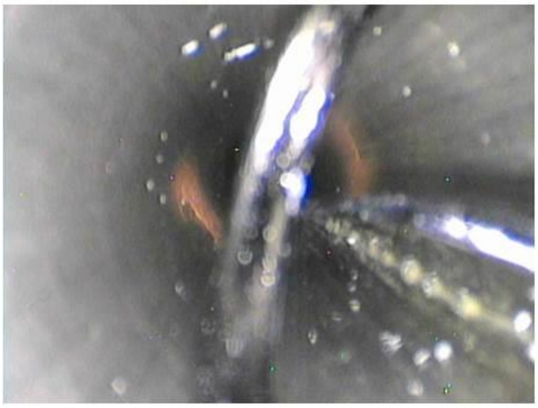
レール溝　拭き取り後

水濡れ

拭き取り後のウェス

Inspection inside PCV of Unit 2
Jan. 20, 2012

TEPCO



Industrial Endoscope
and Thermocouple

72.9Sv/h was observed
At the 2nd entry in Mar. 27, 2012

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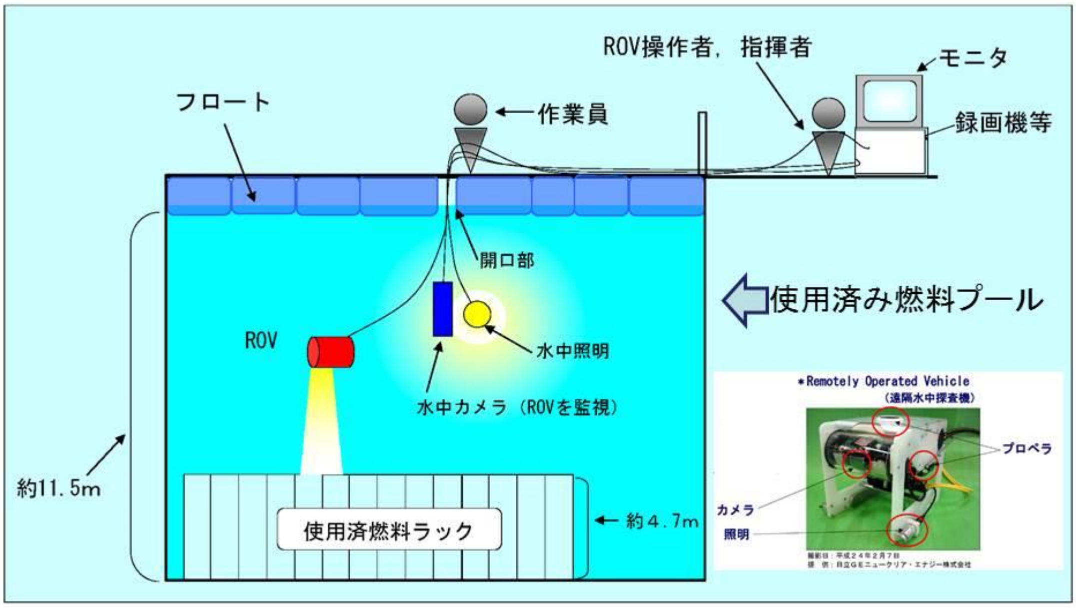
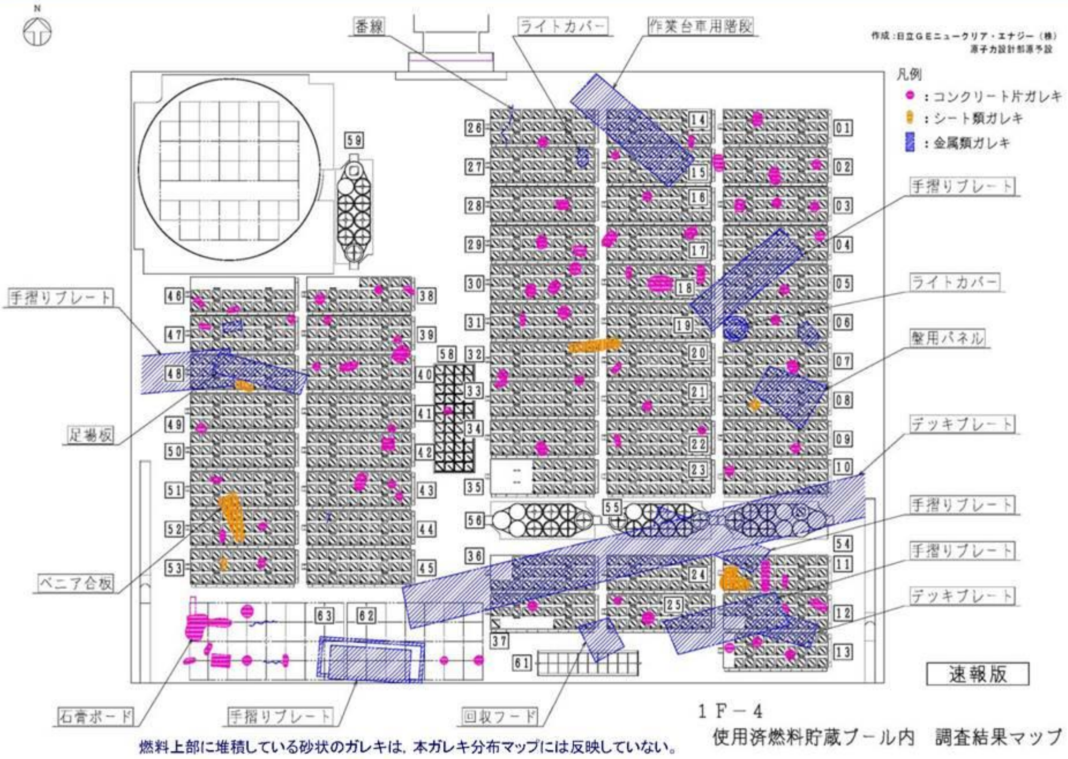
Mapping of Debris in the Fuel Storage Pool in Unit 4

Mar., 2012

使用済燃料プール上を覆っているフロート養生の開口部からROV※を使用済燃料プール内に投入し、オペレーティングフロア上で操作を実施。
※ROV：Remotely Operated Vehicle（遠隔水中探査機）



Mapping of Debris in the Fuel Storage Poon in Unit 4



Investigation of Suppression Chamber Room in Unit 2

Apr. 18, 2012

Survey Runner
TOPY Industries

Radiation dose: 186mSv
For three hours mission

Suppression Chamber SE

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Dept. of Precision Engineering
The University of Tokyo

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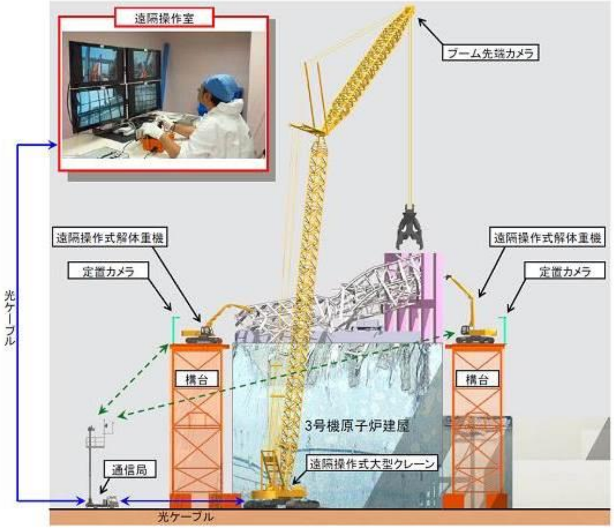
Debris Clearing-up of Operation Floor Using Remotely-controlled Machines

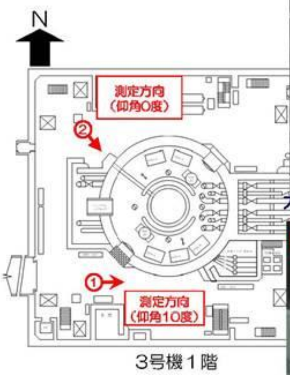


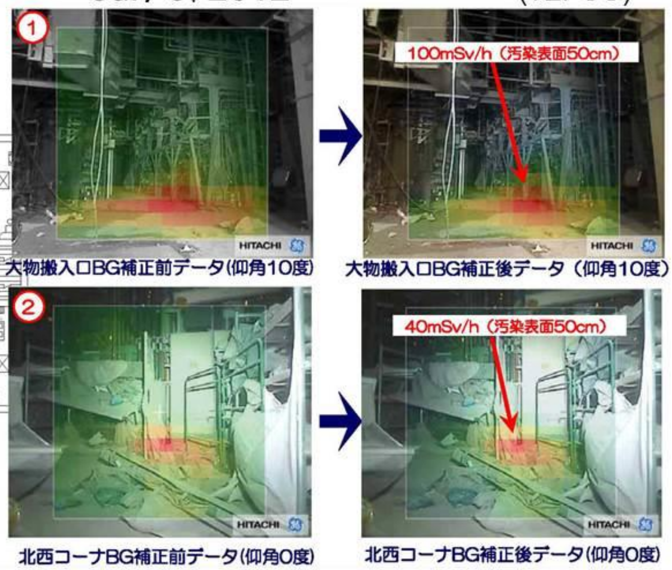
Debris Clearing-up of Operation Floor of Unit 3

Clearing-up on the ground

Radiation Source Localization & Radiation Measurement of Unit 2 and 3 Using γ Camera and Dosimeter

July 5, 2012 (TEPCO)

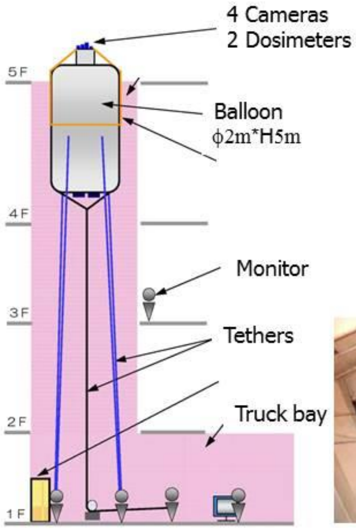




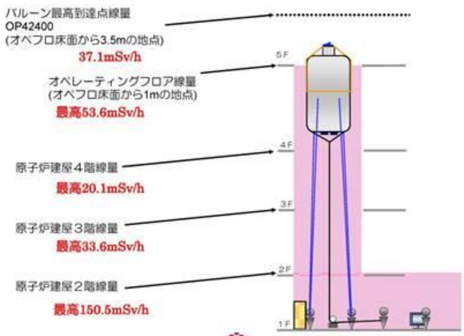
Packbot+ Hitachi γ Camera

Investigation of operation floor of R/B unit 1 using balloon

Oct. 24, 2012 (TEPCO)



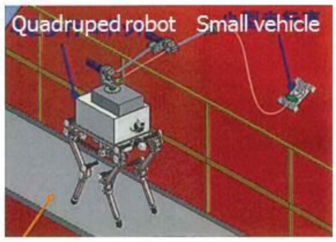
Equipment hatch



Inspection of S/C vent pipe leakage of R/B unit 2 using quadruped robot

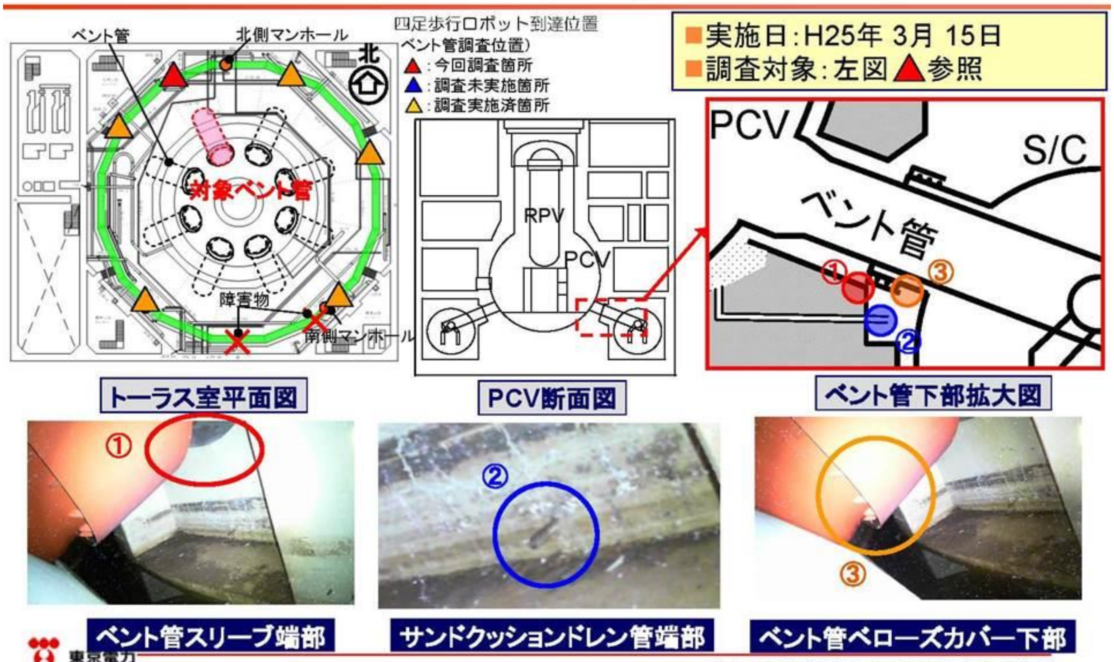
Nov. 22, 2012 (planning) (TEPCO)

Quadruped robot



Small vehicle

Results of vent-line inspection



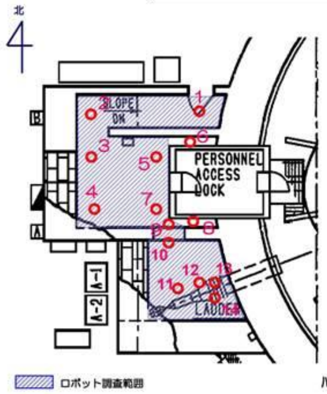
Investigation of Personal Airlock Room

Apr. 9, 2013

(Mitsubishi Electric TOKKI Systems & TEPCO)

FRIGO-MA

L	650mm
W	490mm
H	750mm
Weight	38kg

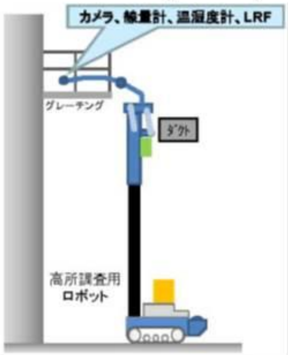


	線量率[mSv/h]		
測定高	0. 35m	1. 90m	備考
1	2	–	
2	6	9	
3	8	8	
4	4	4	
5	5	5	
6	-	10	
7	11	10	
8	-	10	
9	19	66	
10	34	100	
11	130	-	床近傍
12	2100	-	床近傍
13	-	110	配管上
14	-	230	配管上

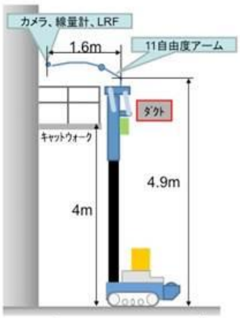
ﾊﾟｰｿﾅﾙｴｱﾛｯｸ室内　温度１４℃、湿度５０％

Inspection by Inspection Robot for high location

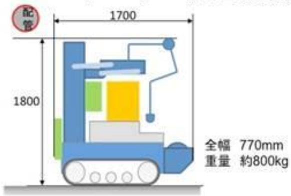
June 13, 2013 (Honda & AIST) (TEPCO)



システム安全検討



高所のモニタリング



移動姿勢

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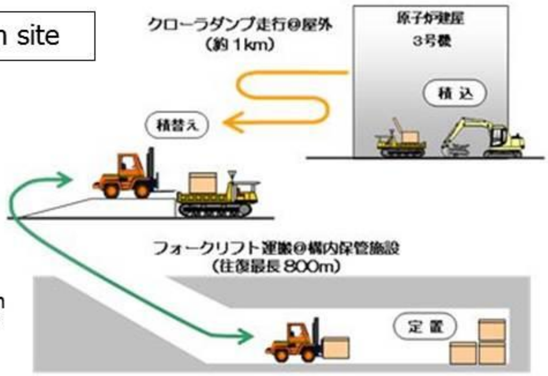
Dept. of Precision Engineering
The University of Tokyo

Automated system for debris transportation

June 24, 2013

(Kajima Corp.)

Destruction site



1km
Automatic transportation by a crawler damp truck

Temporal storage facility

800m
Automatic transportation by forklift

Final storage

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Dept. of Precision Engineering
The University of Tokyo

Removal of debris and obstacles by dual arm construction machine ASTACO-SoRa

Hitachi Engineering & Services (TEPCO)

(June 24, 2013)

装置名	小型双腕重機型ロボット
重量	約2.5トン
外形寸法 (突起部除く)	幅：980～1,280mm(クローラー可変) 長さ：1,570mm 高さ：1,500mm(アーム込み最低)
駆動方式	ディーゼルエンジン 定格出力 11kW / min-1(15PS /2,400 rpm)
燃料	軽油
燃料タンク容量	19.5リットル
駆動時間	約15時間(連続使用の場合)
吊上荷重	両腕約300kg/片腕約150kg
走行速度	約2.6km/h
操作方式	無線(非常時：有線)

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The University of Tokyo

Remotely controlled robot for inspection and maintenance

Mitsubishi Heavy Industries

MHI-MEISTeR (TEPCO)

寸 法(外形)	長さ:1,250mm、幅:700mm、高さ:1,300mm
質　　量	440kg
移 動 方 式	対地自動追従式独立4クローラー式
移 動 速 度	2km／時
走 行 性 能	傾斜40度、段差220mmまでの階段昇降、不整地走行、狭い場所の走行
通　　信	無線・有線の選択 （無線時はバッテリーで2時間稼働）
ロボットアーム	7軸アームを2本搭載。1本あたりの可搬質量15kg

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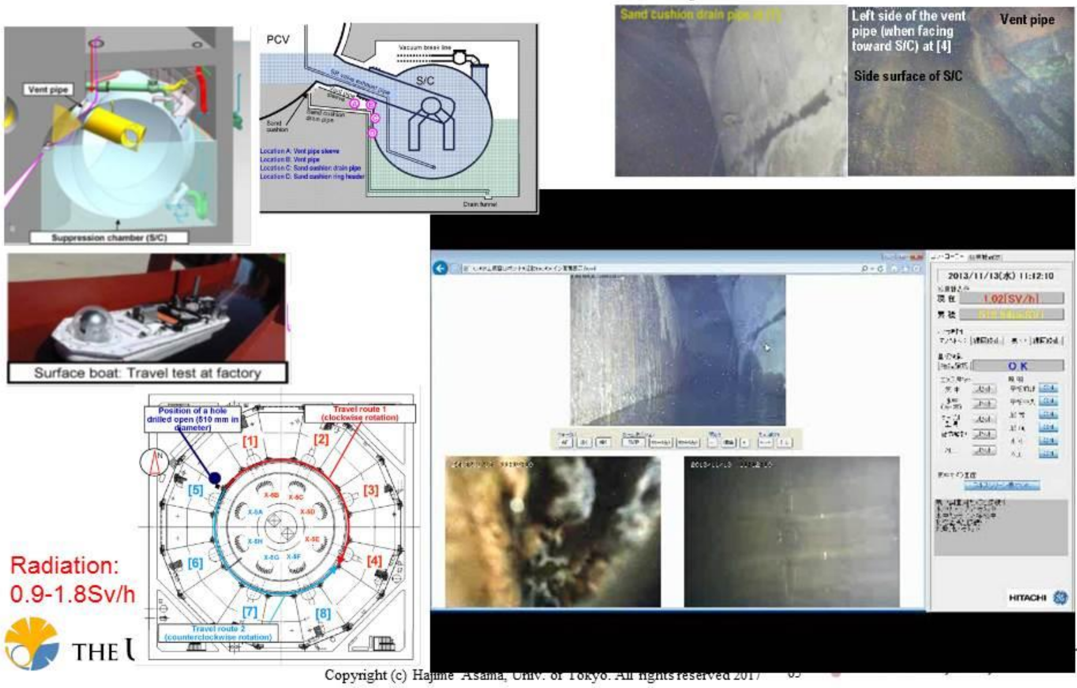
Investigation around Lower Parts of Unit 1 Vent Pipes

（Nov. 13, 2013） (TEPCO)

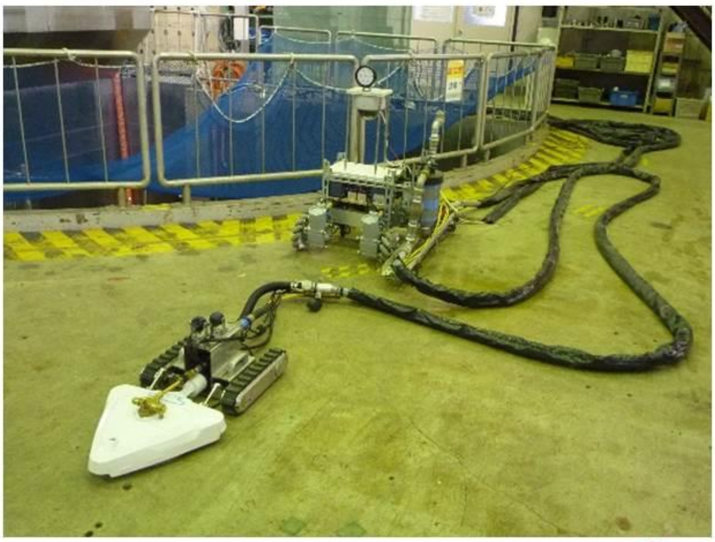


Radiation:
0.9-1.8Sv/h

Decontamination of 1st floor of Unit 2

（Nov. 28-, 2013）

Raccoon: Decontamination Robot (ATOX, Japan)



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Decontamination of Operation Floor of Unit 3

（Nov. 22-, 2013）

Moose+Attachments (Dozer, Vacuumer, Scabbler: Pentek, USA)

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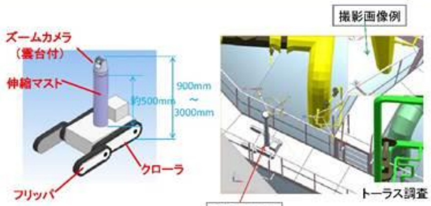
The University of Tokyo

3D laser scan and 3D model construction inside unit ½

(Dec. 26, 2013)

■計測機器を搭載した遠隔操作装置を自走させて3Dレーザスキャンを行う。
■遠隔操作装置の運搬や自走アクセスが難しい箇所は、有人による計測（作業員が計測装置のみを運搬して測定）を行う（1階の一部、三角コーナー）。
■作業エリア
- 1号機原子炉建屋　地上1階、トーラス室※
  ※1号機トーラス室については、今年度に国PJで製作するS/C上部調査装置（下図参照）を使い来年度（H26年度）以降に計測を行う予定。
- 2号機原子炉建屋　地上1階、トーラス室、中地下階（三角コーナー）

■計測装置：FARO社製3Dレーザ計測装置
計測装置を使い3D点群データを取得する。
■遠隔操作装置：1/2号機で計測時期が重なることから、別々に準備



東京電力

The University of Tokyo

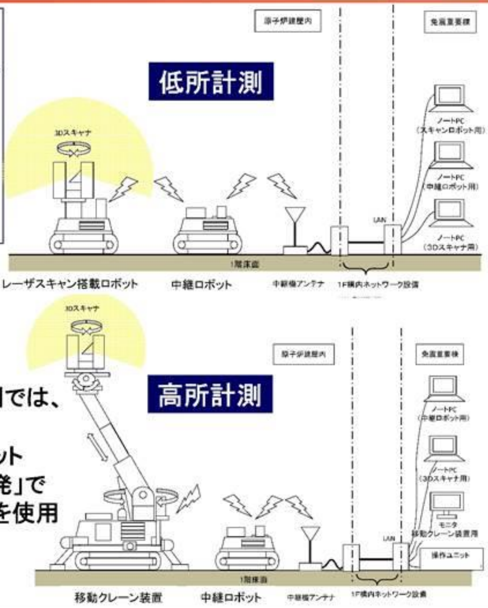
3-1. 遠隔操作装置の概要（1号機）

4

- R/B1階低所部の計測では、レーザスキャンを搭載したロボットを自走し行う。
- 高所部の計測では、移動クレーン装置を用いて、計測装置を高所まで持ち上げて行う。
- いずれの装置も中継用ロボットを用い て、無線通信にて遠隔操作する。

