Teleoperated manipulation and locomotion for humanoid robots in partially unknown real environments by using task sequences

Rafael Cisneros-Limón

Workshop on Teleoperation of Humanoid Robots
IEEE-RAS International Conference on Humanoid Robots 2019

Outline

- Social demands for humanoid robots
- Goal and approaches
- Motivation
- Teleoperation system
- Effective teleoperated manipulation
- Recent improvements
- Challenges
- Conclusions

Social demands for humanoid robots

Disaster response and decommissioning

- Dangerous for humans
- Tools and facilities thought for humans
- Unknown state and unstructured
- Unreliable communication
  - High level of autonomy required

Large-scale assembly / manufacturing

- Airplanes, boats, buildings, houses…
- Very repetitive, somehow precise tasks
- Unstructured, not completely unknown (CAD)
- Scarce (or null) use of robots
  - Necessity to move inside of the product




Goal and approaches

- Develop a practical robot to perform the required task(s) and succeed! But how?

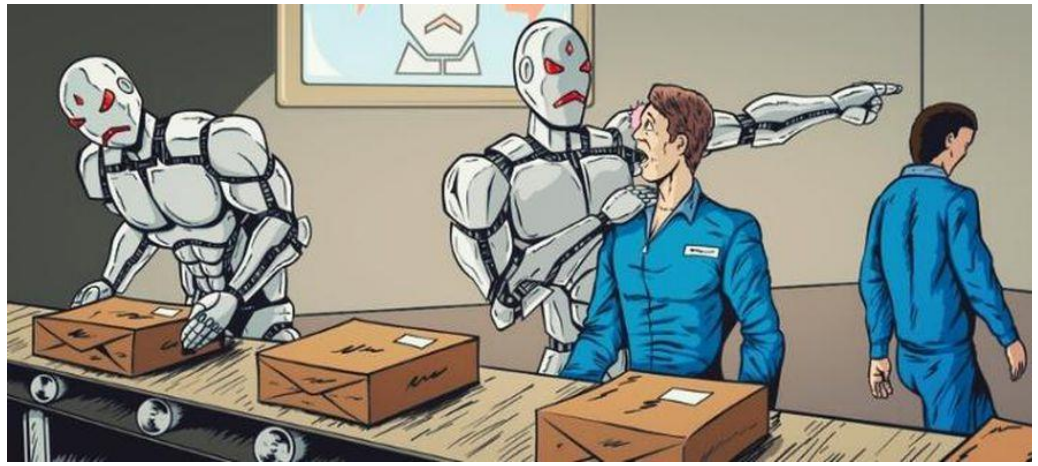
Manual teleoperation

Super Cockpit for HRP-1S

- Not practical, many DOF!
- Expensive, large space
- Highly dependent on skills of the operator

Truly practical solution!