R/B1階低所部の計測では、「総務省　委託研究 ライフサポート型ロボット 技術に関する研究開発」で開発した調査ロボットを使用

遠隔操作装置（レーザスキャン搭載ロボット）の外観



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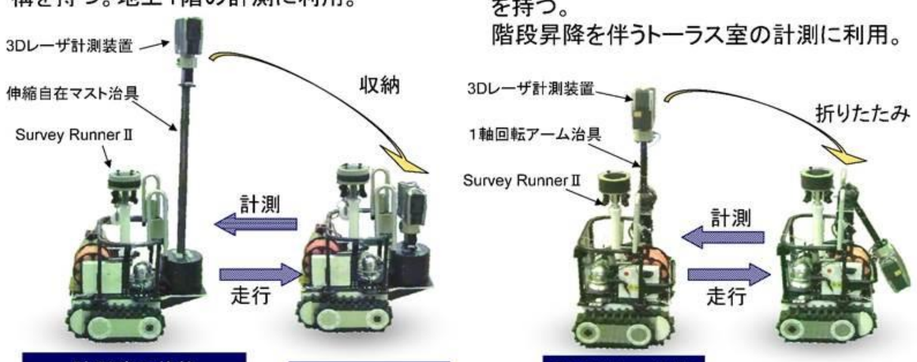
3-2. 遠隔操作装置の概要（2号機）

5

- Survey Runner Ⅱ（トピー工業社製）に3Dレーザ計測装置を搭載して走行できるように改造し、遠隔操作により計測を行う。

伸縮自在マスト搭載
計測器を任意の高さに昇降させられる機構を持つ。地上1階の計測に利用。

1軸回転アーム治具搭載
階段昇降時に計測器を搭載する治具を回転させて重心バランスを調整する機構を持つ。
階段昇降を伴うトーラス室の計測に利用。

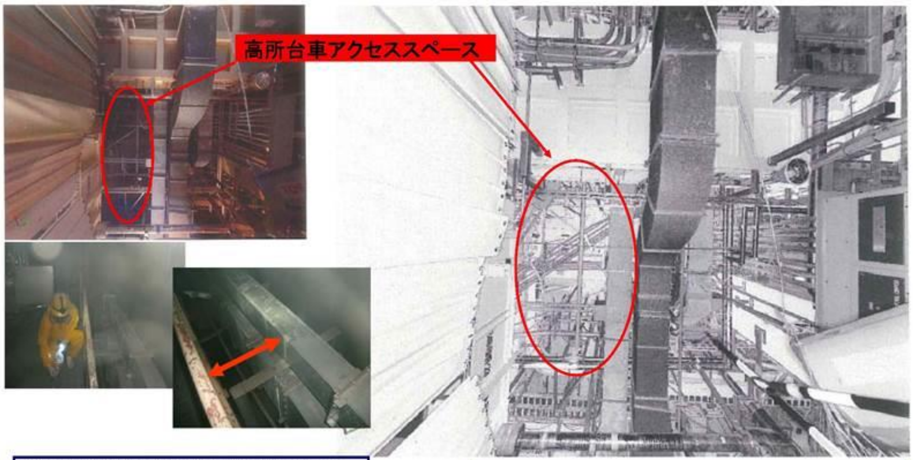


計測時の状態 高さ 最大300cm(可変)　走行時の状態　計測時の状態 高さ 約120cm　走行時の状態

東京電力

活用例1：モックアップ計画へのデータ活用例（例：高所台車） 13

従来の現場調査イメージ | レーザーデータを活用したイメージ



作業エリア確認（干渉物確認、装置設計のための寸法測定等）は、人が現場に立ち入りメージャー等で実測

レーザスキャンで取得した計測データから、設備を明確に識別・計測

東京電力

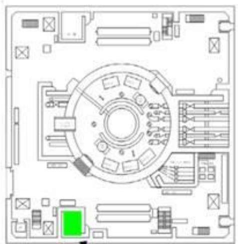
The University of Tokyo

Water-level Measurement of S/C of Unit 2

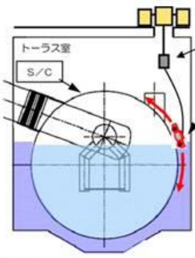
（Jan. 14-15, 2014）

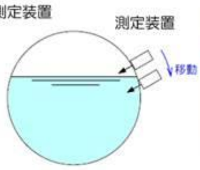
(TEPCO)

ATOX社製
調査ロボット



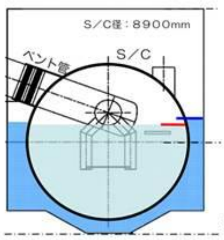
吊り降ろし回収装置設置場所
（2号機原子炉建屋1階　RHR熱交換器（B)室）





S/C内水位測定イメージ図

測定時の状況



2号　原子炉建屋1階床レベル
OP10，200mm

測定日	1月14日	1月15日	1月16日
S/C内水位	約OP3，210mm	約OP3，160mm	約OP3，150mm
トーラス室滞留水水位（参考）	約OP3，230mm	約OP3，190mm	約OP3，160mm
水位差	約20mm	約30mm	約10mm
測定方法	水中構造物の直接距離計測		

【補足】S/C内の水位は、トーラス室滞留水水位の変化の影響を受けると考えられる。

S/C赤道　OP1，900mm

2号　原子炉建屋地下1階（最下部）
OP−3，360mm

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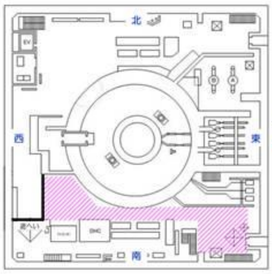
Dept. of Precision Engineering
The University of Tokyo

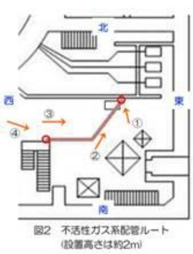
Contamination Inspection in South Area in Unit 1

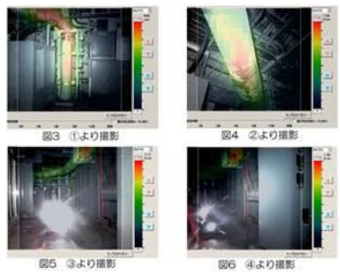
(Jan. 17, 2014)

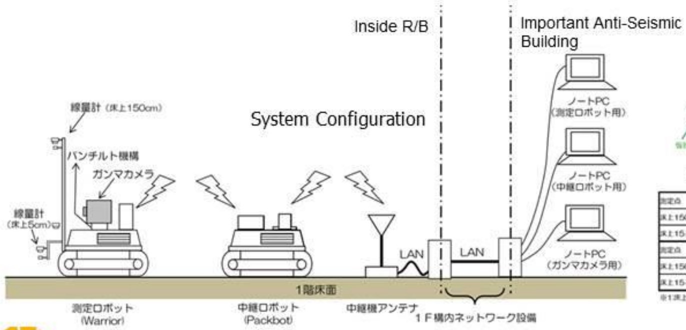
(TEPCO)

Inspection Area (R/B 1st Floor)









線量率[mSv/h]

測定点	1	2	3	4	5	6	7	8	9	10	11	12	13
床上150cm	254	321	132	1900	881	290	/	/	/	/	/	/	/
床上15cm	238	251	77	840	406	254	93※1	55※1	34※1	40※1	102※1	132※1	57※1
測定点	14	15	16	17	18	19	20	21	22	23	24	25	
床上150cm	/	1110	1620	1050	345	538	/	/	/	/	/	130※2	
床上15cm	109※1	528	777	520	311	474	2070※3	5150※4	85※1	96※1	168※1	/	

※1床上約60cm ※2床上約106cm ※3ファンネル上部 ※4床貫通部上部

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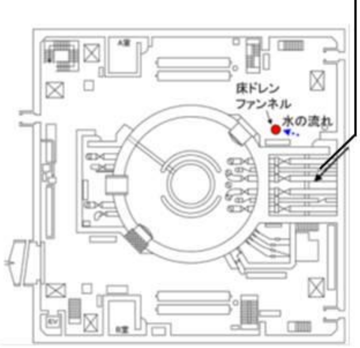
Contaminated Water Leakage Detection near MSIV Chamber in Unit 3

(Jan. 18, 2014)

(TEPCO)

MSIV Chamber



Inspection by ASTACO-SoRa

Hajime Asama
Dept. of Precision Engineering
The University of Tokyo

Core Sampling and Fence Removal in Operation Floor of Unit 2

(TEPCO)

（Mar. 13-14, 2014）　　　　（Mar. 21-22, 2014）

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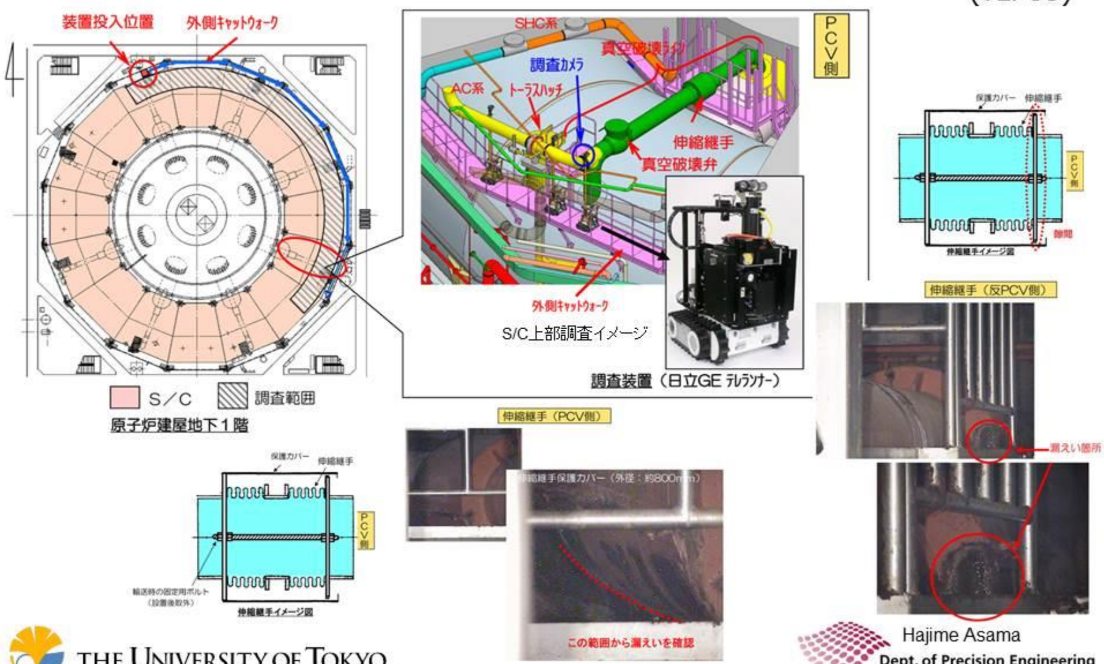
Inspection of High Location Area in S/C of Unit 1

（May 27, 2014）

(TEPCO)



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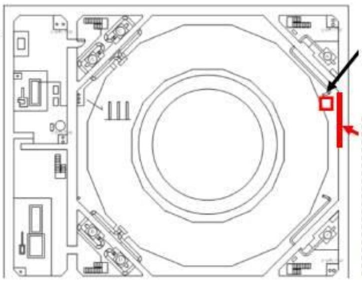
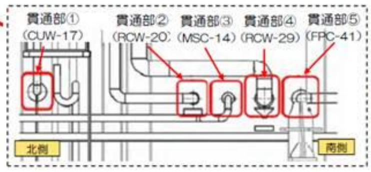
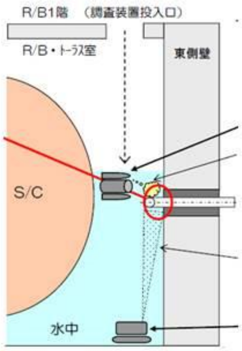
Investigation of Walls in Torus Room in Unit 2 by ROVs

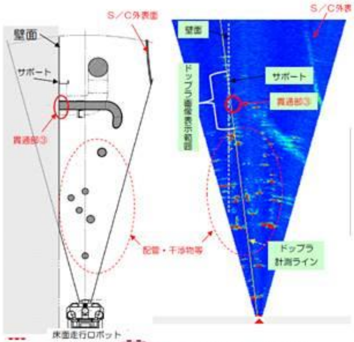
(TEPCO, IRID)

(July 28, 2014)









Hajime Asama
Dept. of Precision Engineering
The University of Tokyo

Investigation of Bottom Outer Surface of S/C in Unit 2 by Underwater Wall Climbing Robot

(Sep. 30, 2014)

(TEPCO, IRID)

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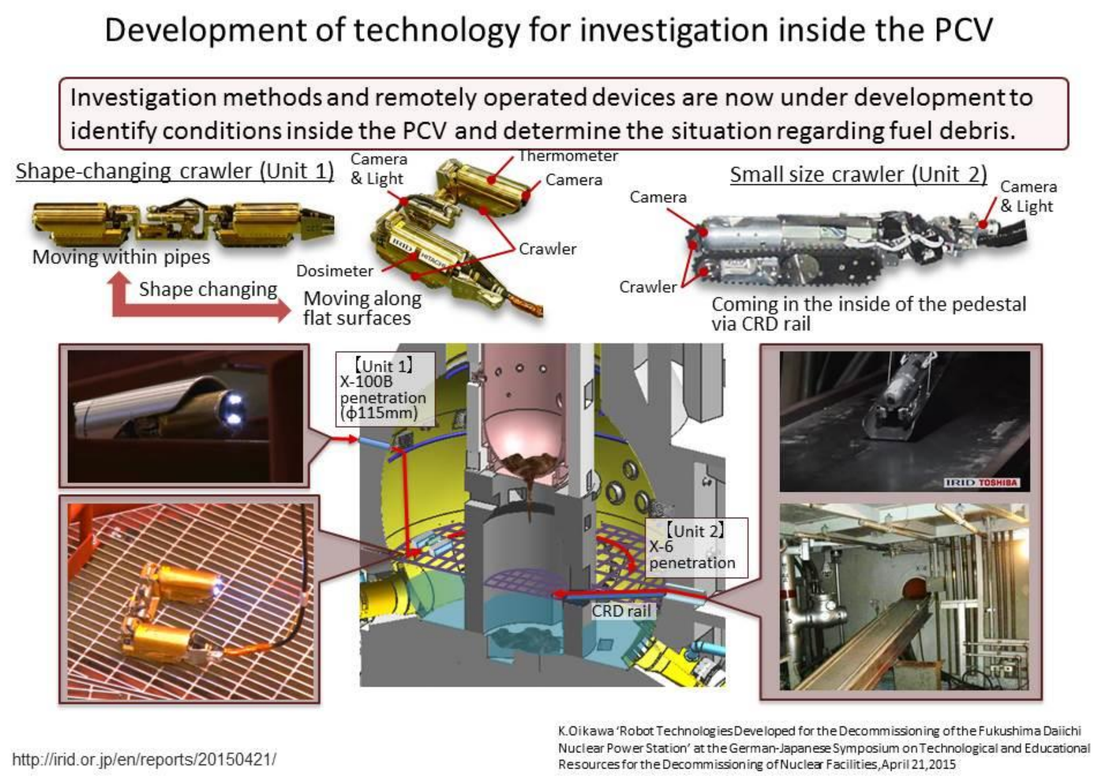
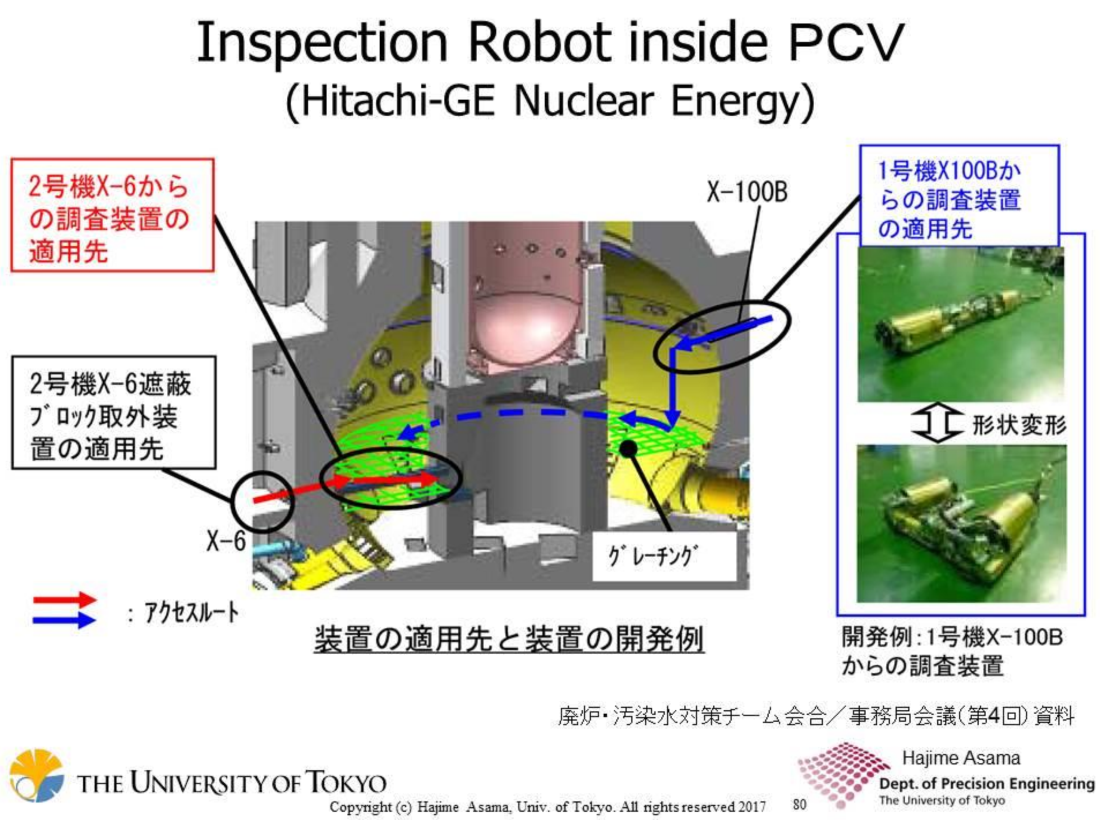

Development of technology for investigation inside the PCV
Investigation methods and remotely operated devices are now under development to identify conditions inside the PCV and determine the situation regarding fuel debris.
Shape-changing crawler (Unit 1)
Camera & Light
Thermometer
Camera
Crawler
Dosimeter
Moving within pipes
Shape changing
Moving along flat surfaces
Small size crawler (Unit 2)
Camera
Camera & Light
Crawler
Coming in the inside of the pedestal via CRD rail
【Unit 1】 X-100B penetration (φ115mm)
【Unit 2】 X-6 penetration
CRD rail
http://irid.or.jp/en/reports/20150421/
K.Oikawa 'Robot Technologies Developed for the Decommissioning of the Fukushima Daiichi Nuclear Power Station' at the German-Japanese Symposium on Technological and Educational Resources for the Decommissioning of Nuclear Facilities, April 21, 2015


Inspection Robot inside PCV
(Hitachi-GE Nuclear Energy)
2号機X-6からの調査装置の適用先
X-100B
1号機X100Bからの調査装置の適用先
2号機X-6遮蔽ブロック取外装置の適用先
形状変形
X-6
グレーチング
：アクセスルート
装置の適用先と装置の開発例
開発例：1号機X-100Bからの調査装置
廃炉・汚染水対策チーム会合／事務局会議(第4回)資料
THE UNIVERSITY OF TOKYO
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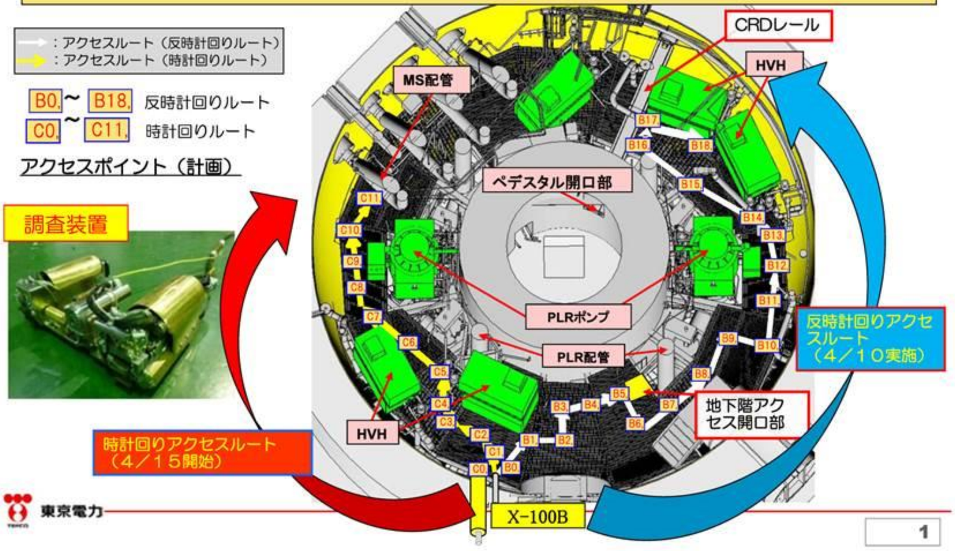
Inspection inside PCV
(operated by IRID/Hitachi GE and TEPCO)

目的：1号機について，X−100Bペネより調査装置を投入し，『PCV内の1階グレーチング上』の情報取得を目的とした調査を実施する。



Inspection inside PCV
(operated by IRID/Hitachi GE and TEPCO)

Apr. 19, 2015

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Dept. of Precision Engineering
The University of Tokyo

Leakage Investigation of Equipment Hatch of Unit 3 PCV by Crawler robot with Smartphone

(Nov. 27, 2015) (TEPCO)

https://www.youtube.com/watch?v=11jlirSNFrQ

Hajime Asama
Dept. of Precision Engineering
The University of Tokyo

Decontamination Machine for Upper Levels

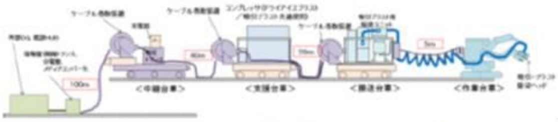
(IRID)

Press announcement: Dec. 16, 2015

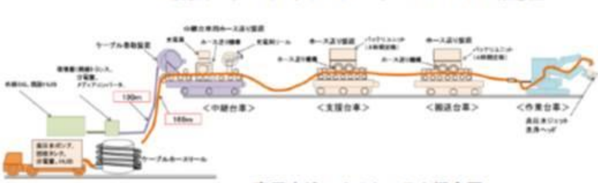
除染対象	2・3階の床面及び壁面(高さ約2m)
除染方式	吸引、ブラスト、ドライアイスブラスト、高圧水ジェットの4技術＊
上部階アクセス方法	昇降リフタ(実機で手配)で機器搬入口より進入
非常時装備	非常用電源および通信装備

＊台車は共用化を図りメーカで分担開発。適用する除染方式に応じて除染ユニットを交換する

吸引・ブラストユニットを搭載した装置



吸引、ブラスト、ドライアイスブラストのシステム概念図



高圧水ジェットのシステム概念図

http://www.imart.co.jp/houshasen-level-jyouhou.html

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Fuel Handling Machine for Unit 3
(Toshiba)

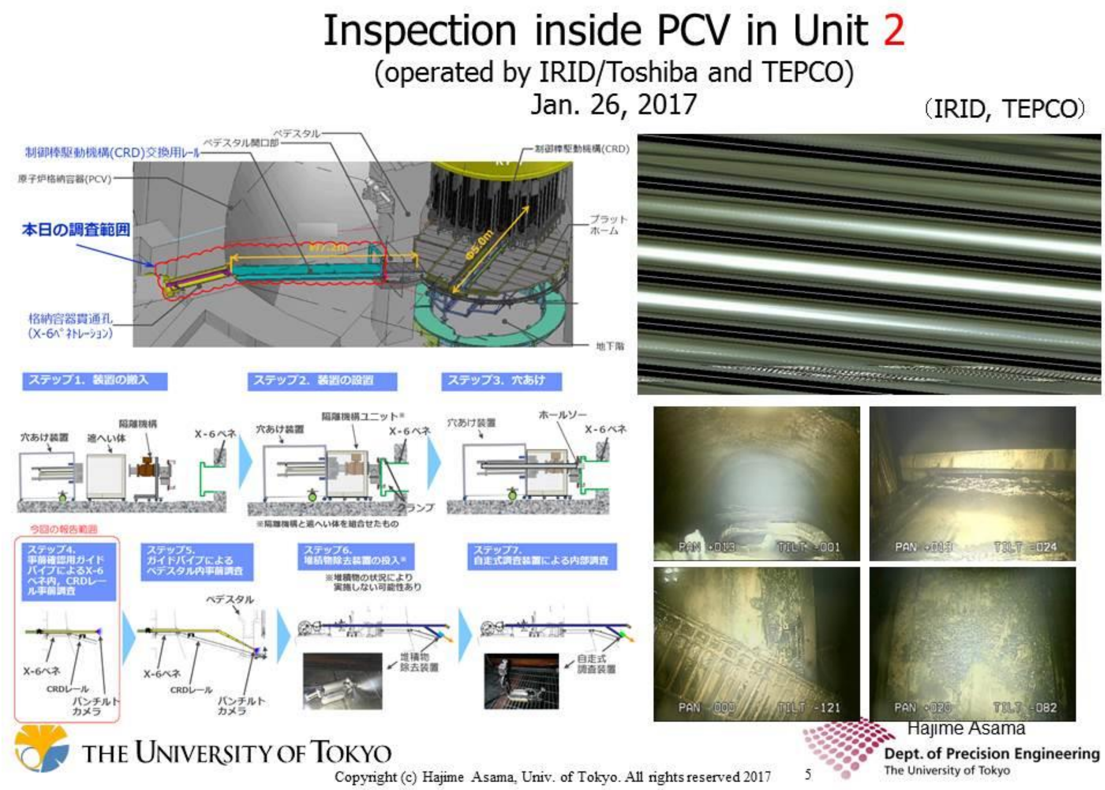
Press Announcement: Jan. 18, 2016

http://www.kahoku.co.jp/tohokunews/201601/20160119_61009.html

Tensile Truss (PaR Systems, Inc.)
Suspension-type parallel manipulator

Investigation of Operation Floor of R/B of Unit 1 By Using Active Scope Camera
(Mar.-May, 2016) (TEPCO)

Results of Preliminary Investigation of Rubbles


Inspection inside PCV in Unit 2
(operated by IRID/Toshiba and TEPCO)
Jan. 26, 2017
（IRID, TEPCO）
制御棒駆動機構(CRD)交換用レール
ペデスタル開口部
ペデスタル
制御棒駆動機構(CRD)
原子炉格納容器(PCV)
本日の調査範囲
プラットホーム
格納容器貫通孔
(X-6ペネトレーション)
地下階
ステップ1. 装置の搬入
ステップ2. 装置の設置
ステップ3. 穴あけ
穴あけ装置
遮へい体
隔離機構
X-6ペネ
隔離機構ユニット※
ホールソー
クランプ
ステップ4.
ステップ5.
ステップ6.
ステップ7.
ペデスタル
X-6ペネ
CRDレール
パンチルトカメラ
堆積物除去装置
自走式調査装置
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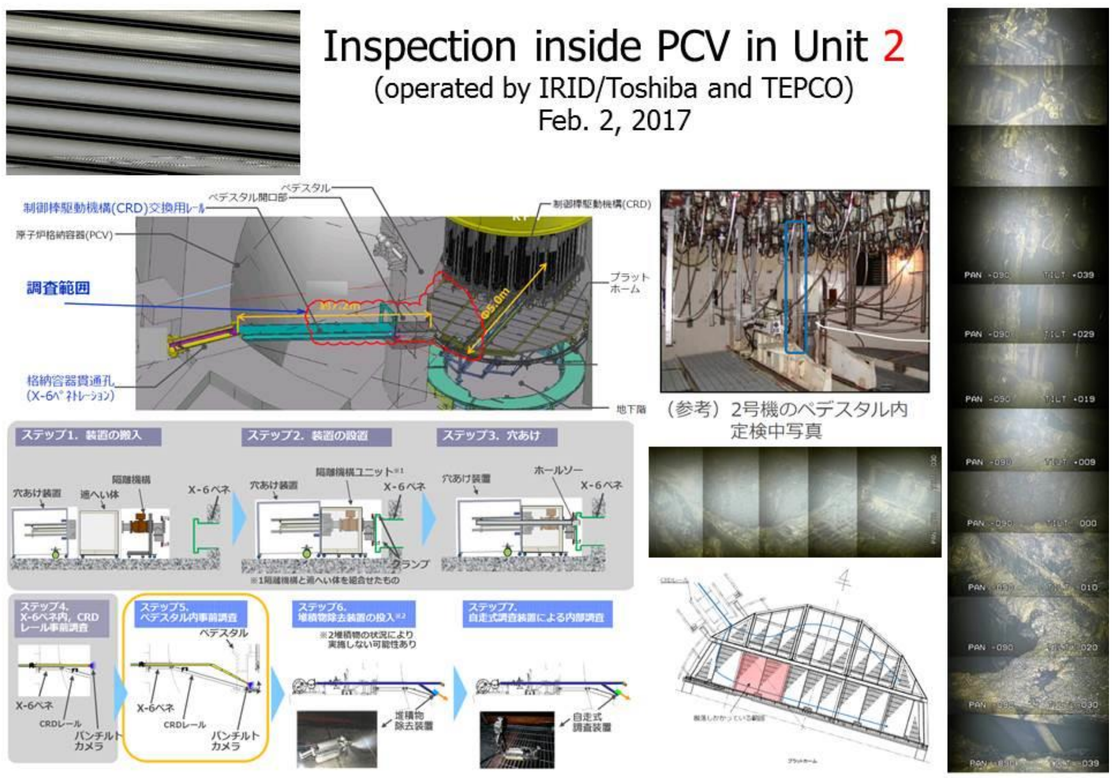
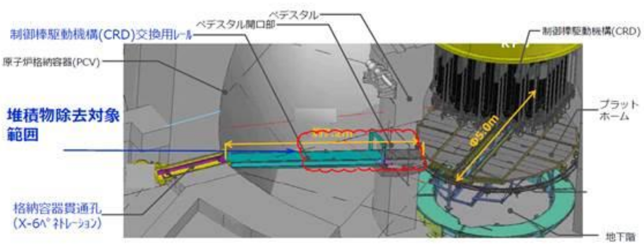
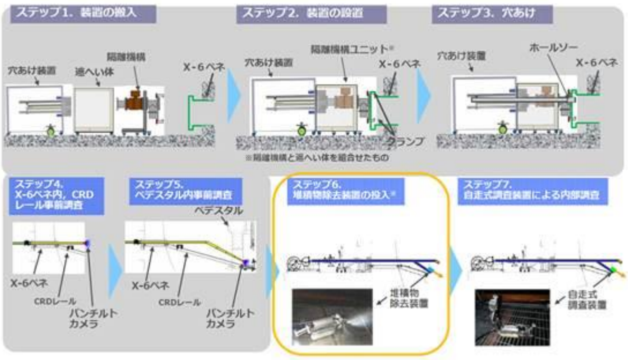
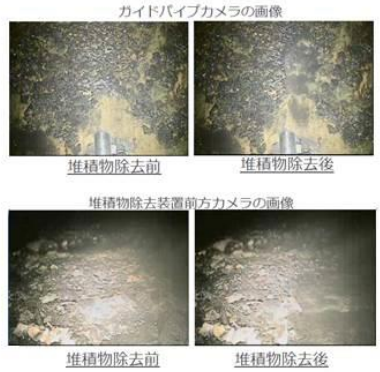

Inspection inside PCV in Unit 2
(operated by IRID/Toshiba and TEPCO)
Feb. 2, 2017
制御棒駆動機構(CRD)交換用レール
ペデスタル開口部
ペデスタル
制御棒駆動機構(CRD)
原子炉格納容器(PCV)
調査範囲
プラットホーム
格納容器貫通孔
(X-6ペネトレーション)
地下階
（参考）2号機のペデスタル内
定検中写真
ステップ1. 装置の搬入
ステップ2. 装置の設置
ステップ3. 穴あけ
穴あけ装置
遮へい体
隔離機構
X-6ペネ
隔離機構ユニット※1
ホールソー
クランプ
ステップ4. X-6ペネ内, CRDレール事前調査
ステップ5. ペデスタル内事前調査
ステップ6.
ステップ7.
ペデスタル
X-6ペネ
CRDレール
パンチルトカメラ
堆積物除去装置
自走式調査装置

Inspection inside PCV in Unit 2
(operated by IRID/Toshiba and TEPCO)
Feb. 9, 2017

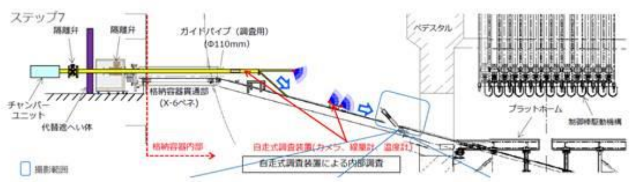


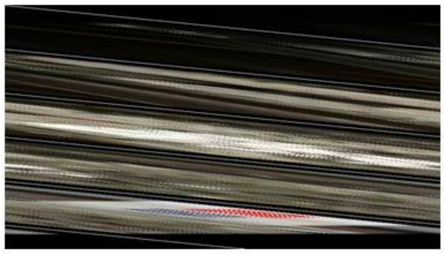


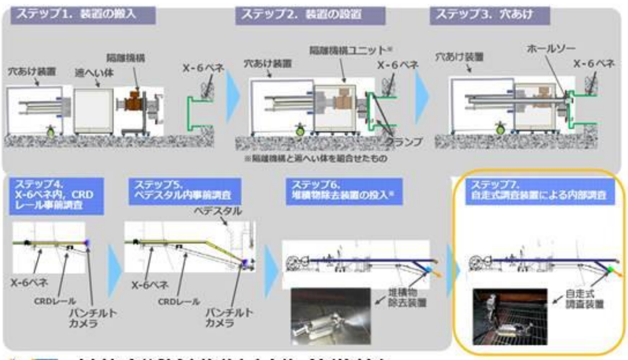


Inspection inside PCV in Unit 2
(operated by IRID/Toshiba and TEPCO)
Feb. 16, 2017

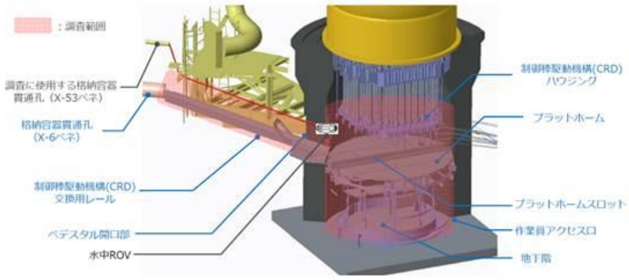
(IRID, TEPCO)







Inspection inside PCV in Unit 3
(operated by IRID/Toshiba and TEPCO)
July 19-22, 2017



Mini Mola Mola

Mola Mola (Sunfish)

- Structures
- Melt
- Deposits

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The University of Tokyo

Remotely controlled machines utilized for the response of accident of nuclear power plant (Foreign Machines)

Putzmeister Concrete Pump Truck

iRobot Packbot

Brokk-90

Brokk-330

QinetiQ Talon

Pentek Moose

Honeywell T-HAWK

iRobot Warrior

QinetiQ Bob Cat

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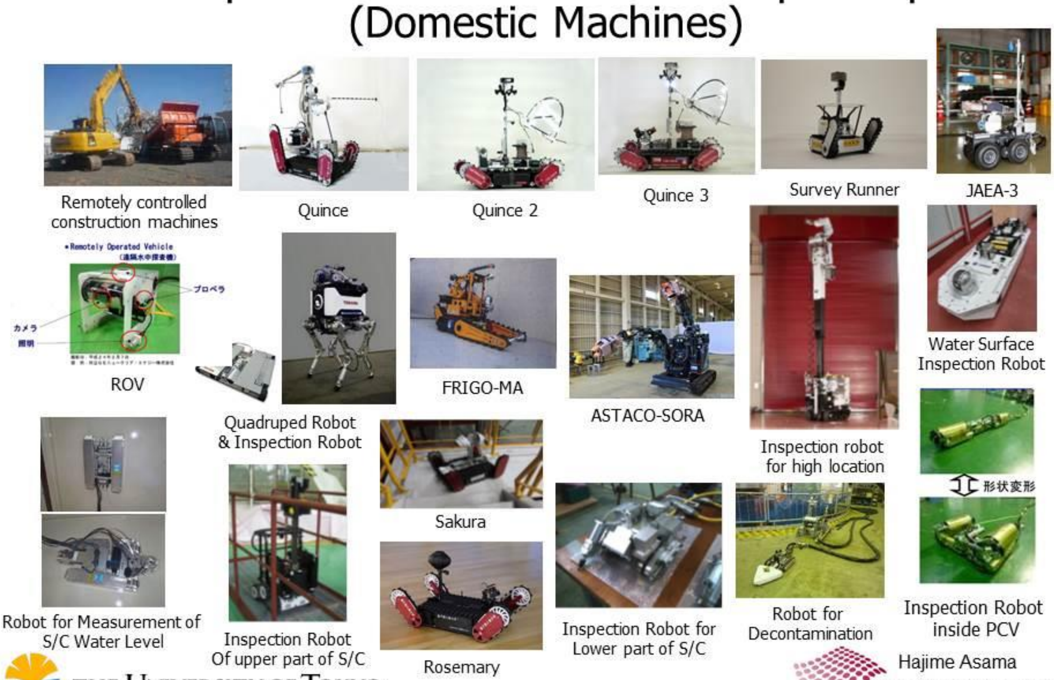
Remotely controlled machines utilized for the response of accident of nuclear power plant (Domestic Machines)



Needs for Robots

- For Other Disaster Response
  - Victim search and rescue
  - Inspection, diagnosis and recovery of plants and facilities
  - Surveillance of coast underwater
  - Mapping of the damaged area
  - Power assist for heavy load tasks
  - Mental care of evacuees

Achievements of Disaster Response Robots

Investigation of Building
(Kohga3: Matsuno, Kyoto U.)

Investigation under Water
(Anchor Diver III: Hirose, TITech.)

Investigating under Water
(Remote-Controlled ROV: Ura, U. Tokyo)

Mapping of the Destroyed Area
(Omni-directional Camera on a Vehicle
Ikeuchi, U. Tokyo, Deguchi, Tohoku U.)

UAV
(Nonami, Chiba Univ.)

Assist of Heavy Load Task
(Smart Suit Light:
Tanaka, Hokkaido U.)

Active Scope Camera
(Tadokoro, Tohoku U.)

Mental Care in Refuge
(Paro: Shibata, AIST)

Phases in equipment utilization

Complex, diverse, and dynamic requirements in tasks and environment

Phase 1: Utilize off-the-shelf robots and equipment
(for general purpose)
Phase 2: Modify developed system and technology
Phase 3: New development
(for specific use)

What have achieved so far

- Exploration, investigation & measurement
  - States, Spatial Radiation Dose (Level & Distribution), 3D data, etc.
- Rubble removal
  - On Site Field (Outdoor), Inside R/B, Inside Spent Fuel Pool, on Operation Floor
- Decontamination
  - Limited
- Sampling
  - Dust, Water, Core Samples, etc.
  - Limited

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For future

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Lessons Learned

- Causes of failures
  - Loss of communication
  - Poor situation awareness
  - Malfunctions by radiation
- Common fundamental technology
  - From specific system development to standardized components
- Improvement of Efficiency
  - Fast, Reliable, Dependable

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Unrecoverable Robots

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Factors for Failures in Operation

- Prototypes (not products)
  - Risk assessment for failures
  - Testing
- Misoperation
  - Training
  - Improvements of Human Interface
- Unknown environment
  - Advance investigation
  - Assumption of various situation

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Needs for Robots

- For Other Disaster Response
  - Victim search and rescue
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  - Surveillance of coast underwater
  - Mapping of the damaged area
  - Power assist for heavy load tasks
  - Mental care of evacuees

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Achievements of Disaster Response Robots

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Mental Care in Refuge
(Paro: Shibata, AIST)

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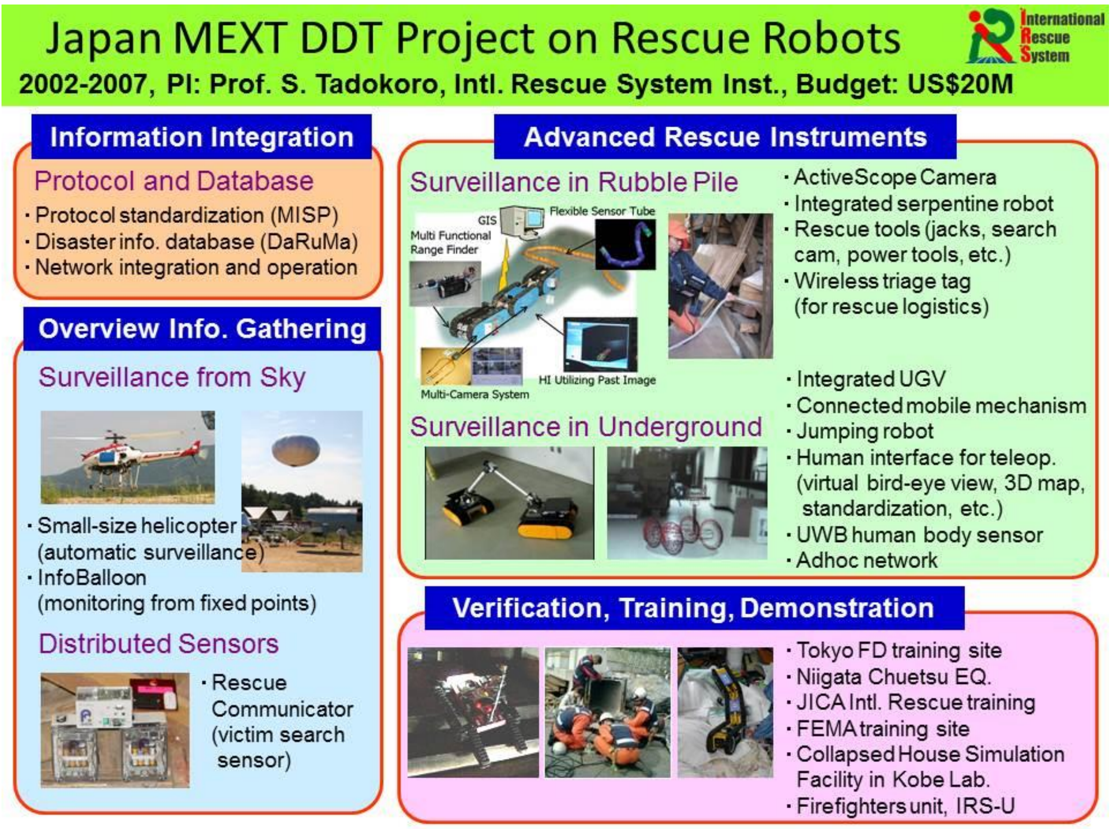
Diversity of Disasters

1923.9.1
関東大震災
Great Kanto Earthquake
火災による焼死
Burned to death by fire

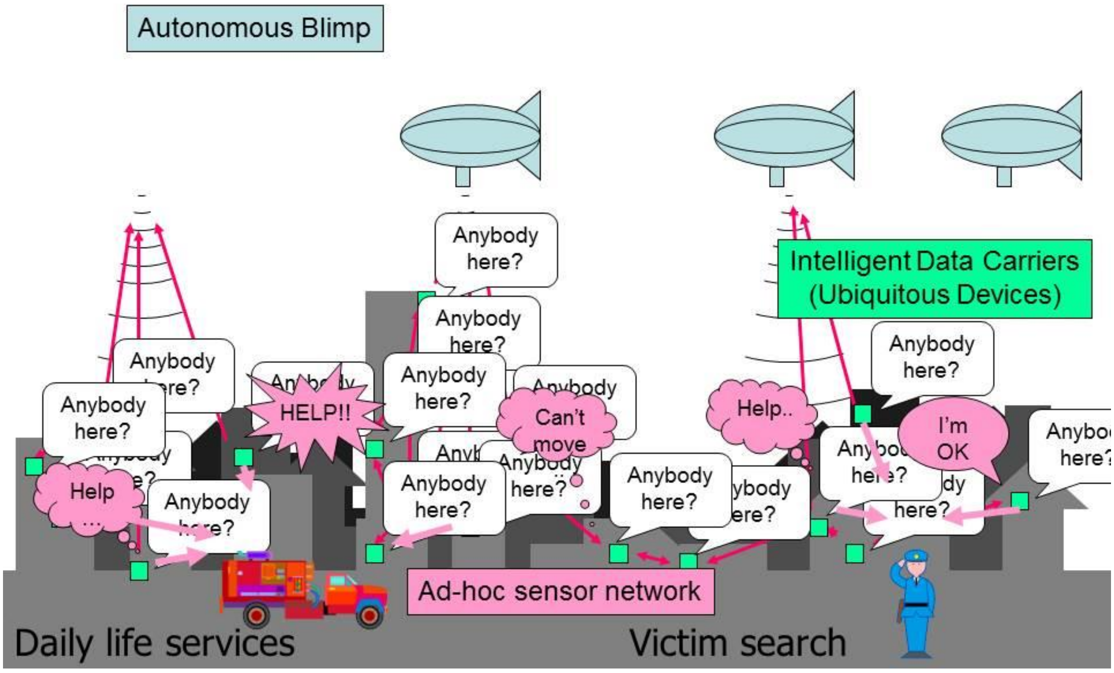
19951.17.3.11
阪神淡路大震災
Great Hanshin-Awaji Earthquake
建物の崩壊による圧死
Crushed to death by the collapse of the building

2011.3.11
東日本大震災
Great Eastern Japan Earthquake
津波による溺死
Drowned to death by tsunami


Japan MEXT DDT Project on Rescue Robots
2002-2007, PI: Prof. S. Tadokoro, Intl. Rescue System Inst., Budget: US$20M
International Rescue System
Information Integration
Protocol and Database
· Protocol standardization (MISP)
· Disaster info. database (DaRuMa)
· Network integration and operation
Overview Info. Gathering
Surveillance from Sky
· Small-size helicopter (automatic surveillance)
· InfoBalloon (monitoring from fixed points)
Distributed Sensors
· Rescue Communicator (victim search sensor)
Advanced Rescue Instruments
Surveillance in Rubble Pile
GIS
Flexible Sensor Tube
Multi Functional Range Finder
HI Utilizing Past Image
Multi-Camera System
· ActiveScope Camera
· Integrated serpentine robot
· Rescue tools (jacks, search cam, power tools, etc.)
· Wireless triage tag (for rescue logistics)
Surveillance in Underground
· Integrated UGV
· Connected mobile mechanism
· Jumping robot
· Human interface for teleop. (virtual bird-eye view, 3D map, standardization, etc.)
· UWB human body sensor
· Adhoc network
Verification, Training, Demonstration
· Tokyo FD training site
· Niigata Chuetsu EQ.
· JICA Intl. Rescue training
· FEMA training site
· Collapsed House Simulation Facility in Kobe Lab.
· Firefighters unit, IRS-U

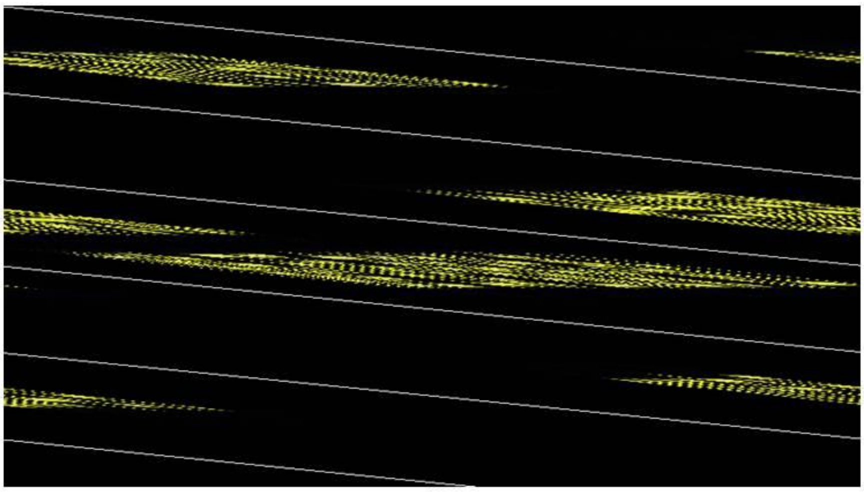

Prototype robots developed by 33 teams
防災用インテリジェント
エアロロボット
(京都大学 中西弘明)
小型自律飛行船
(理化学研究所 川端邦明/
東京大学 淺間一)
探査ロボット「アスタリスク」
(大阪大学 新井研究室)
瓦礫内探索ロボットシステム
"Hyper蒼龍IV"(東工大/
神戸大/東北大/茨城大)
瓦礫上探査用クローラ型
レスキューロボット "KOHGA2"
(電気通信大学 松野文俊)
地下街探査用レスキュー
ロボット "Hibiscus"
(千葉工業大学 小柳栄次)
多連結クローラ型ロボット
"KOHGA"
(電気通信大学 松野文俊)
跳躍・回転移動体
(東京工業大 北川能・
塚越秀行)
アーム搭載移動ロボット
"HELIOS VIII"
(東京工業大学 広瀬茂男)
瓦礫上情報収集用牽引
ロボット "HELIOSキャリア"
(東工大/東北大/電通大)
車輪型情報収集
レスキューロボット"FUMA"
(電気通信大学 松野文俊)
レスキュー用ロボティックダミー
(大阪電気通信大学 升谷保博)
International Rescue System Institute
（一部国際レスキューシステム研究機構HPより）

Global Victims Search using Intelligent Data



Autonomous Blimp Operation & Search

(Autonomous blimp and a rescue communicator)



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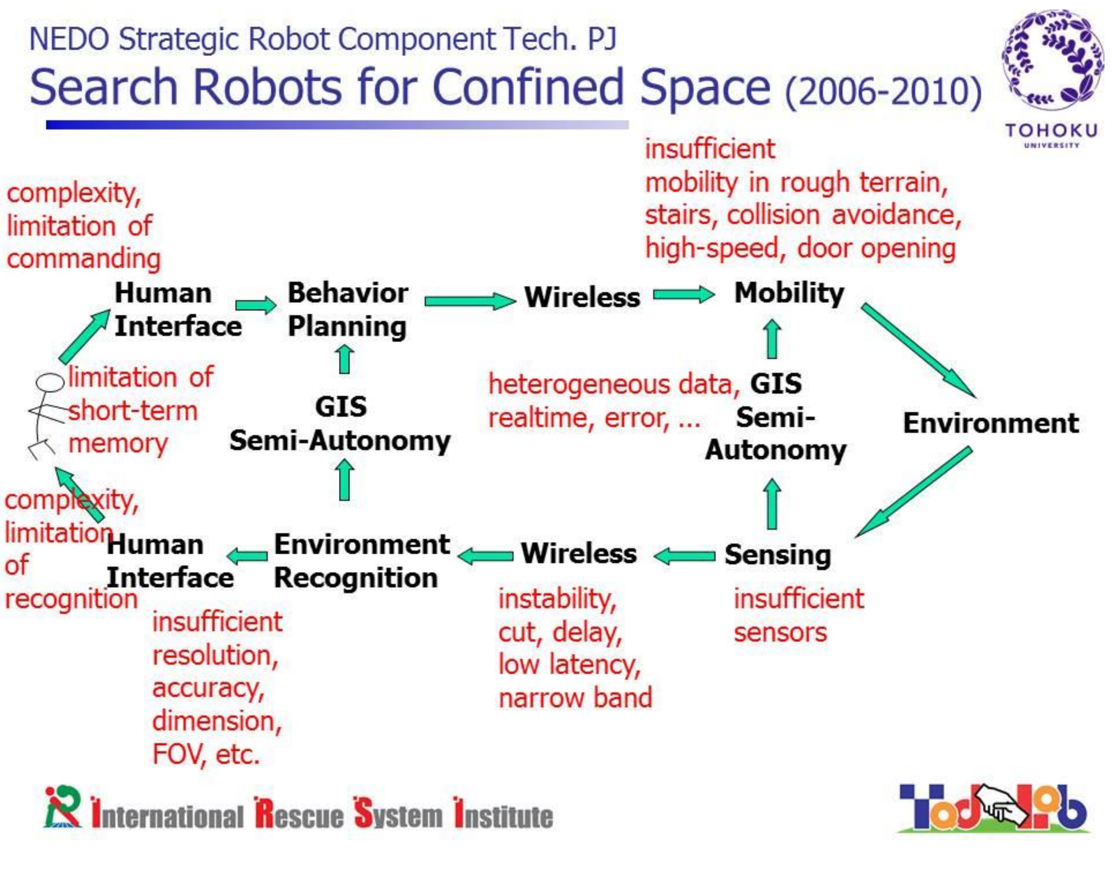
NEDO Strategic Robot Elements
Search Robots for Confined Space

PI Satoshi Tadokoro

IRS, Tohoku U, NICT, AIST, NEDO



NEDO Strategic Robot Component Tech. PJ

Search Robots for Confined Space (2006-2010)

TOHOKU

"Quince" at Disaster City (3/9/2011)

International Rescue System Institute

The World's Window on Japan
The Japan Times ONLINE

Friday, Jan. 6, 2012

NUCLEAR AWAKENING

Domestic robots failed to ride to rescue after No. 1 plant blew

By HIROKO NAKATA
Staff writer
Last of five parts

After the March 11 tsunami slammed into the Fukushima No. 1 nuclear plant and wrecked three reactors, many people expected the nation's cutting-edge robotic technologies to come to the rescue.

That, however, turned out to be wishful thinking, and the public was left wondering why Japanese robots, such as Honda Motor Co.'s Asimo humanoid, weren't sent to the power plant to assist firefighters and workers trying to bring the crippled reactors under control.

In the early stages of the nuclear crisis, many people actually sent messages to the Asimo Twitter account run by Honda Motor Co., asking why the robot wasn't participating in recovery efforts led by the government and plant operator Tokyo Electric Power Co.

The reply they received, however, said only that

Slinky move: Quince moves down stairs at Chiba Institute of Technology

- Responsibility of robot scientists
- Why Honda Asimo cannot be used?
- Disappointment to know RT is not useful in real situation when it is demanded

Hajime Asama
Dept. of Precision Engineering
The University of Tokyo

Expectation to Robot Technology

Gap

Reality

- There are few robots and remotely controlled machines which have sufficient function to be used in the real disaster sites.
- Most of the robots developed in Japan were just prototypes developed by researchers, and there are few products.

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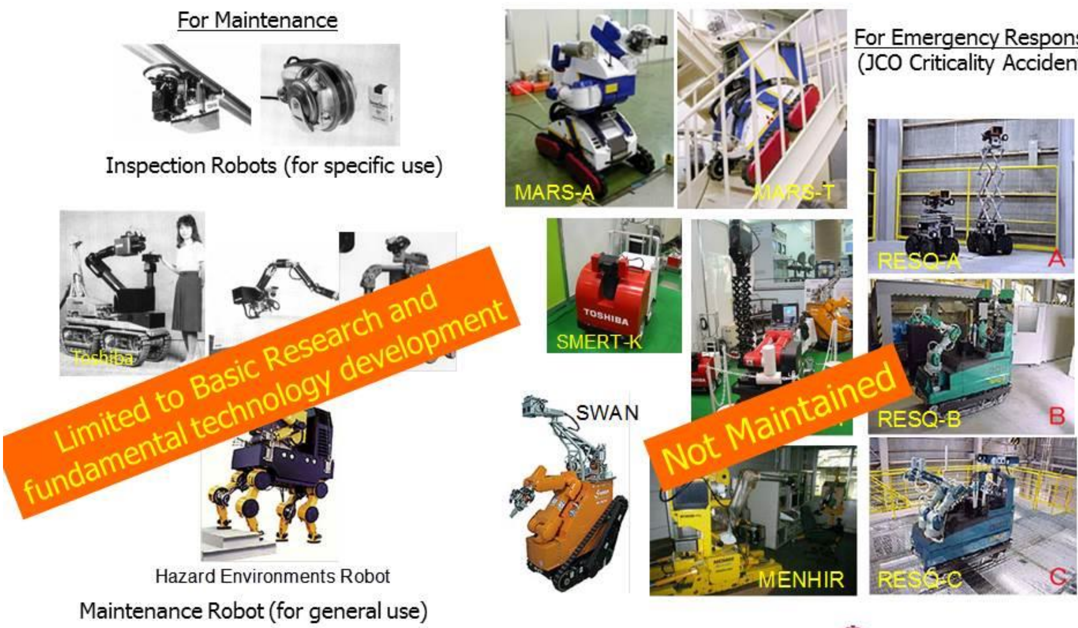
Robots developed in projects for nuclear facilities



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Needs of Robots and Remotely Controlled Machines

Response for The Great Eastern Japan Earthquake, Tsunami and Accident of Fukushima Daiichi N.P.S.

- Victim search and rescue
- Response and decommission of N.P.P
- Recovery and restoration including decontamination
- Preparation for possible nuclear accidents

Preparation for natural disasters and accidents of social infrastructures and facilities

- Threats of natural disasters (Earthquake, typhoon, volcano explosion, etc.)
- Threats of disasters of artificial systems
  - Obsolescence of social infra. (tunnels, highways, bridges, etc.) and facilities (plants, complex, etc.)

Quince

Survey Runner

Remotely controlled construction machines

ASTACO-SoRa

Increase of Threats of Disasters and Accidents

- Difficulty and danger in tasks and environment for human
- Productivity improvement of monitoring, inspection and maintenance

Utilization of robots and remotely controlled machines

Kohga3

Hexa-rotor MAV

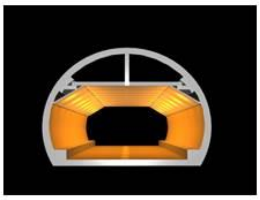
Anchor Diver III

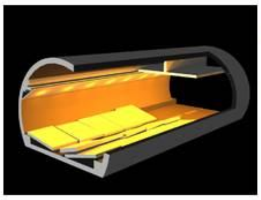
Inspection Robot

Accident in a highway tunnel (Sasago Tunnel)

Dec. 2, 2012

Concrete roof panels over 130m length fell down suddenly.
Several motorcars were crashed and 9 persons were lost.
The first human-loss accident related to maintenance in Japan.





Deterioration of Social Infrastructure

- Bridges
  - 700,000 bridges in Japan (more than 2[m])
  - 43% will be more than 50 years in 10 years
  - 67% will be more than 50 years in 20 years
- Tunnels
  - 10,000 tunnels in Japan
  - 34% will be more than 50 years in 10 years
  - 50% will be more than 50 years in 20 years

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COCN

Council on Competitiveness-Nippon

Objectives

To discuss and put together the diverse knowledge of Japanese industry, then propose scientific and technological policies leading to solution-driven innovation and related industrial policies, while clarifying the role of governmental and private sectors.

To make proposals from industrial sectors to the government and then promote measures to be implemented.

2011-2017 Project on disaster-response robot technologies

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The University of Tokyo

Why is social dissemination of DRR difficult?

Packbot
iRobot
(Product)

- ◆ Small demands
  - Mainly public demand (FF, Defense, Police, MLIT)
  - Low frequency of disasters
- ◆ Biased investment of government
  - R&D
  - Practicalization and Commercialization

Difficult only by effort of industry

Quince
Chiba Inst. Tech., Tohoku Univ.
(Prototype)

Military applications in US

- ◆ R&D investment and procurement
- ◆ Test field and standardization
  - Disaster City (Texas A&M Univ.)
  - Standardization of Functional Evaluation of DRR

Unmanned construction system

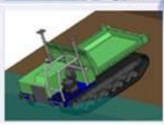
- ◆ Usage of DRR for dangerous tasks in normal situation
- ◆ Utilization and testing of new tech.

Explosion of Unzen-Fugen Mt. (1991)

Hajime Asama
Dept. of Precision Engineering
The University of Tokyo

Robot Technology Required in Disaster Prevention and Response

Aerial vehicles	【使用目的】 （1） 発災直後の広域被災状況の調査 （2） 孤立地域等の細部被害状況の調査 （3） 津波からの避難支援(局地の情報収集・伝達) 【期待する能力】 （1） 夜間、悪天候における情報収集 （2） 映像、位置、生体反応等の情報をリアルタイムに災害対策本部等へ伝送 （3） 津波からの避難に必要な情報・警報を住民に直接連絡
Ground vehicles	【使用目的】 余震・火災・水没等危険な時期・場所での調査・瓦礫除去・救助活動支援 【期待する能力】 （1） 生体反応の感知等捜索能力 （2） 瓦礫、浸水、高温・火災等環境下での機動力 （3） 瓦礫等重量物の除去能力
Underwater vehicles 水中探査ロボット	【使用目的】 津波発生後の海洋における調査・瓦礫除去・救助活動支援 【期待する能力】 （1） 瓦礫、汚濁等劣悪環境下の海洋での探索能力 （2） 同上環境下における機動力、瓦礫除去能力 （3） 被災者等の救助能力
津波避難支援ロボット	【使用目的】 津波からの災害弱者などの避難・誘導活動の支援 【期待する能力】 （1） 津波被害の予測・回避能力 （2） 避難住民を安全、迅速、努めて大量に輸送 （3） 居住地域、避難地域、避難経路の認識



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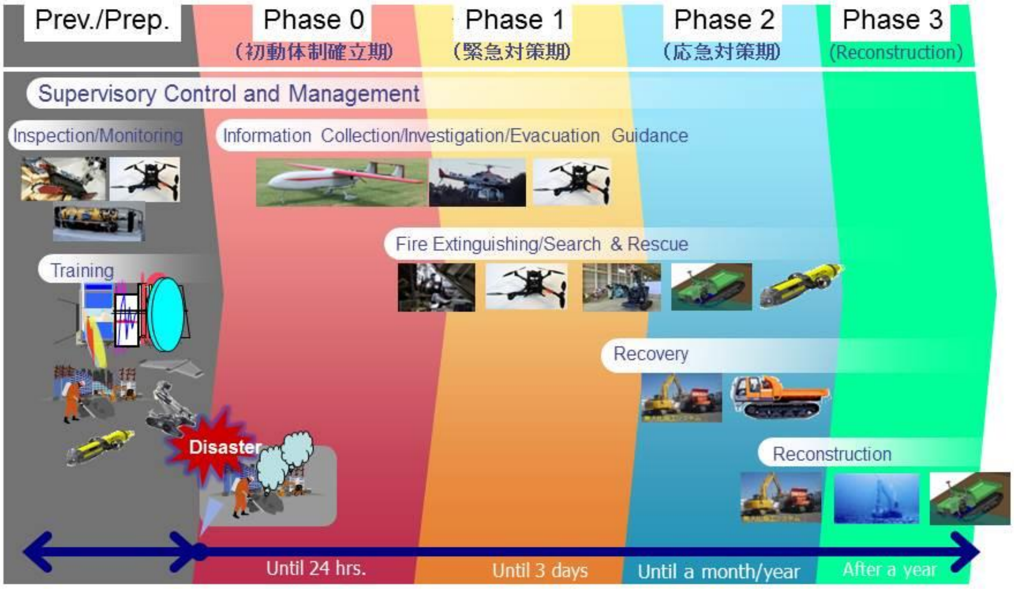
Operation Phases in Disaster Response



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Projects and programs for RT system R&D
- Fundamental technology development (10 years)
- Practical technology development (5 years)
- Competition-type development of system technology and solution design

Introduction ↓ Evaluation ↑

RT testing facility for disaster prevention and response
- Operation test and operator training
  - Testing fields, mockups
    - Disaster City, Japan
    - Construction fields
    - Mockups (Fukushima model, etc.)
- Functional evaluation & certification
  - Explosion proof, radiation proof, safety proof, etc.
  - Organization of evaluation center
- Management of technological information of RT
  - Information provision services on demand
- Emergency response with device deployment and operation

Strategy planning
RT business promotion
Loop formation between R&D and utilization
International cooperation

Standardization
Evaluation of function
Interfaces

Regulation design
Regulation relaxation
Authorization of exceptional zones
Regulation strengthening
Mandatory preparation
Taxation system design
Taxation exemption, etc.
Infrastructural improvement
Preservation of radio frequency for robots, etc.

Utilization ↓ Needs ↑ Deployment ↓

Utilization in ordinary situation
- Inspection/Maintenance
- Operation in dangerous situation

Utilization in emergency situation
- Disaster response
- Accident response

Practical Disaster Response Robot R&D for Social Resilience

Needs-oriented R&D projects for fundamental & practical tech.

- Technology for mobility and access in extreme environment
- Technology for stable communication
- Technology for situation awareness in remote control
- Technology for autonomy to facilitate remote operation
- Sensing Technology for inspection, diagnosis and maintenance

Projects for system integration

- Challenge or competition for solution derivation

Laboratories

Disaster response robots R&D center

Utilization in ordinary situation (Test fields, mockups)

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Unmanned Disaster Response System Research and Development Project

Period: FY2011-FY2012
Budget: \996 million

<Objective>

Research and development of unmanned disaster response system to swiftly grasp the situation, transport equipment and carry out relief activities, when houses, industrial and public facilities, etc. are damaged by disaster or a major accident and it is difficult to send workers inside.

<Development content and structure>

Develop unmanned system for operations at industrial facilities with limited space under harsh conditions where it is difficult to send workers inside.

Sakura

Tsubaki

Super Giraffe

Super lifter

Hybrid inspection robot

Radio Repeater

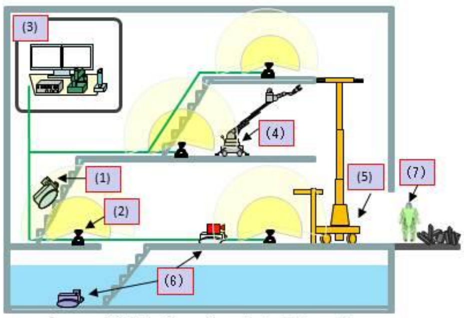
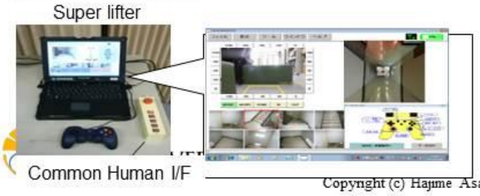


Image of utilization of project deliverables



Common Human I/F

HAL for decommission

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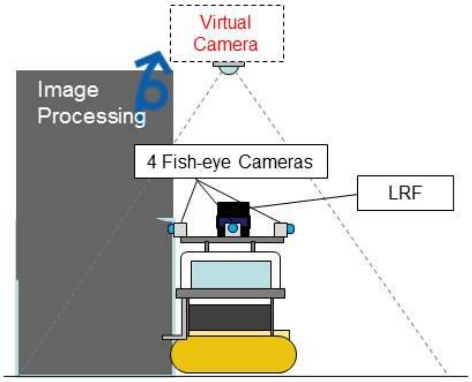
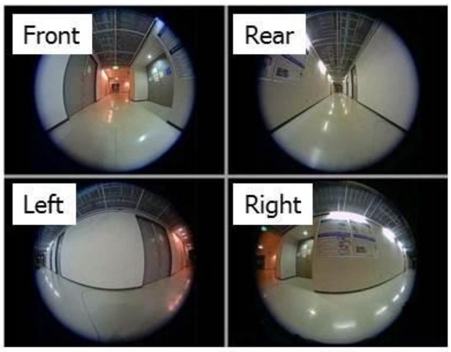
Concept of Bird-eye view Display

- Production of Virtual bird-eye camera image by integrating Multiple Fish-eye cameras
- Obstacle detection by LRF



Concept of Bird-eye View



Multiple Fish-eye Camera Images

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Outcome of the Project

Narrow Passage (Maze)

Bird-eye View Image

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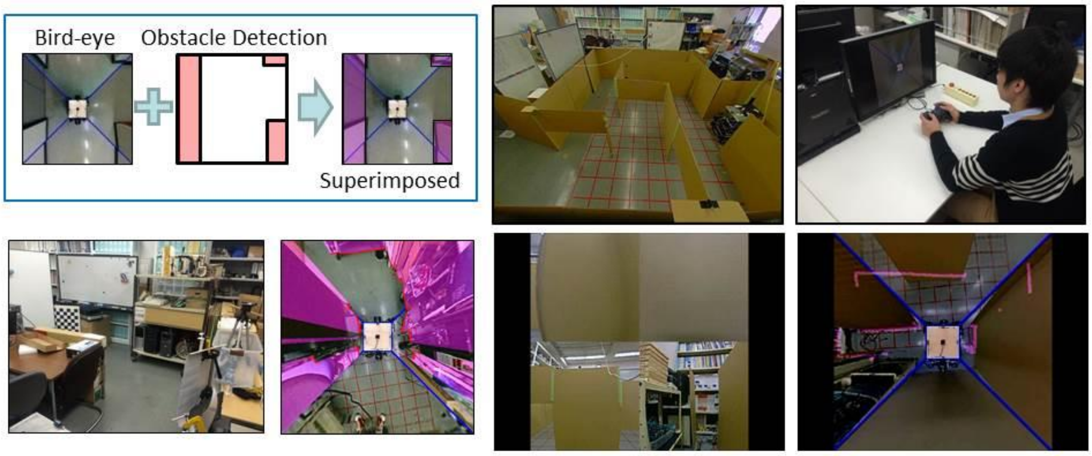
Superimposition of Obstacle Information

Bird-eye View Display (Camera+RFS Images)



Application to Robot for Decommissioning of NPS

MHI Super Giraffe

MHI MEISTeR

Application to Unmanned Construction System

Construction machine

Teleoperation by an Operator

Front View

Bird-eye View

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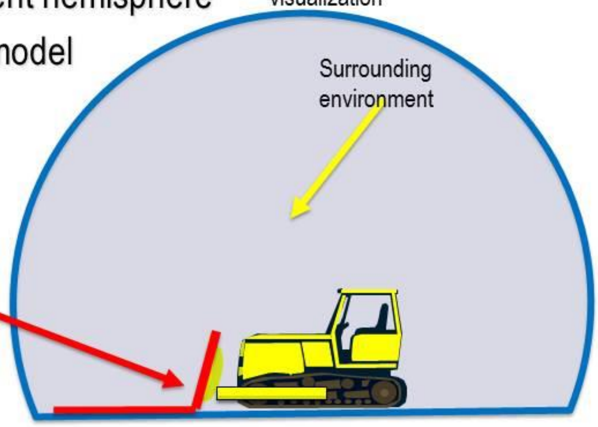
Concept of proposed method(1)

- For real time visualization, using pre-defined shape model
- Surrounding environment hemisphere
- Blade pre-defined 3D model



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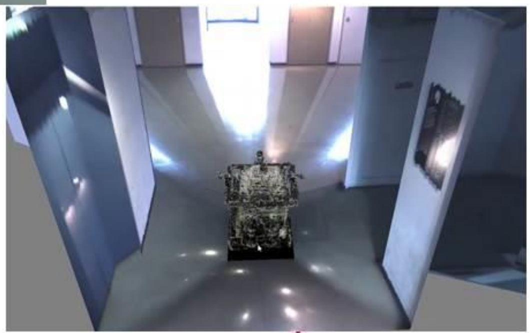
Generation of robot view from arbitrary viewpoints



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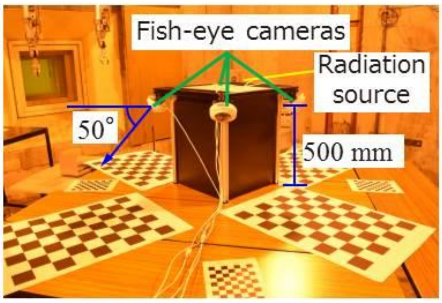
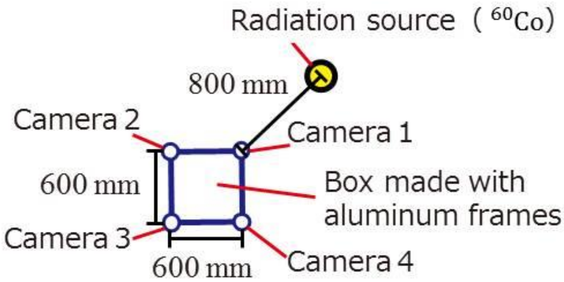
Gamma irradiation experiment

- The gamma irradiation was conducted in the Technology Development Center of ATOX Co., Ltd.

Camera model : AXIS M3007-PV



Experimental environment



Experimental layout seen from above

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2016/4/5

Gamma irradiation experiment : Movie

- After 23 min irradiation

Bird's-eye view

Bird's-eye view generation corresponding to camera malfunction

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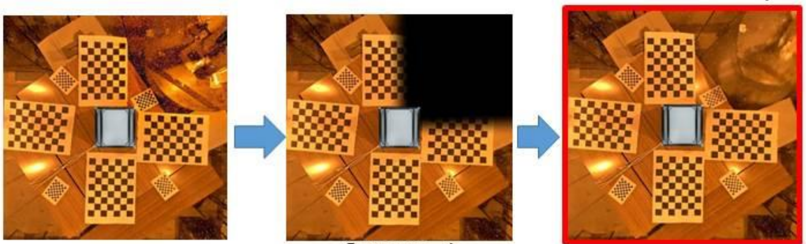
Gamma irradiation experiment : Result(1)

- Camera 1 malfunctioned after 23 min irradiation (Integral dose: 192.1 Gy)



4 cameras → Camera 1 malfunctioned → Proposed method

- Camera 2 malfunctioned after 54 min irradiation (Integral dose: 141.3 Gy)

3 cameras → Camera 2 malfunctioned → Proposed method

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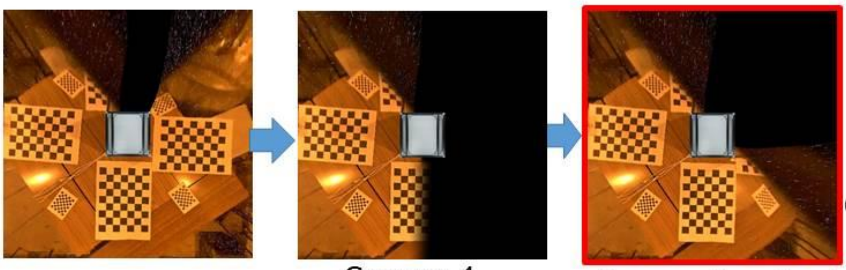
Gamma irradiation experiment : Result(2)

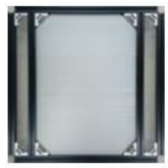
➢Camera 4 malfunctioned after 82 min irradiation (Integral dose: 224.1 Gy)



2 cameras | Camera 4 malfunctioned | Proposed method

Camera 3 Camera 4

➢Camera 3 malfunctioned after 94 min irradiation (Integral dose: 162.9 Gy)



Camera 3

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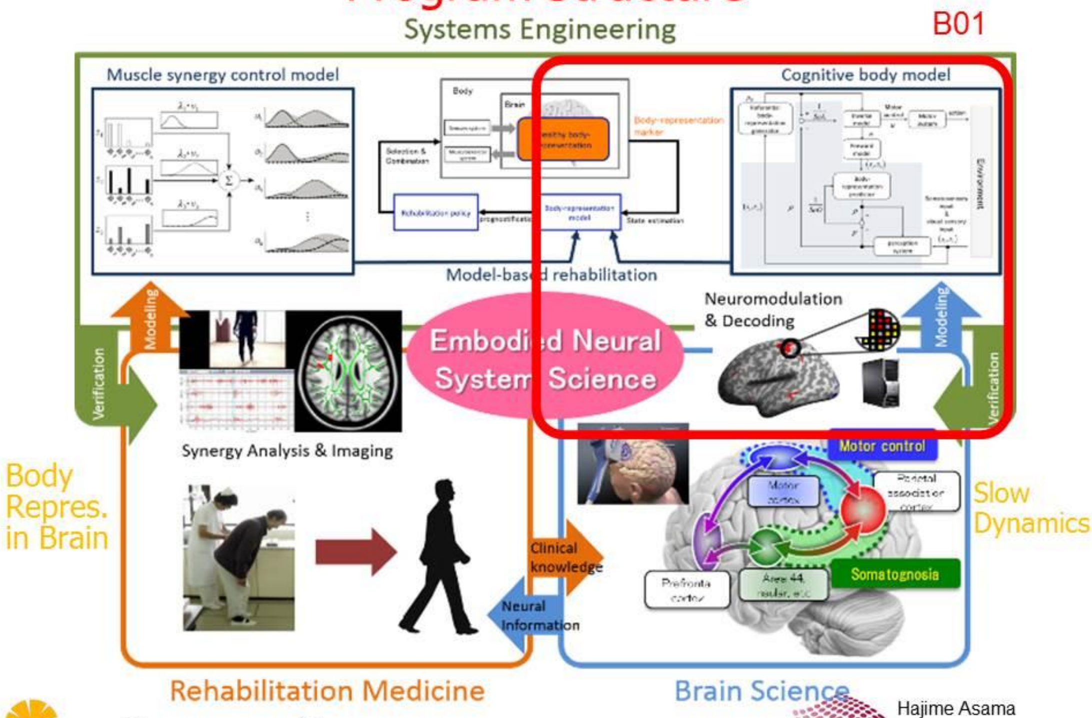
Program Structure



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B01 Project

Modeling of Mechanism Generating Body Representation based on Slow Dynamics Driven by Body Consciousness

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Department of Precision Engineering
the University of Tokyo

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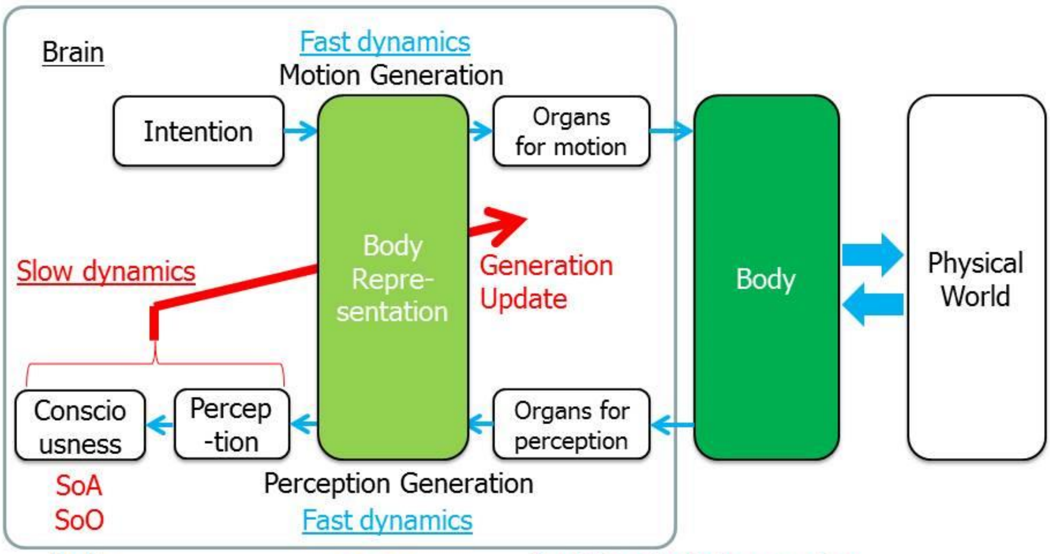
Modeling of Mechanism Generating SoA & SoO based on Perception Modified by Body Representation in Brain



Body Consciousness

Modified
Noise reduction
Interpolation
Integration

Conditions for SoA generation:
- Time delay
- Consistency of multimodal sensory feedback
- Intention

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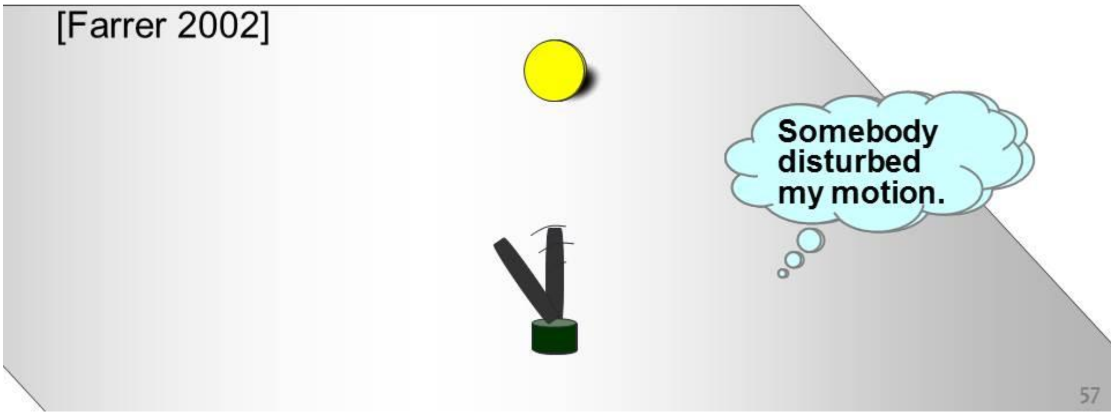
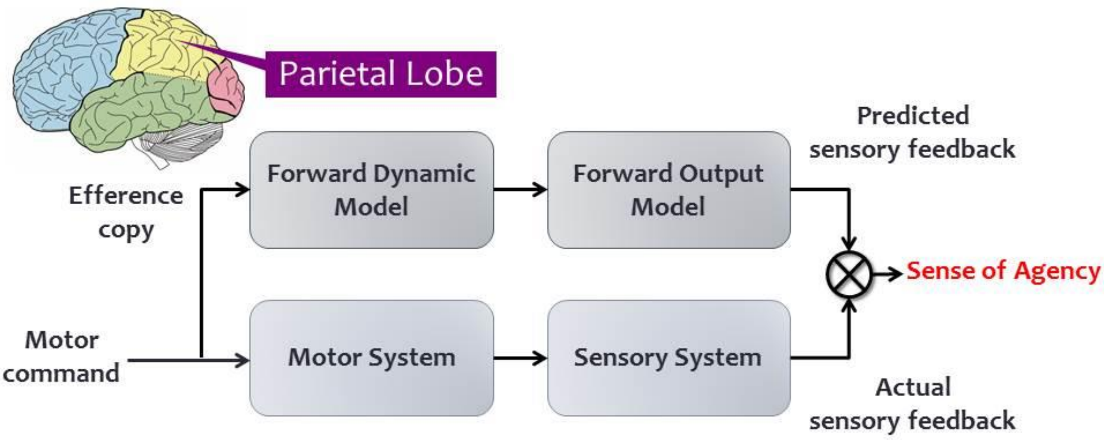
Sense of Agency (SoA)

- **The sense that the subject is the one who is causing or generating an action.**
  - Generated in the brain
  - Associated to the active motion of the subject



Comparator Model



(Blakemore, 2003)

Difference is small: Motion is attributed to "self"
Difference is large: Motion is attributed to "others"

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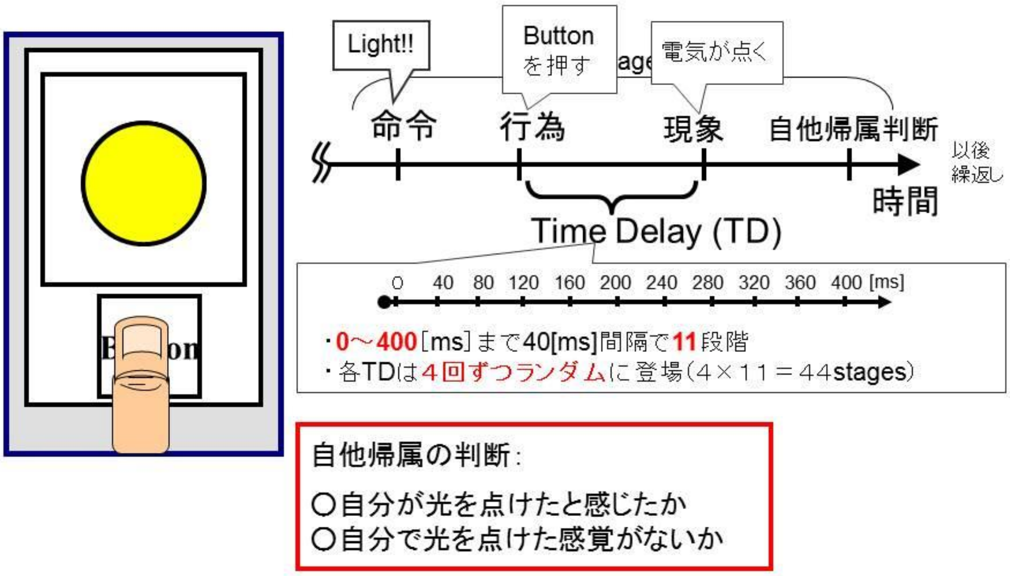
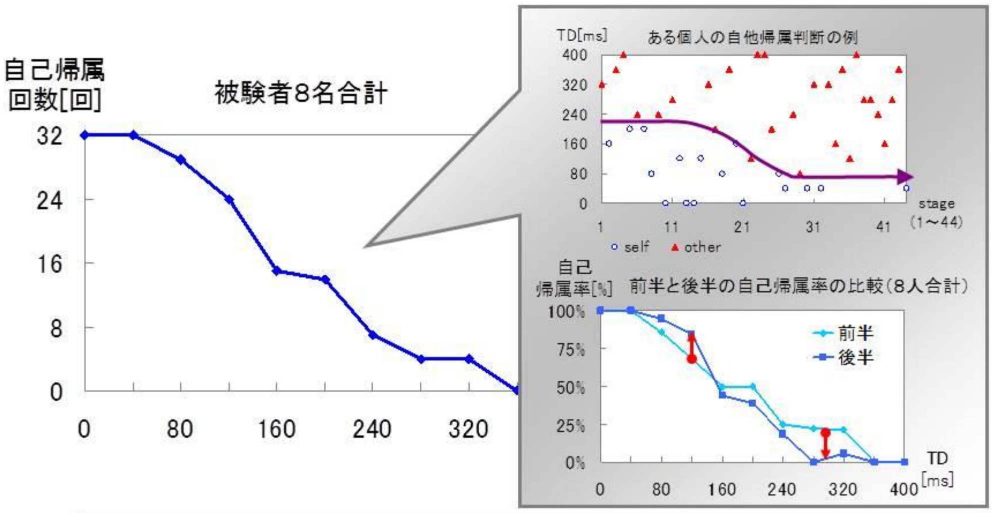
実験方法

時間遅れと自他帰属性の関係を調べる実験



実験結果



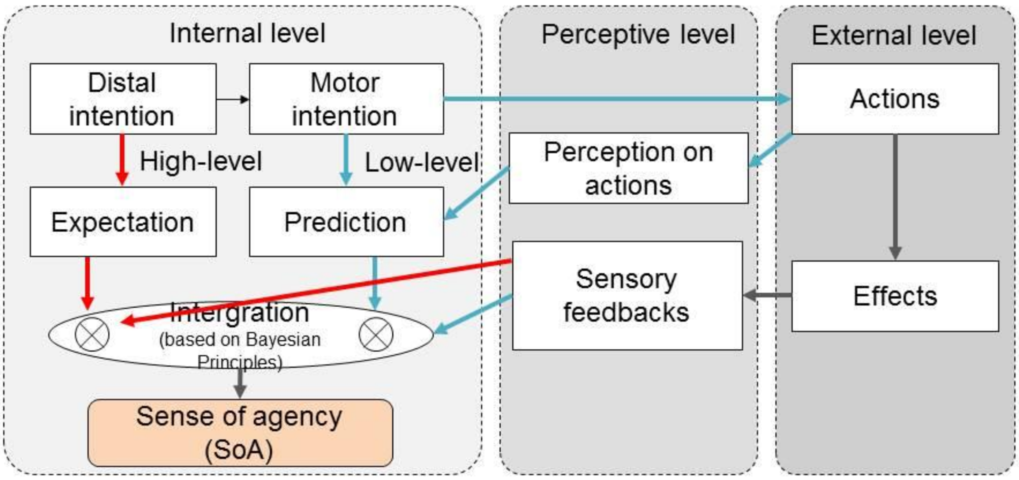
・TDが大きくなるほど自己帰属回数は下がる
・0から400[ms]の間でロジスティックな形(逆S字型)になる
・自他帰属判断基準はタスク進行に伴い変化し，**明確化**する

Rubber Hand Illusion (RHI)

- **Synchronized stimulation provides illusion to think a rubber hand as their own hand**
- **Clarification of Sense of Ownership**

The Influence of High-level Cognitive Process on SOA

- Modified Comparator Model

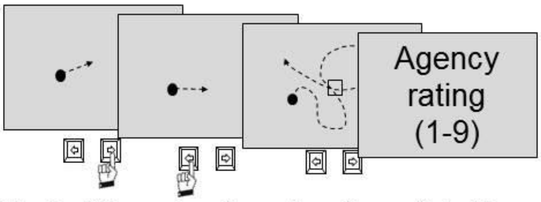


→ Sensory processes mentioned in the comparator model

→ High-level cognitive process (the present study)

Wen Wen, Atsushi Yamashita, Hajime Asama: "The Influence of Goals on Sense Control", Consciousness and Cognition, Vol.37, pp.83-90 (2015). 62

Study 1: Influence of Goals on SoA



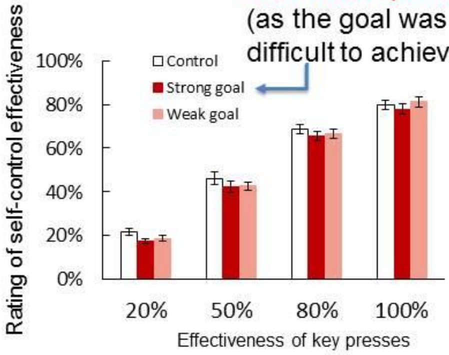
Task: Changing the direction of dot by pressing the left and right keys

Independent variables

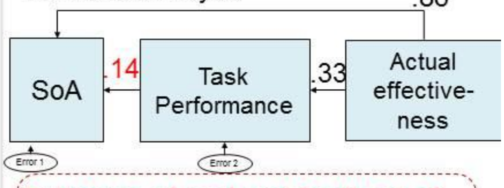
- Effectiveness of key presses (20%, 50%, 80%, or 100%)
- Existence of goal

Goals: directing the dot into the square (the strong goal), or keeping the dot in the central area of the screen (the weak goal).

SoA was impaired (as the goal was difficult to achieve)



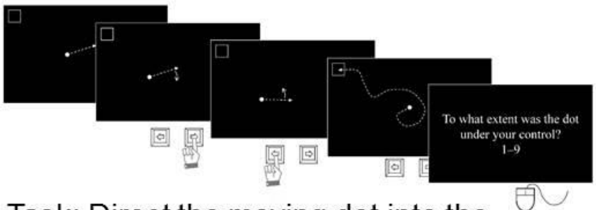
Multivariate Analysis



Existence of goal and feedback of goal-achievement significantly influenced SoA.

Wen Wen, Atsushi Yamashita, Hajime Asama: "The Influence of Goals on Sense Control", Consciousness and Cognition, Vol.37, pp.83-90 (2015).

Study 2: High-level vs. Low-level processes

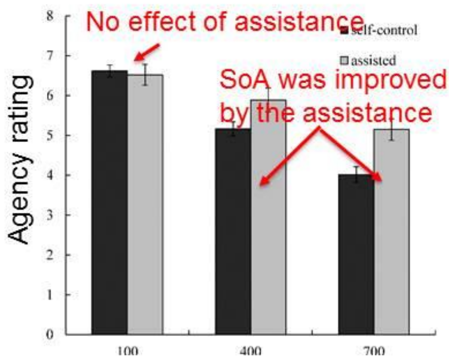


Task: Direct the moving dot into the square as quickly as possible.

Independent variables

- Delay in response (100, 400, or 700 ms)
- Assistance of computer (Improving task performance by ignoring erroneous commands)

Assistance: Promotes high-level process (performance-based inference) while impairing low-level process (action-effect comparison)



SoA are influenced by both the high- and low-level processes, and the high-level process would be more dominate when the low-level process is less reliable.

Wen Wen, Atsushi Yamashita and Hajime Asama: "The Sense of Agency during Continuous Action: Performance is More Important than Action-Feedback Association", PLoS ONE, vol. 10, no. 4, e0125226, pp. 1-16 (2015).

Cognition Performance

- **in Passive Condition**
  - Cognition from Perception
  - Prediction only based on Perception

- **In Active Condition**
  - Cognition from Perception
  - Prediction based on not only Perception but also SoA Automatically Driven by Active Interaction

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Hypothesis

- An operator's sense of agency has a positive effect on his/her cognitive performance.

Objective

- Clarification of the relationship between the sense of agency and task performance in human-System interaction with temporal delay between human input and its feedback.

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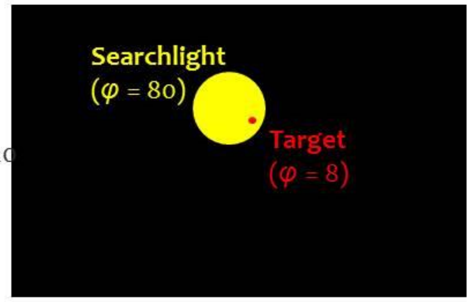
Experiment: Condition

- Participants
  - 21 healthy volunteers
    - 20-28 years, mean=22.5
    - 12 men, 9 women



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500 (mm)

- Experimental Set-up
  - Visual stimuli
    - Created using Visual C++ and OpenGL on a Windows PC.
    - Displayed on a 24-inch computer screen.
  - Input device
    - Joystick (Cyborg evo Force, Saitek)
      - Equipped with a trigger to input user commands.

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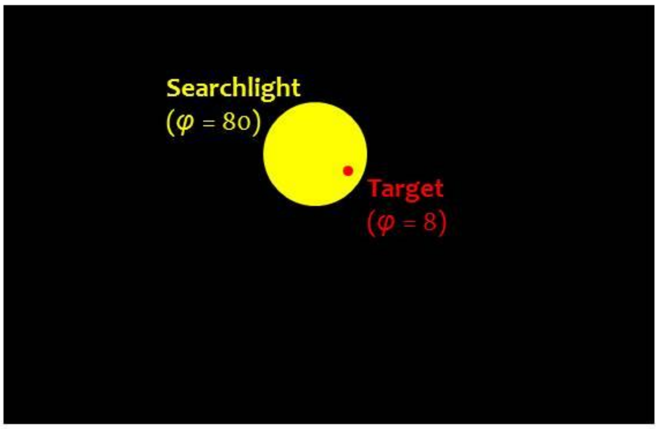
Experiment: Visual stimuli

Searchlight
- Yellow circle with radius 40 mm
- Speed: 60 mm/s

Target
- Red dot with radius 4 mm
- Randomly located and invisible without the searchlight



320

500 (mm)

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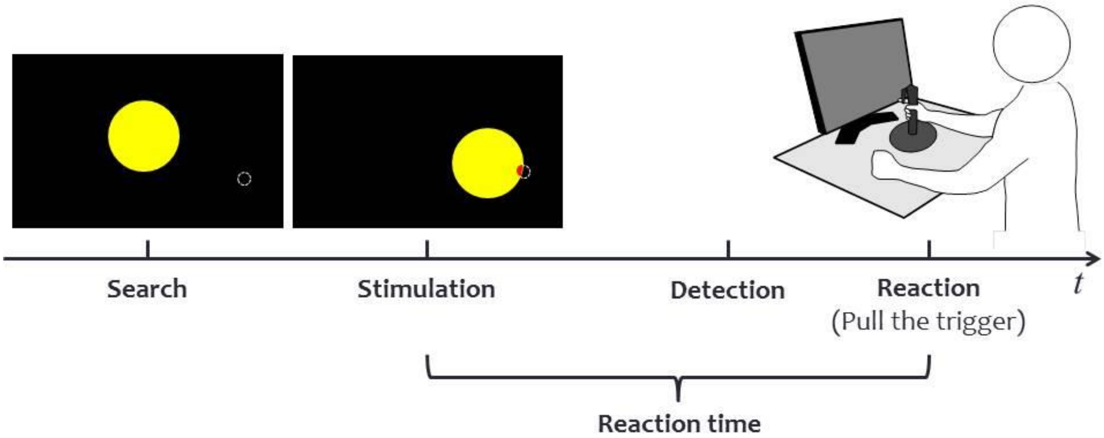
Experiment: Task

The participants were required to pull the trigger as soon as they detect the target.



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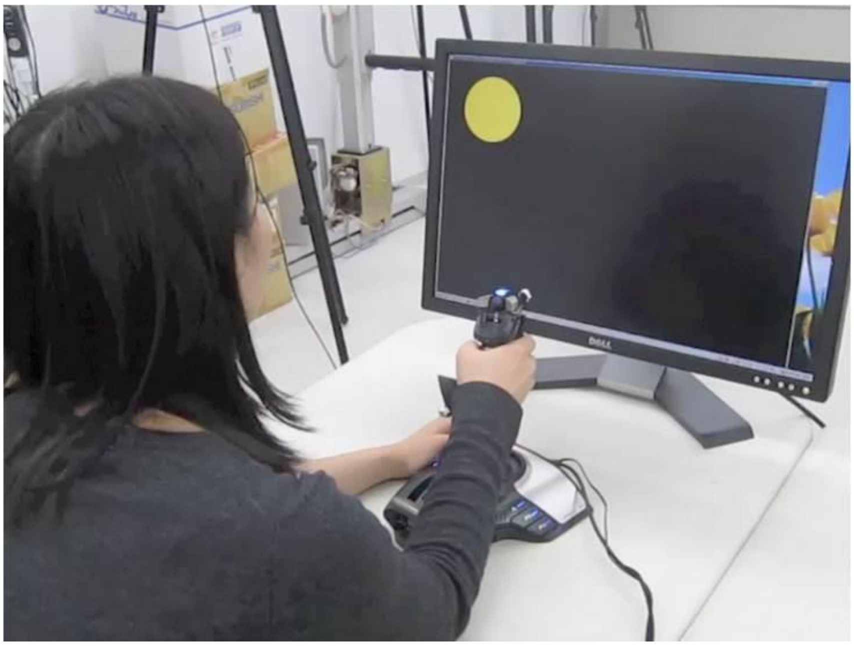
Experiment: Video



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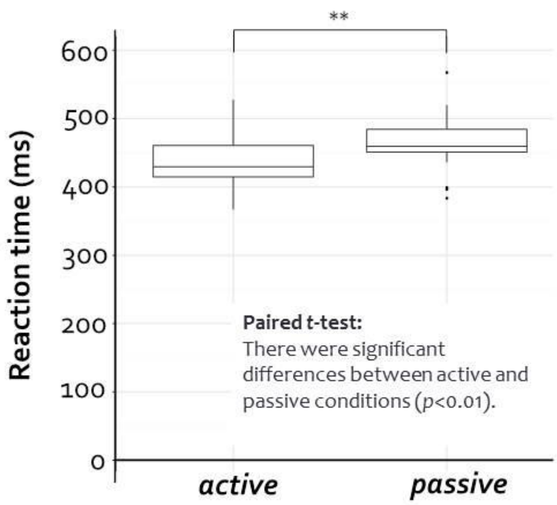
Activeness vs. Reaction time (without time delay)

***Active*:** Participants use the joystick to control the searchlight.
***Passive*:** The searchlight moves automatically.

Participants:
21 volunteers (12 men, 9 women)

The experiment consists of 4 blocks
(2 active + 2 passive conditions)
In each block, 20 trials were conducted.



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In order to prepare for emergency,

Use robots in ordinary times

1. In testing
2. In training
3. In usage in
   - recovery sites
   - Inspection and maintenance of social infrastructures or facilities
   - tasks in dangerous fields

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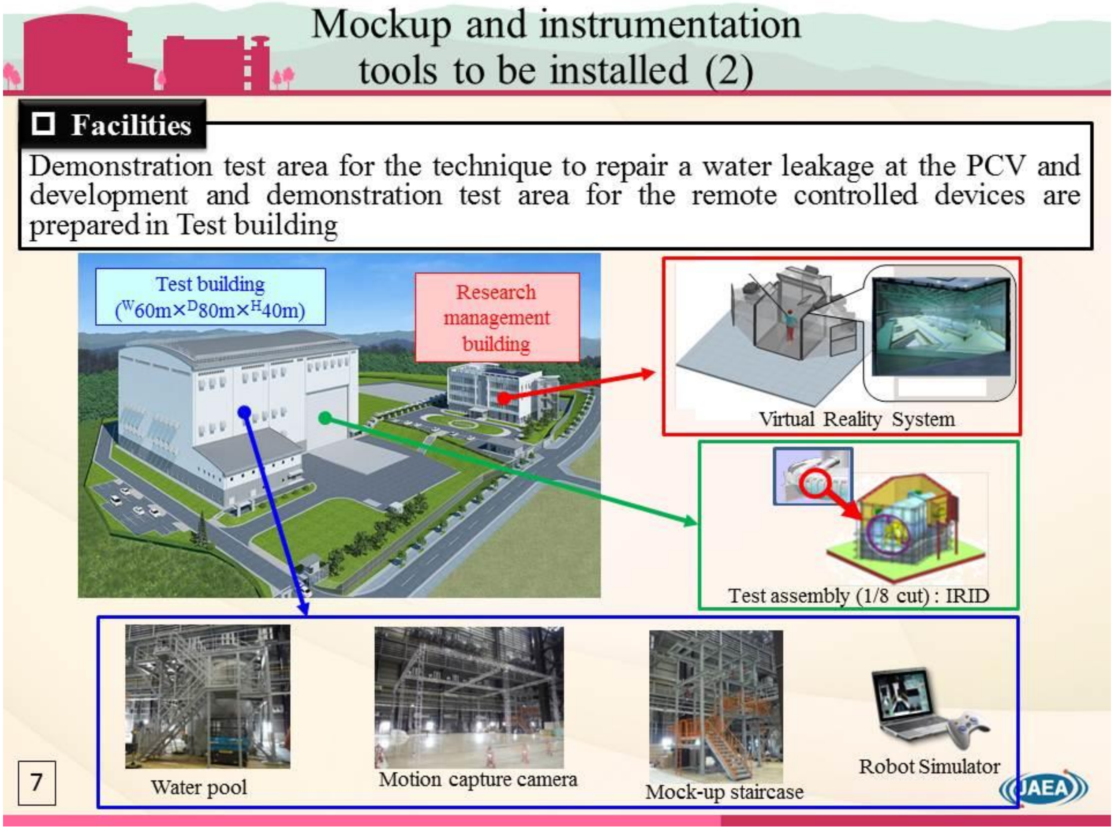
Disaster City
TEEX (Texas A&M Univ), Texas, USA

（三菱総研瀬川氏レポート）

Test fields and Mockup facilities
(1) Mockup facility for robots in indoor environment



Test fields and Mockup facilities

(2) Robot Test Field for field robots

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Fukushima U.

Fukushima Innovation Coast Vision

R&D bases, organization for ollaboration, human resource development in Fukushima prefecture 1

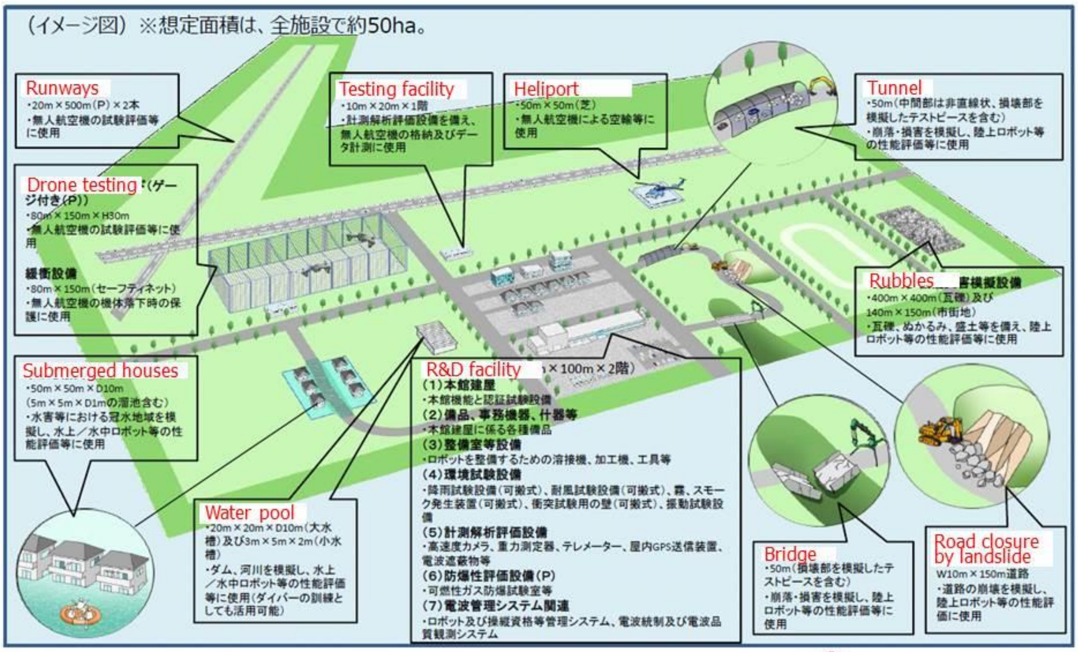
成（テクノアカデミー、工業高校等）

- テクノアカデミー
  - ・再エネ、医療など本県復興を担う人材を育成
- 福島高専、県内工業高校
  - 例)郡山北工高生徒が開発の探査ロボが世界2位
- 相双技塾…機械金属加工技術、メカトロ産業技術分野

携（ハイテクプラザ等）　()数字は構成機関・団体数

- 福島県廃炉・除染ロボット技術研究会(ハイテクプラザ)
  - ・各メーカーからの情報収集、情報共有化に関する産学ネットワークの構築(109)
- 関連産業協議会・研究会
  - ・医療機器(258)　・再エネ(501)　・輸送用機械(376)　・半導体(134)
- ハイテクプラザの取組実績
  - ・技術相談…1,500社4,000件/年　・機器開放…30000時間/年
  - ・依頼試験…3,500件/年
  - ・放射能測定…工業製品1000検体/年、加工食品2500検体/年

Concept of Test Field for Field Robots (METI)



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FUKUSHIMA Robot Test Field (Scheduled to open in FY 2018)

Drone Area
・Runway
・Airfield with safety net
・Drop test field
・Heliport

Infrastructure Inspection and Disaster Response Area
・Tunnel and bridge
・Debris and landslides (Damaged road)
・Mock-city area: residences and buildings
・Plant

ROV, AUV and Unmanned ship Area
・Flooded town
・Large outdoor water tank
・Deep indoor water tank with water flow
・Indoor water tank with turbidity control

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Necessity of explosion-proof function

Amagasaki Rail Crash
(JR Fukuchiyama-Line derailment)
Apr. 25, 2005

Petrol leakage in parking

Niigata tunnel gas explosion
May 24, 2012

Outbreak of natural gas

Difficult usage of device causing possible ignition

⇩

Evaluation and certification of explosion-proof function

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Japan Revitalization Strategy

Three pongs or "Arrows"

- Aggressive monetary policy
- Flexible fiscal policy
- New growth strategy "Japan Revitalization Strategy"
  - SIP (Strategic Innovation Promotion Program)
    - Tech. for Maintenance/Upgrading/Management of Infrastructure (PD: Prof. Yozo Fujino) Disaster Response robot
  - ImPACT (Impulsing Paradigm Change through Disruptive Technologies)
    - Tough Robotics Challenge (PM: Prof. Satoshi Tadokoro)

Disaster Response robot

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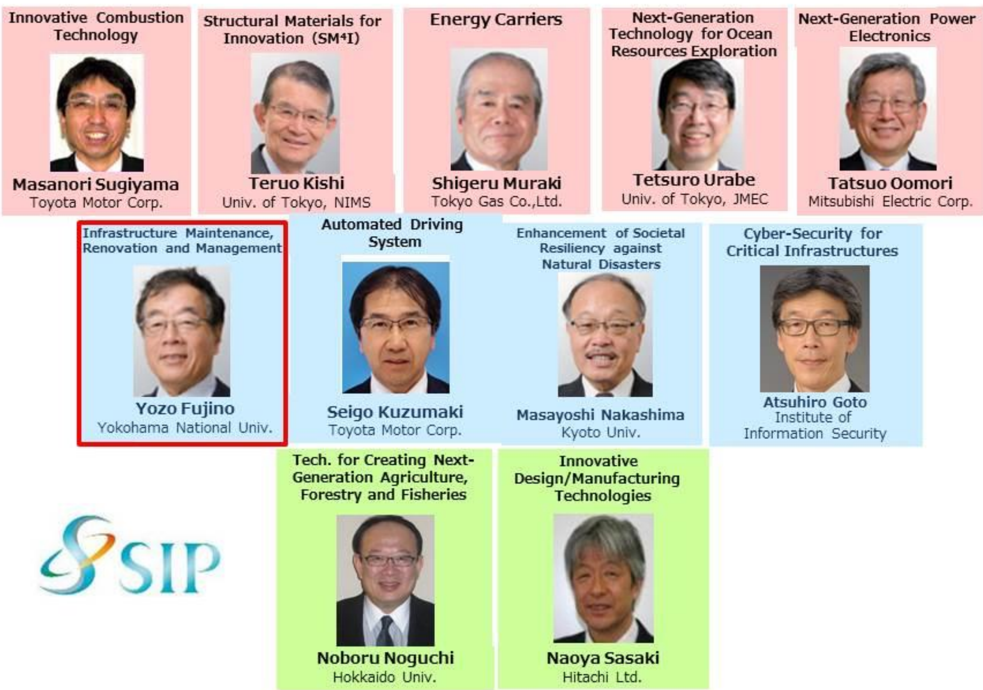
SIP (Cross-Ministerial Strategic Innovation Promotion Program)

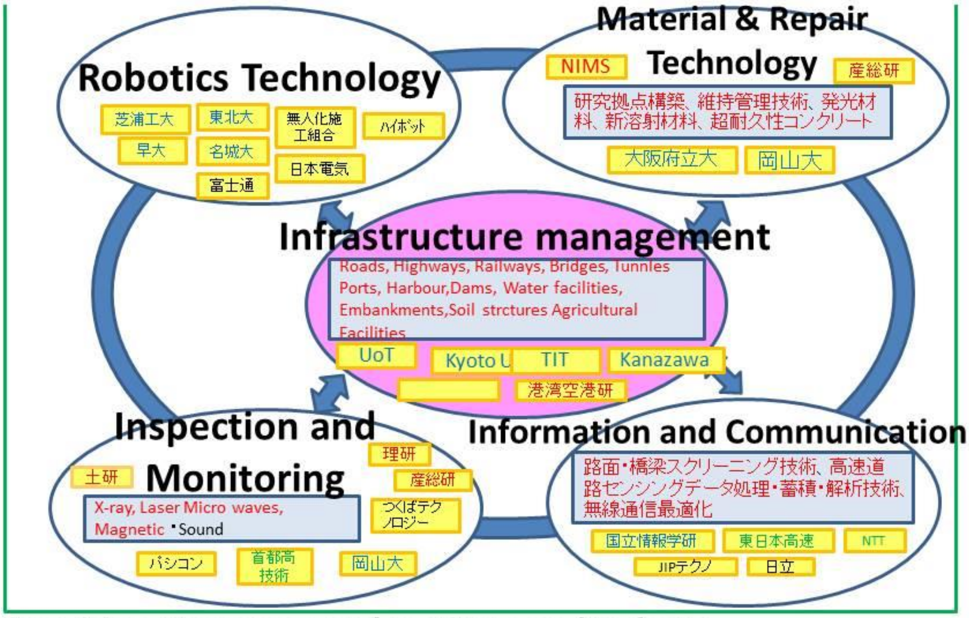
- Program Directors for SIP -



SIP

11

SIP: R&D in Infrastructure Maintenance, Renovation and Management



Universities, Governmental Institute and Industry.
Approx. 60 projects. More than 1000 researchers/engineers

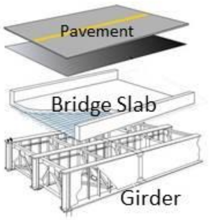
Inspection of bridges

Hands-on inspection for every 5 years was mandated.

Machine-assisted
Use of Robots

Flying robot

Most vulnerable element in bridge: slab



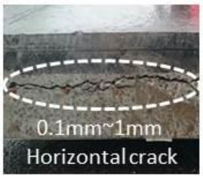
Serious damage

Damage Area Estimation By Hammer test

- Lane restrictions for long time
- Labor cost
- Should remove pavements
- Results depend on labor capacity

Pavement

Bridge deck



Bridge slabs in USA

Damage of Concrete Bridge Slabs need be detected.

SIP NEDO JAPAN

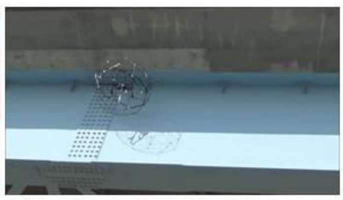
Development of UAV for Bridge Inspection

Tohoku Univ., RICOH Co., Chiyoda Eng. Co. JAST, Tokyu Cons. Co.

Passive Rotational Spherical Shell (PRSS) UAV:

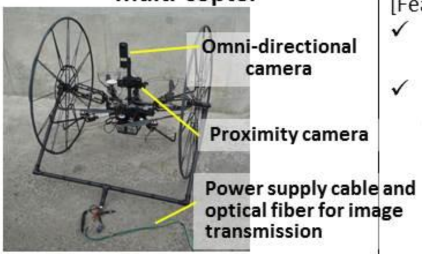
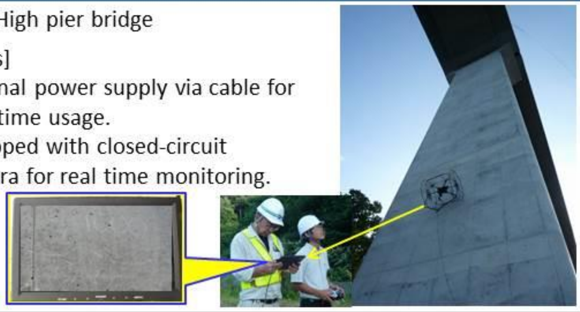
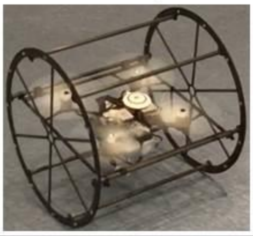
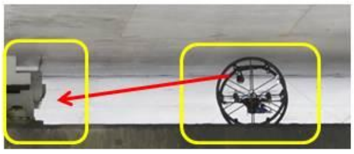
- PRSS UAV can enter beams under the bridges and take close images of slabs and beams instead of human workers.
- It can reduce cost of safety facilities for workers and traffic control.

Damage Report Software for PRSS UAV 's Camera Images



Two-wheeled flying robot for bridge inspection

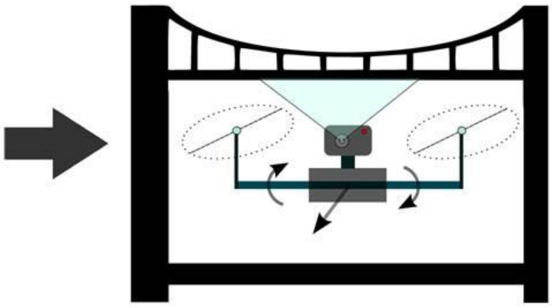
Features	
Features	• It can taka proximity-images with constant distance to bridge surface. • It is robust against windy condition because of skin friction of the wheels.

Type	Specifications
Large size two-wheeled multi-copter  	[Target] High pier bridge [Features] ✓ External power supply via cable for long-time usage. ✓ Equipped with closed-circuit camera for real time monitoring. 
Small size two-wheeled multi-coper 	[Target] Narrow space (shoe, and so on) [Features] ✓ Quadcopter in 'cage' for protection. ✓ It can run on a pier to take a picture of shoe.  

Demonstration of Small size Two-wheeled multi-copter

Current Research

- SIP Fujitsu Project – Bridge Inspection



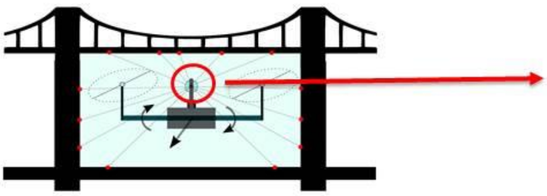
- Difficult for humans to inspect, so inspect using robots

=> Create 3D Model with texture for easy offline inspection

○12

Current Research

Spherical Cameras to see in all directions



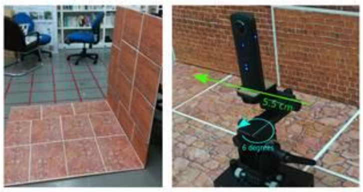
Equirectangular Image

Spherical Image

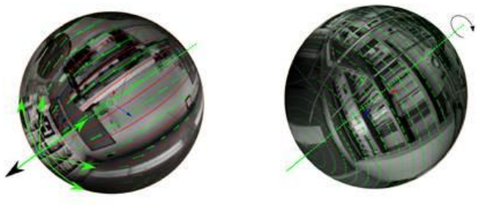
3D Reconstruction using Spherical Cameras

○13

Current Research

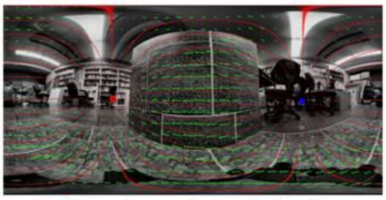


Click multiple images (複数映像撮影)

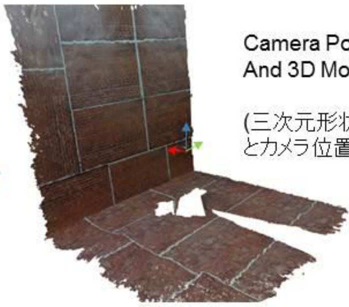


(a) Translation (spherical) (b) Rotation (spherical)

Dense Optical Flow (密なピクセル移動情報)



Split rotation and translation flow
(回転と併進のフローを分ける)



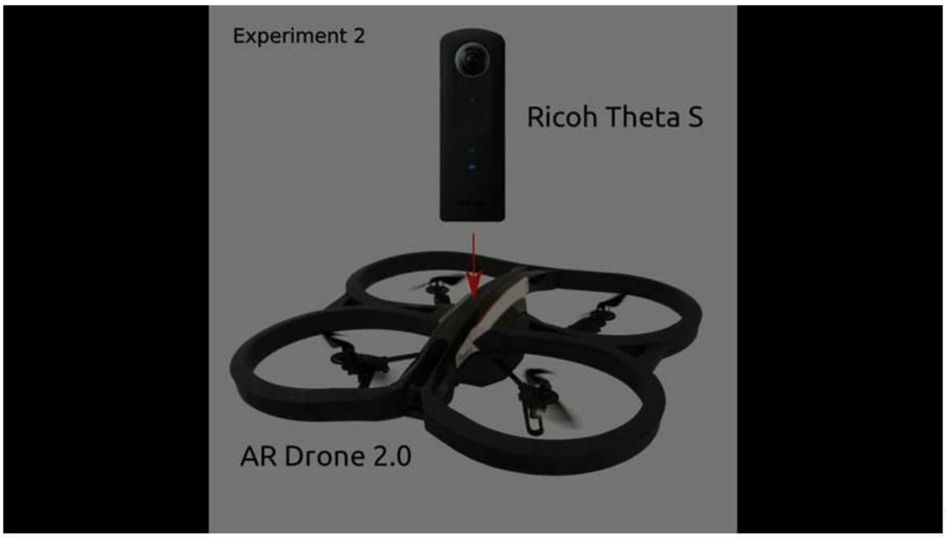
Camera Positions
And 3D Model

(三次元形状計測
とカメラ位置姿勢)

○14

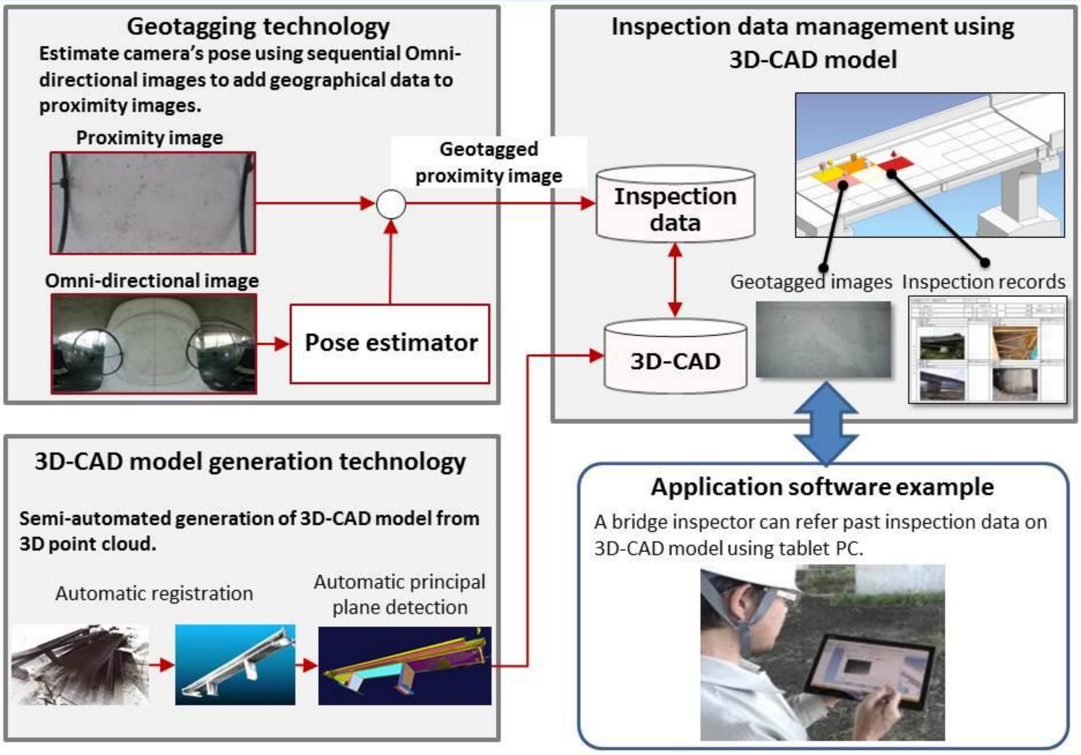
Current Research

- Spherical Image Stabilization – Virtual Camera
  Rotation-less Camera (回転無カメラ)

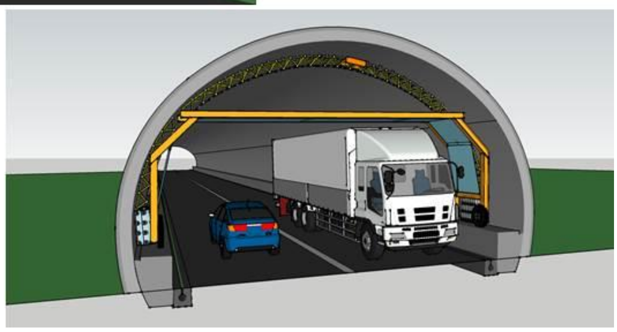


○15

Inspection data management using 3D-CAD model



Movable flexible truss for tunnel inspection

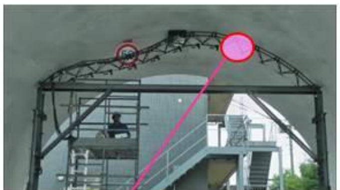


Defect Detection with Estimation of Material Condition Using Ensemble Learning for Hammering Test

Department of Precision Engineering,
The University of Tokyo, Japan
Hiromitsu FUJII,
Atsushi YAMASHITA, Hajime ASAMA

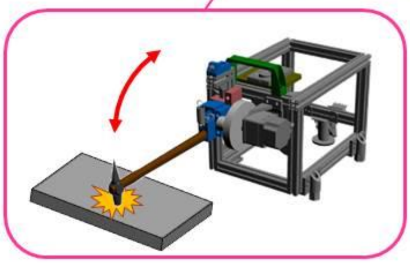
Motivation: Automation of social infrastructure inspection

- *Hammering test* is a non-destructive inspection method
  - high accuracy by listening for difference of impact sounds
  - high efficiency by using no contact sensor



- Essentials for the automation is auto-diagnostic system
  - to detect defects accurately
  - to estimate defect condition

  from hammering sound

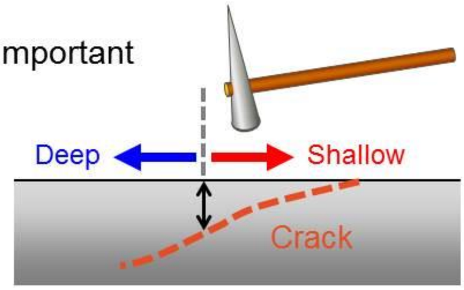


Purpose and our contribution

Construction of accurate diagnostic algorithm
using acoustic impact signal
with function to estimate defect condition

Defect material condition

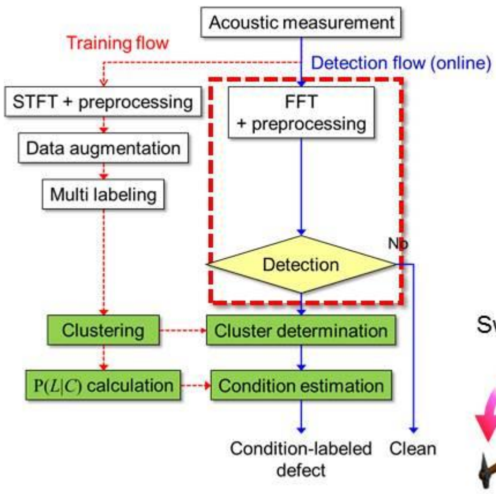
e.g. Crack depth estimation, which is important
- to find the extent it progress to
- to select the repair method depending on the depth.



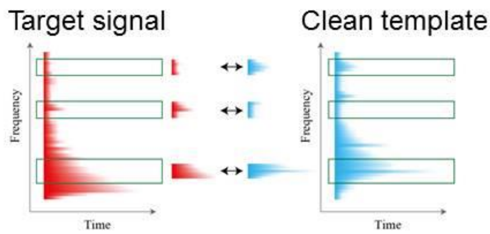
Proposed method: *Defect detection*

1. Pattern recognition in the time-frequency domain

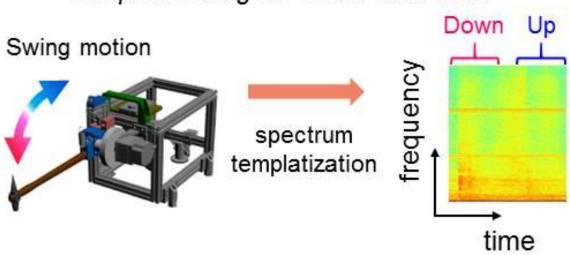
Pipeline of our system



Pattern matching in sub-bands



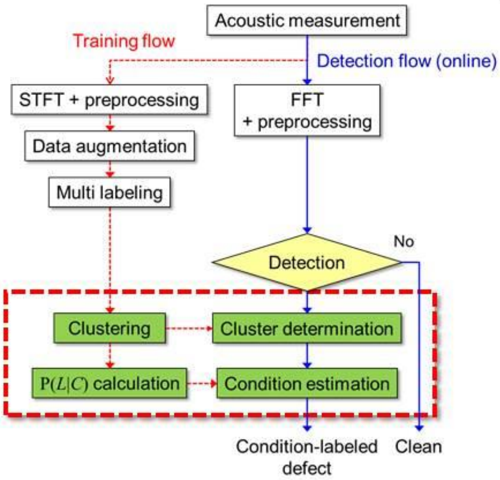
Preprocessing for noise reduction



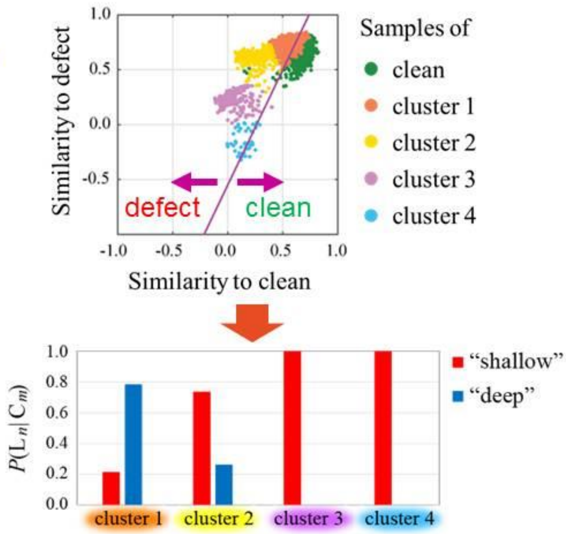
Proposed method: *Condition estimation*

2. Obtaining probabilistic expression of defect condition

Pipeline of our system



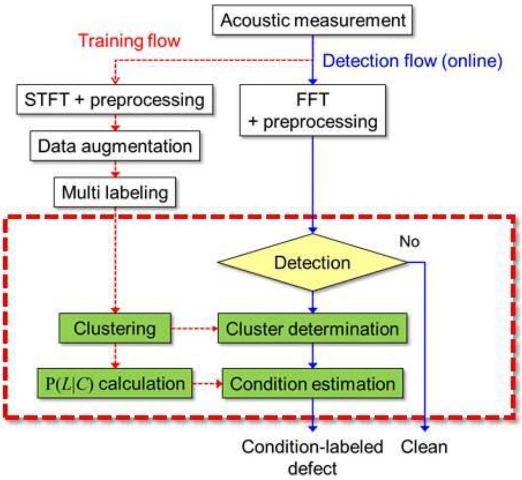
Clustering-based expression of posteriori probability of defect condition



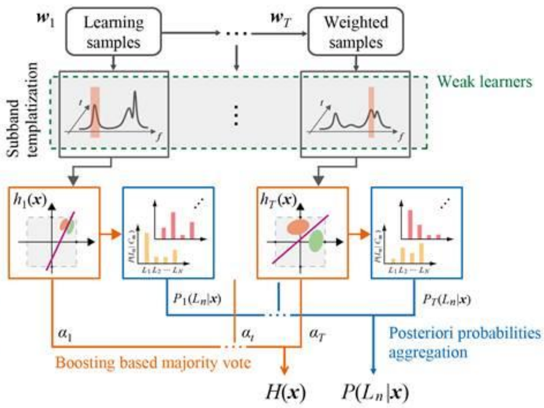
Proposed method: Improvement of accuracy

3. Integration by our ensemble learning algorithm

Pipeline of our system

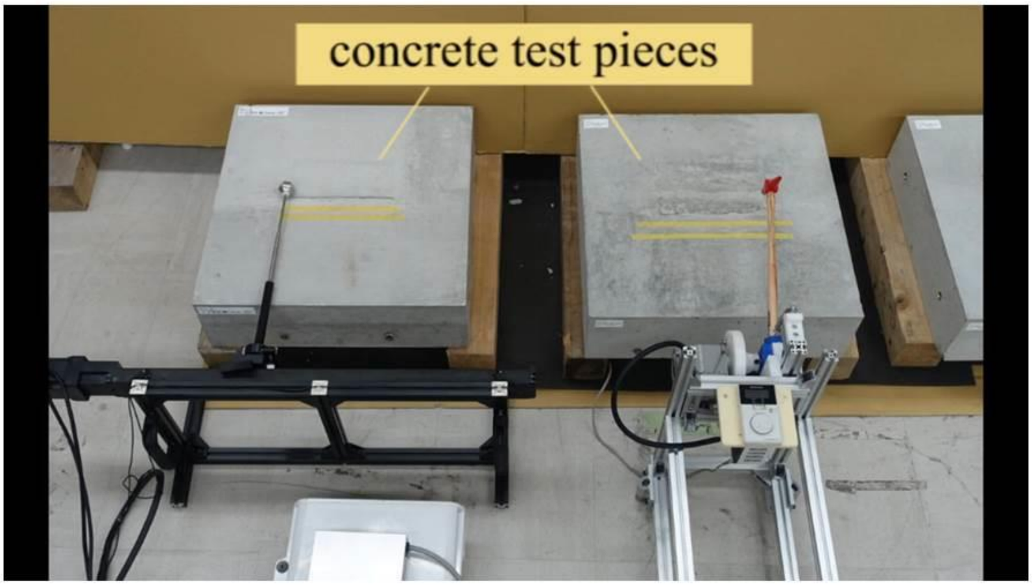


Accuracy of defect detection and condition estimation are improved by combining *boosting* and *bagging*



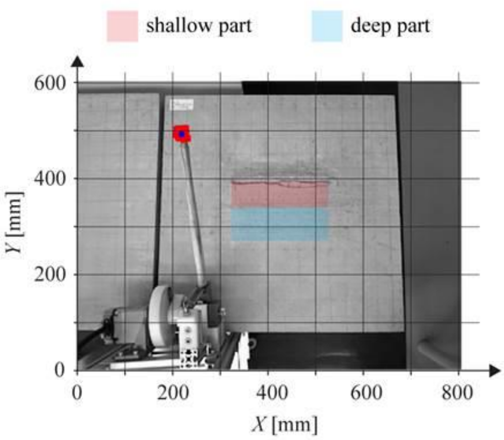
Experiment and result

● clean ● "shallow" ● "deep"

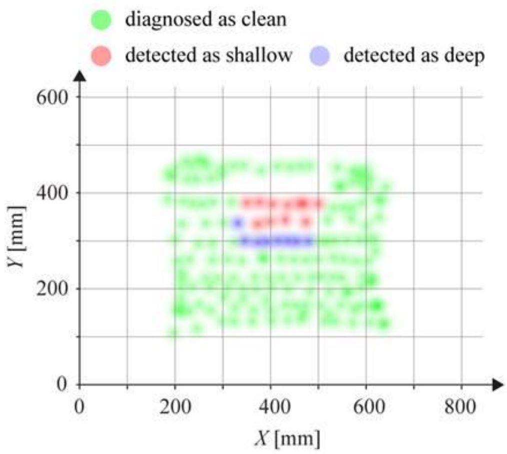


Experimental results

Defect part and the depth are correctly identified.



Ground truth



Estimation result

Outline of Development Project for Infrastructure Maintenance and Disaster Survey

インフラ維持管理・更新等の社会課題対応システム開発プロジェクトの概要

New Energy and Industrial Technology Development Organization
新エネルギー・産業技術総合開発機構（NEDO）
Robot and Machinery System Technology Department (ロボット・機械システム部)
Yusuke Yasukawa (安川　裕介)

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Collaborative Activities Between Japanese Ministries 省庁連携プロジェクト

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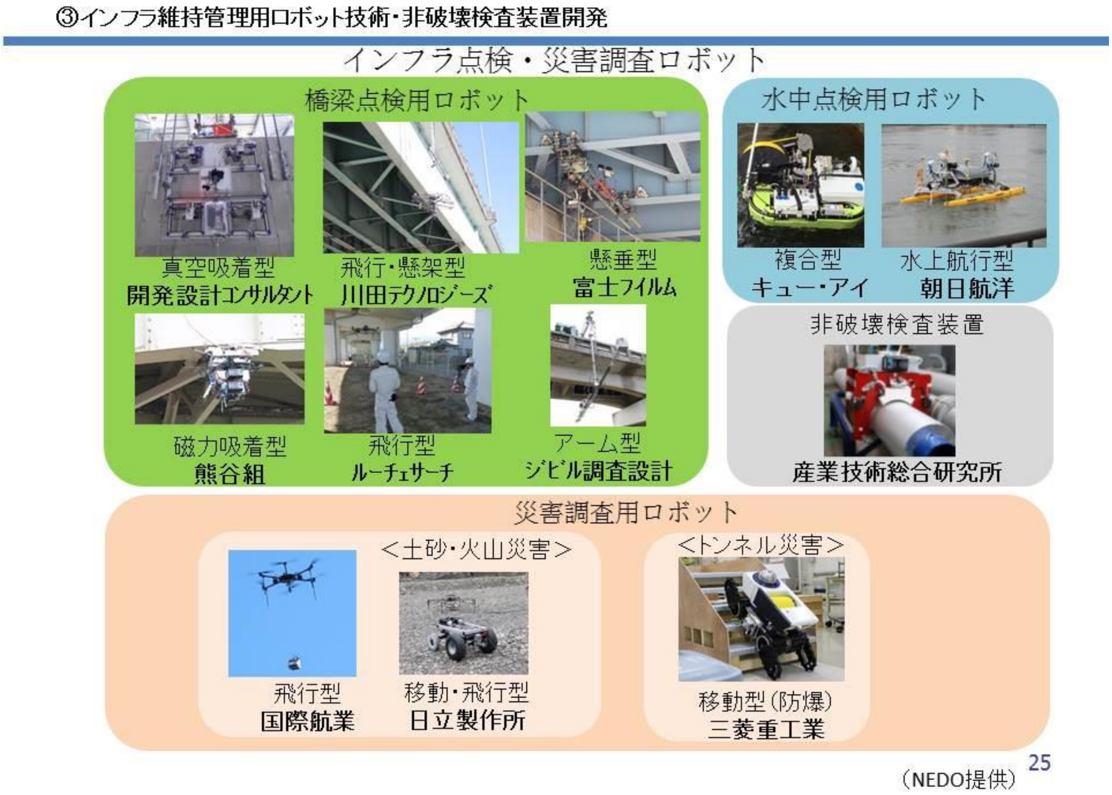
MLIT
Ministry of Land, Infrastructure, Transport and Tourism
国土交通省

Evaluation and Test Use of the Robotic System at the **Real Site** of Maintenance and Disaster (based on Public Offering)
現場ニーズ
実験場所の提供
開発システムの評価

METI
経済産業省
Ministry of Economy, Trade and Industry

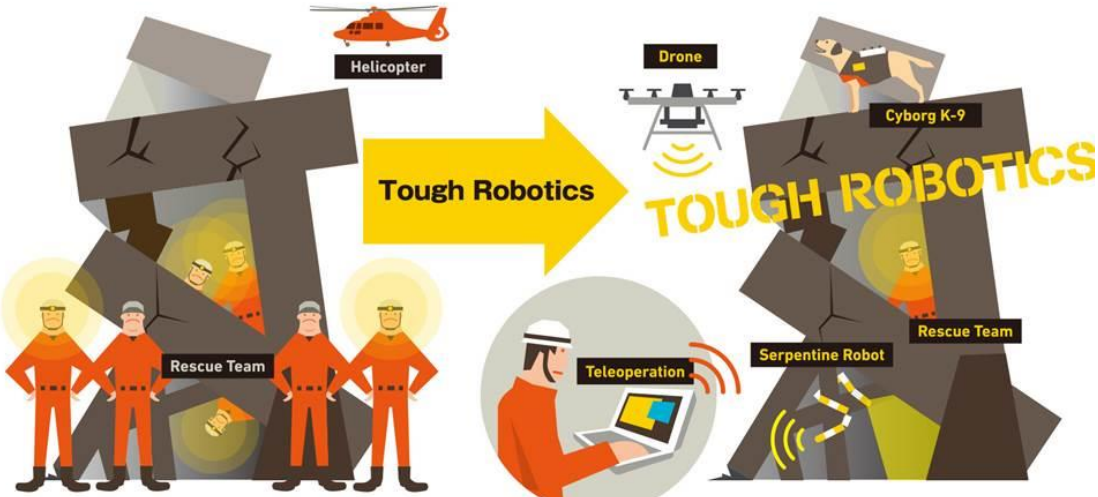
Development of Robot Technology and Systems via NEDO
インフラ用システムの開発


③インフラ維持管理用ロボット技術・非破壊検査装置開発
インフラ点検・災害調査ロボット
橋梁点検用ロボット
真空吸着型
開発設計コンサルタント
飛行・懸架型
川田テクノロジーズ
懸垂型
富士フイルム
磁力吸着型
熊谷組
飛行型
ルーチェサーチ
アーム型
ジビル調査設計
水中点検用ロボット
複合型
キュー・アイ
水上航行型
朝日航洋
非破壊検査装置
産業技術総合研究所
災害調査用ロボット
<土砂・火山災害>
飛行型
国際航業
移動・飛行型
日立製作所
<トンネル災害>
移動型(防爆)
三菱重工業
25
(NEDO提供)


革新的研究開発推進プログラム
ImPACT
Impulsing Paradigm Change through Disruptive Technologies
2014-2018, 55BY(440M$)
Realizing an Ultra-Thin and Flexible Tough Polymer
(program01.html)
Kohzo Ito
Turning Serendipity into Planned Happenstance
(program02.html)
Keisuke Goda
Ubiquitous Power Laser for Achieving a Safe, Secure and Longevity
(program03.html)
Yuji Sano
Achieving ultimate Green IT Devices with long usage times without charging
(program04.html)
Masashi Sahashi
Innovative Cybernic System for a ZERO Intensive Nursing-care
(program05.html)
Yoshiyuki Sankai
Super High-Function Structural Proteins to Transform the Basic Materials Industry Society Society
(program06.html)
Takane Suzuki
Tough Robotics Challenge (TRC)
(program07.html)
Satoshi Tadokoro
Reduction and Resource Recycle of High Level Radioactive Wastes with Nuclear Transmutation
(program08.html)
Reiko Fujita
Ultra high-speed multiplexed sensing system beyond evolution for detection of extremely small amounts of substances
(program09.html)
Reiko Miyata
Innovative visualization technology to lead to creation of a new growth industry
(program10.html)
Takayuki Yagi
Actualize Energetic Life by Creating Brain Information Industries
(program11.html)
Yoshinori Yamakawa
Advanced Information Society Infrastructure Linking Quantum Artificial Brains in Quantum Network
(program12.html)
Yoshihisa Yamamoto

Overview

Japan is one of the most disaster-prone countries in the world. A large-scale earthquake is predicted to occur directly beneath the Tokyo metropolitan area in the near future, and there is an urgent need for measures to reduce the risk. Although the usefulness of robots in a disaster was recognized during the Great East Japan Earthquake, robots that can actually be used in unknown extreme environments where the situation is always changing are still a work in progress. The goal of this program is to develop essential technologies for remote autonomous robots that are tough and can function without faltering even in an extreme disaster conditions. At the same time, this research provides key fundamental technologies for outdoor service robots for establishing foundation of the future advanced outdoor robot services.



Rescue operations in disaster situations are extremely difficult. In many cases, it is difficult to approach disaster sites by the risk.

Robots, drones and cyborg K-9s support rescue teams at difficult disaster sites.

Disruptive Innovation

Keys to breakthrough

- Advance three technologies of active robustness, large-scale real time information, and bio-machine Fusion. Integration with five types of robot bodies. Establish remote autonomous robotics that can operate robustly in extreme environments, implement commercialization and create a foundation for social implementation.

Hajime Asama
Dept. of Precision Engineering
The University of Tokyo

The Challenges for the Impact of Success

Overview of TRC

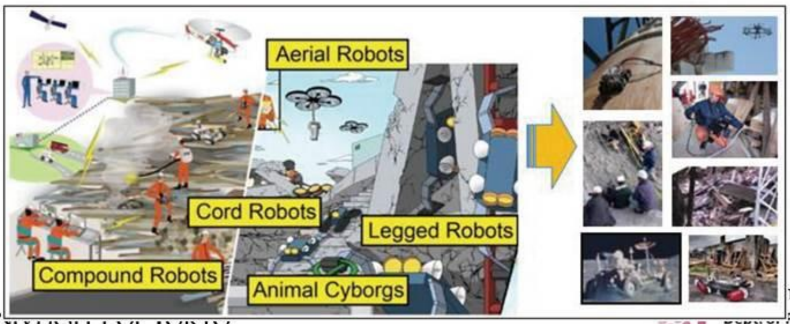
- Jointly research and develop the key fundamental technologies for outdoor robots (accessibility, sensing and perception, recovery from failure, and environmental compatibility) in a cooperative competitive environment, with the aim of achieving remote autonomous robots that can work robustly without faltering even in the unknown, time-varying extreme disaster environments. Conduct focused field evaluations to make robot technologies and their performance visible, and lower the barriers to social application.

Background

- In recent years, large scale disasters have occurred frequently. Application of robot technologies to improving disaster response, recovery, preparedness and mitigation capabilities, improving efficiency, and at the same time ensuring the safety of responders is an urgent issue. However, current robots are delicate goody-goodies that cannot show the same performance of work in the extreme environment of disasters as they can indoors. Their ability to respond to unexpected situations is low.

Impact on industry and society in the event of achievement

- Application of robots to emergency response, recovery, preparedness and mitigation of disasters to contribute the world safety and security. Furthermore, pave the way to commercialization of advanced outdoor robot services by promoting technology spillover.



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Hajime Asama
Dept. of Precision Engineering
The University of Tokyo

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Robots developed in Tough Robotics Challenge Project

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Hajime Asama
Dept. of Precision Engineering
The University of Tokyo

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Committee for the Realization of the Robot Revolution

- New Industrial Revolution by robots
- Incorporation of robot revolution in the Growth Strategy
- Showcase of robot applications

Robot New Strategy

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Overview – Background and attitude about "Robot Revolution"

◇ Japan as **"a Robotics superpower"**

- The world biggest number of shipments and operating units of industrial robot in the world

◇ Japan is **"an issue advanced country"** for such as low birth rate and longevity, aging infrastructure, which is expected to utilize robot technology.

◇ Europe and the United States are catching up with the new production systems with digital and network technology as a key to advancement. **China and developing country** are also accelerating **investment to robots**. (Chinese robot introduction amount outnumber Japan.)

➡ **Lead the world by intensive utilize of robot in data-driven era.**

What is Robot Revolution?

1. Dramatic changes in robot ("autonomy", "being information terminal", "networking") **Even car, consumer electronics, mobile phone and house become robots**
2. Utilizing robot in various fields **from manufacturing to daily life**
3. Through the resolution of social issues and strengthening of international competitiveness, realizing a society in which the robot creates new value.

Towards Robot Revolution

Three Pillars realizing the revolution

1. Becoming the robot innovation hub of the world,
2. the world's leading robot utilization society, (SME, nursing/medical care, infrastructure, etc.)
3. Leading the world with robotics in IoT era (Robot with IT utilizing big-data, network and AI)

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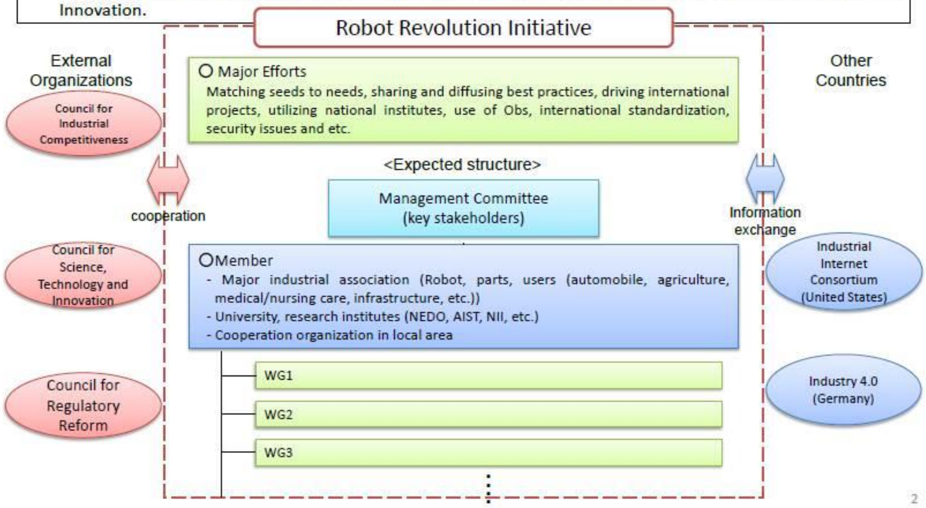
Action plan - Cross-cutting issue (1) the foundation of "Robot Revolution Initiative" -

◇ Based on the results of "the robot revolution realization council", establish a promoting organization that involves the industry, academia, and government to realize robot revolution in actual fields. Considering discussion on AI and IoT in Industrial Competitiveness Council and the Council for Science, Technology and Innovation.



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Action Plan - Cross-cutting issue (2) Technology development towards next generation -

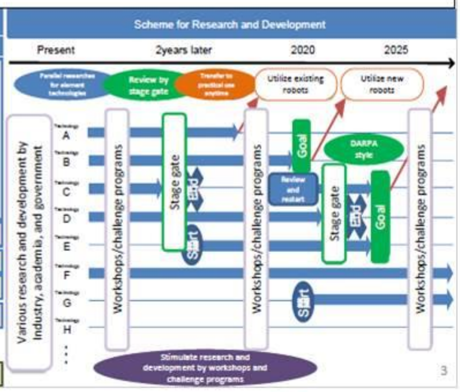
◇ Need to promote research and development for core element technologies and/or innovative next-generation technologies in order to win the data drive society.

◇ The next-generation technologies (AI, sensor and cognition systems, mechanisms/actuators and its control systems and platform technologies to integrate these core elements) that give a significant impact when implemented in industry and society must be developed.

◇ Research and development of element technologies must be performed with collaboration and information sharing among researchers by workshops, promoting competition among research institutes by contest and award scheme, and introducing the open innovation.

Expected technologies to be developed

Core technology		Current major issues	Expected researches for issues
Artificial Intelligence Technology for automated Behavior based on human indication and environment	Reasoning	Although it is possible to provide one answer to one question based on given information, it is difficult to give a natural response based on the analogy of the context of conversation or instruction or by reading between the lines, or respond to unknown situations (machine translation is still developing).	○ Advancement of data-driven (AI technology learns from big-data) ○ Advancement of knowledge representing and reasoning AI (Technology for reasoning from existing knowledge) ○ Advancement of artificial brain AI (Simulating brain functions by software, and hardware realize brain like functions)
	Learning	Pre-programmed movements can be made, but it is difficult to autonomous change or determine tasks by recognizing task progress or situations in the surrounding, or make a movement by imitating the craftsmanship.	
	Intelligence Architecture	It is necessary to study modularization of AI and software (e.g., thinking system and reflex system in the brain structure) in terms of concentration of research and development resources and improvement of development productivity	
Sensing and cognition		···	···
Mechanism, actuator and control		···	···
OS, middleware, etc.		···	···
Safety evaluation, standard		···	···
Other technologies			
Technologies from other fields		···	···



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Dept. of Precision Engineering
The University of Tokyo

Action Plan - Cross-cutting issue (3) Standardization and Field-Testing -

◇ Act from cross-cutting and medium-long term prospective such as international standardization, Field-Testing of Robots which is valid for acceleration for development and introduction, human resource development who progress the introduction and expansion of robot.

◇ The executive committee will be started within this year to establish the system, the concrete style and competition items will be determined by 2016, and also a preparatory competition will be held in 2018. And then, the Robot Olympic will be held in 2020.

◆ **International standardization**
→ indispensable for expanding our robotics technology to the world
- Securement of the compatibility (e.g. connection, interface, OS)
- Assurance of quality and safety (Safety, certification)
- Establishment of necessary test method (e.g. collision test, stability test)

◆ **Field-Testing of Robots**
→ Valid for acceleration for development and introduction
- Stable operation for securing the needs for equipment
- Clarifying the concrete and institutional effect that leads to future commercialization
- Endure into the future
- Locate the "Fukushima Hama Doori Robot Testing Zone(provisional name)"

◆ **Robot Olympic**
→ Utilize as a good chance for introducing and expanding robots
- Progressing and acceleration of research and development and supplying the place of demonstration for 5 years
- Establish an executive committee within this year and determine the competition items by 2016
- Held a preparatory competition in 2018

◆ **Human Resource Development**
→ fostering software human resources and SIers is a key for robot utilization by
- Make use of retired workers in production technical fields and OJT-type expansion (short term)
- Utilization of public job training
- Integrative curriculum at the graduate school

◆ **Robot Award**
→ A large impact by evaluating the excellent cases
- Publication of advanced cases and utilization and share the best practice
- Establishment of new award and expansion of awards

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The University of Tokyo

Action Plan - Cross-cutting issue (4) Implementation of Robot Related Regulation Reform-

◇ Promote regulatory reforms that are well-balanced in both of deregulation and rule establishment aimed at robot utilization.
◇ Sort out issues occasionally through "Robot Revolution Initiative". Coordinate with government Regulatory Reform Council and implement comprehensive reform which look down on the related systems. Construct a robot barrier-free society.

◆ **Establishment of new radio wave utilization system that supports robot utilization (Radio Act)**
(Treating of radio used for remote controlling and unmanned robot such as the rule of sharing the frequency with existing radio wave systems and the simple procedure for radio station licenses)
→Implement necessary action serially after considering the requirement condition and technical review by 2016FY.

◆ **Smooth pre-market review process for brand-new medical devices (The Act on Securing Quality, Efficacy and Safety of Pharmaceuticals, Medical Devices, Regenerative and Cellular Therapy Products, Gene Therapy Products, and Cosmetics)**
(Handling of new medical device which utilize robotic technique such as surgical robot which is expected to alleviate the burdens of patients)
→Conduct smooth pre-market review for brand-new medical devices, increase the ratio where medical devices are approved in the standard review period (10 months for priority items) up to 80 percentage in 2018FY.

◆ **Reviewing the various legal systems related nursing care**
(Flexibility of the procedure that require to add the new nursing-care insurance devices which are currently carried out once in three years
(Reception of the request and consideration that can respond to the technical innovation))
→From 2015, MHLW receives the requests regarding the coverage of the nursing-care insurance system occasionally and add the new target items occasionally.

◆ **Road Traffic Act and Road Transport Vehicle Act**
(electric personal assistive mobility devices use at public road)
→in addition to the utilizing the relaxation of the standards for road transport vehicles, based on the evaluation results of "Evaluation and Research Committee for Structural Reform Special Districts", which is planned to be conducted during FY2014, the way to deal with these assistive mobility devices will be considered, including whether to make the use of "Special System for Corporate Field Tests", which was created in 2014.

◆ **Laws and Regulations related to uninhabited airborne robot(Aviation Law and the like)**
(Concrete rule about uninhabited airborne type robots (UAV) which is expected to be used at the disaster sites and the like)
→As for the Large-size uninhabited aerial vehicles, domestic rules will be established by participating the consideration of the revision of the international standards at International Civil Aviation Organization (ICAO) and based on such revision which is expected to take place in 2019 or later. As for the small-size uninhabited aerial vehicles, while identifying their operational situation, further examination will be proceeded to the laws and regulations.

◆ **Laws and regulations related to public infrastructure maintenance and repair**
(Valid method for utilizing robot effectively (a rule related to the utilizing robot in checking where visual inspection is required)
→Through the based on the on-site verification results, trial, and evaluation, examination will be proceeded about the method for utilizing robot. Based on the results, method will be applied to the fields where robots are to be utilized

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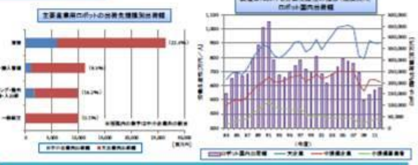
Action plan－Sectoral issue (1) Manufacturing, service－

Manufacturing



Robots are introduced to mainly major companies, labor productivity have levelled off in recent years

Priority areas

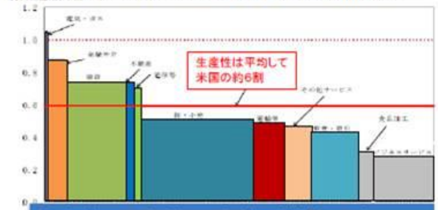
- ✓ Promote to introduce robot to mainly labor-intensive work such as parts processing and assembly and food processing
- ✓ Challenge for robot introduction to setup process where robotization has been difficult in the past, and sophisticate robot by utilizing IT
- ✓ Foster SIer who integrates users and producers
- ✓ Standard modularization for Robots (Hardware/Software) and streamlining the common platform（Robot OS (=Operating System for Robots))

The 2020 vision to aim for

- ◆ Increase the rate of robotization in the assembly process: 25% for large-scale companies･10% for small and medium-sized companies
  ※The rate of robotization in the automobile assembly process is about 7%: by the Economic Research Institute, Japan Society for the Promotion of Machine industry
- ◆ Best practice of utilizing next-generation robots：30 cases
- ◆ Interoperable hardware products：more than 1,000 types
- ◆ Expand the market scale related to SIer business（exceed the increase in the size of the market for robots）

Service

＜Comparison between Japan and US in the service field of the labor production standard＞



Need to improve the labor production which is lower than any other country

Priority areas

- ✓ Promote to introduce robot to backyard operations such as logistics, wholesale, retail, hotels, and restaurants
- ✓ Through collecting examples of the best practice and dissemination nationwide, create a virtuous cycle of solving labor shortage in the service industry, improving productivity, and increasing wages
- ✓ Bring into perspective a study toward automating human-based process, such as development of the next-generation element technologies

The 2020 vision to aim for

- ◆ The rate of use of robots for picking, screening, and checking operations: about 30%
- ◆ Collect the best practice mainly for the backyard operations including collecting and placing tables and cleaning in the wholesale and retail businesses, hotels, and restaurants（about 100 examples）

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Action plan－Sectoral issue (2) Nursing and medical fields－

Nursing

Rise of the aging rate, increase of the necessary care workers, 70% of workers suffer from backache

Priority areas

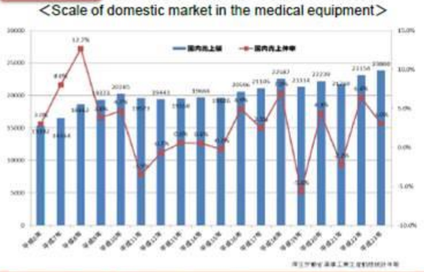
- ✓ Support the development and practical realization and spread in the important 5 development fields, transfer support from bed, walking support, excretion support, watching over who have dementia, bathing support

The 2020 vision to aim for

- ◆ Expand the domestic market scale of nursing care robots to 50 billion yen
- ◆ Lower the risk of care givers of suffering from a backache to zero by using nursing care robots for helping the aged transfer
- ◆ Change the awareness of nursing methods using the newest robot technology
  - Increase the percentage of people who wish to use nursing care robots for providing care to 80% from the current 59.8%.
  - Increase the percentage of people who wish to have robots used when undergoing care to 80% from the current 65.1%

Medicals

＜Scale of domestic market in the medical equipment＞



Though the sales figures increase, increase rate rise and fall

Priority areas

- ✓ Spread the medical devices such as surgical robots
- ✓ Smooth pre-market review of brand-new medical device

The 2020 vision to aim for

- ◆ More than 100 cases of support to put medical care-related equipment using robot technology will be implemented in 5 years from 2015 to 2020

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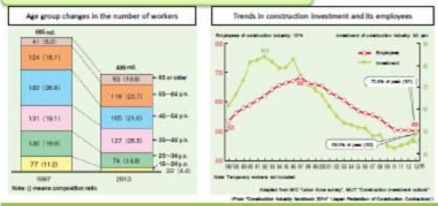
Action plan－Sectoral issue (3) Infrastructure, disaster, construction/agriculture, food industry－

Infrastructure, disaster, construction



A decrease and aging of the number of workers cause serious labor shortage

Priority areas

- ✓ Aim for solving the medium- and long-term labor shortage, by labor-saving and automation in construction.
- ✓ Aim for more efficient and sophisticated maintenance, by leveraging the robot to visual inspections of infrastructure.
- ✓ Aim for faster understanding disaster situation by disaster survey robot, and efficient construction by unmanned systems in landslide disaster site.

The 2020 vision to aim for

- ◆ Aim for 30% of the adoption rate of intelligent construction for high productivity and labor-saving.
- ◆ Aim for high effective maintenance and repair by sensor, robot and non-destructive inspection to at least 20% of the aging important infrastructure, .
- ◆ Achieve for unmanned construction efficiency comparable with manned construction in harsh landslide and volcanic disaster site.

Agriculture, food industry

Possibility facing serious labor shortage by aging progresses

Priority areas

- ✓ Achieve to unprecedented large-scale, low-cost production by overcoming the work capacity limitation by automation introducing the GPS automatic navigated farm machines including tractor.
- ✓ Aim for mechanization and automation of human-intensive hard work by introducing assist-suits and herbicides robots.
- ✓ Realize labor saving and high-quality production by advanced environmental control systems, damaged produce inspection systems and big-data analysis.

The 2020 vision to aim for

- ◆ Achieve for implementation of automatic driving tractors to actual field until 2020.
- ◆ Aim to introduce more than 20 types robots for labor-saving in agriculture and food industry.

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Hajime Asama
Dept. of Precision Engineering
The University of Tokyo

Concept

WRS
World Robot Summit

The World Robot Summit (WRS) is a combination of robot competition and trade show that brings together the best and latest in robotics technologies from around the world in the hopes of realizing a world where robots and humans live and work together.

WRS will feature two events:
World Robot Challenge, in which robots compete with one another, and World Robot Expo, where the latest robotic technologies will be exhibited. Robot Excellence from around the world will come together in one location with the aim to implement robotics in real daily life/society/industry and accelerate the research and development of robots.

● **Goals**

Acceleration of R&D of robots	Implementation of robots in actual society, including daily lives of individuals and industrial sectors	Realization of a world where robots and humans live and work together

● **Approach**

By combining robot challenges (WRC) and exhibition (WRE), the WRS will bring together and showcase Robot Excellence from around the world. WRS shall

Encourage scientists and engineers to interact with each other and stimulate each other's R&D	Provide opportunities for ordinary people to connect with researchers and industry experts and learn directly from them about the latest studies and use cases in the field of robotics	Raise awareness, interest, expectation, and understanding of ordinary people toward robotics

● **Factors that will be Examined**

Physical and intellectual functionalities of robots	Applicability of robots in actual society, including daily lives of individuals and industrial sectors	Ordinary people's increased accessibility and acceptance of robots

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World Robot Challenge

World Robot Challenge

World Robot Challenge (WRC)

WRS will bring together the world's most advanced robots and robotic technologies along with researchers and developers of robots and key government and private industry players from around the world. The Robot Excellence gathered here will face off in these challenges and exhibitions(through competitions, demonstrations, discussions and award presentations) to show the changes that will take place in industry, society and daily life.

As a part of WRS, the World Robot Challenge will feature competitions in four categories: Industrial Robotics Category, Service Robotics Category, Disaster Robotics Category, and Junior Category.

Industrial Robotics Category | Service Robotics Category | Disaster Robotics Category | Junior Category

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About

World Robot Summit

World Robot Summit 2018 TOKYO

@Tokyo Big Sight

October 17-21

World Robot Summit 2020 AICHI/FUKUSHIMA

@Aichi International Exhibition Centre
/Robot Test Field located in Fukushima Pref.

August and October

2018 — 2019 — 2020

*Held alongside Japan Robot Week 2018
10/17-10/21 @Tokyo Big Sight

【Tentative】
*Held alongside RoboCup Asia-Pacific Open and Japan Robot Week 2020

World Robot Summit 2018 TOKYO

Name	World Robot Summit 2018
Venue	Tokyo Big Sight East 7/8 Halls
Schedule	October 17-21, 2018 *Held alongside Japan Robot Week 2018
Host	Ministry of Economy, Trade and Industry (METI) /New Energy Industrial Technology Development Organization (NEDO)

organized by METI NEDO

World Robot Summit 2020 AICHI/FUKUSHIMA

Name	World Robot Summit 2020
Venue	Aichi International Exhibition Centre
Schedule	Early October 2020 for one week * Held alongside RoboCup Asia-Pacific Open and Japan Robot Week 2020 (tentative).

Two of the challenges under the Disaster Robotics Category are scheduled as follow:

Venue	Robot Test Field located in Fukushima Prefecture
Schedule	Mid-August 2020 for about 3 days
Host	Ministry of Economy, Trade and Industry (METI) /New Energy Industrial Technology Development Organization (NEDO)

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Challenges under World Robot Challenge (WRC)

A total of 8 challenges are planned to be held: under 4 categories.

Category	Challenge	Venue	Participants	Challenge Summary	Evaluation Criteria
Industrial Robotics	Assembly Challenge	Aichi International Exhibition Center	Teams from universities, research institutes, companies, or other entities	Quick and accurate assembly of model products containing technical components required in assembling industrial products and other goods	Speed, accuracy, cost-effectiveness, contribution to energy saving rates, etc.
Service Robotics	Partner Robot Challenge			Clean or tidy up rooms at homes and house-sitting	Achievement levels in overcoming challenges, level of human help needed, contribution to energy saving rates, etc.
	Future Convenience Store Challenge			Shelf-stocking and replenishment of multiple types of products such as food, interaction with customers and staffs, and cleaning restrooms	Achievement levels in overcoming challenges, speed, quality of work (alignment, etc.), contribution to energy saving rates, etc.
Disaster Robotics	Plant Disaster Prevention Challenge	Robot Test Field in Fukushima Prefecture		Inspecting or maintaining infrastructures based on set standards (e.g. opening/closing valves)	Achievement levels in overcoming challenges, quality of work, contribution to energy saving rates, etc.
	Tunnel Disaster Response and Recovery Challenge			Collecting information and providing emergency response in case of a tunnel disaster (e.g. life-saving, removing obstacles from tunnels)	Achievement levels in overcoming challenges, quality of work, contribution to energy saving rates, etc.
	Standard Disaster Robotics Challenge	Aichi International Exhibition Center		Assessing standard performance levels (e.g. mobility, sensing, information collection, wireless communication, remote control on-site deployment, durability, etc.) required in disaster prevention and responses	Achievement levels in overcoming challenges by performance, quality of work, etc.
Junior	School Robot Challenge		Teams of members aged 19 or younger	Programming the standard platform robots to complete tasks that might be useful in a school environment	Innovativeness, effectiveness, creativity, teamwork, etc.
	Home Robot Challenge			Setting tasks equivalent to those in the service robotics category's Partner Robot challenge and making robots that complete such tasks	

Note: With regards to competition details in 2020, stated details are all present assumptions and the final details will be confirmed by referring to the progress of technology and the results of pre-competition which will be held in 2018.

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Autonomy ≠ Non-controllability

Autonomous

Astro Boy

Complementary

Tele-operated

Tetsujin 28

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Hajime Asama
Dept. of Precision Engineering
The University of Tokyo

Summary

- Meet the societal needs
  - Needs-driven development
- Intelligence required for robots
  - Adaptiveness for diverse (dynamic) tasks and indefinite (unknown) environment
- Technological advancement
  - SLAM, SfM, Drones, AI, etc.
- Can intelligent robots be realized only by mounting AI on the robot platforms?
- International Competition & Cooperation

Outline of IFAC 2023

Venue:

PACIFICO Yokohama (All-in-One Venue)

Dates (tentative):

July 9th (Sun) – 14th (Fri), 2023

Vision:

Wa: of Traditional Culture
and Innovative Technology

Control for Solving Societal Problems
and Creating Social Values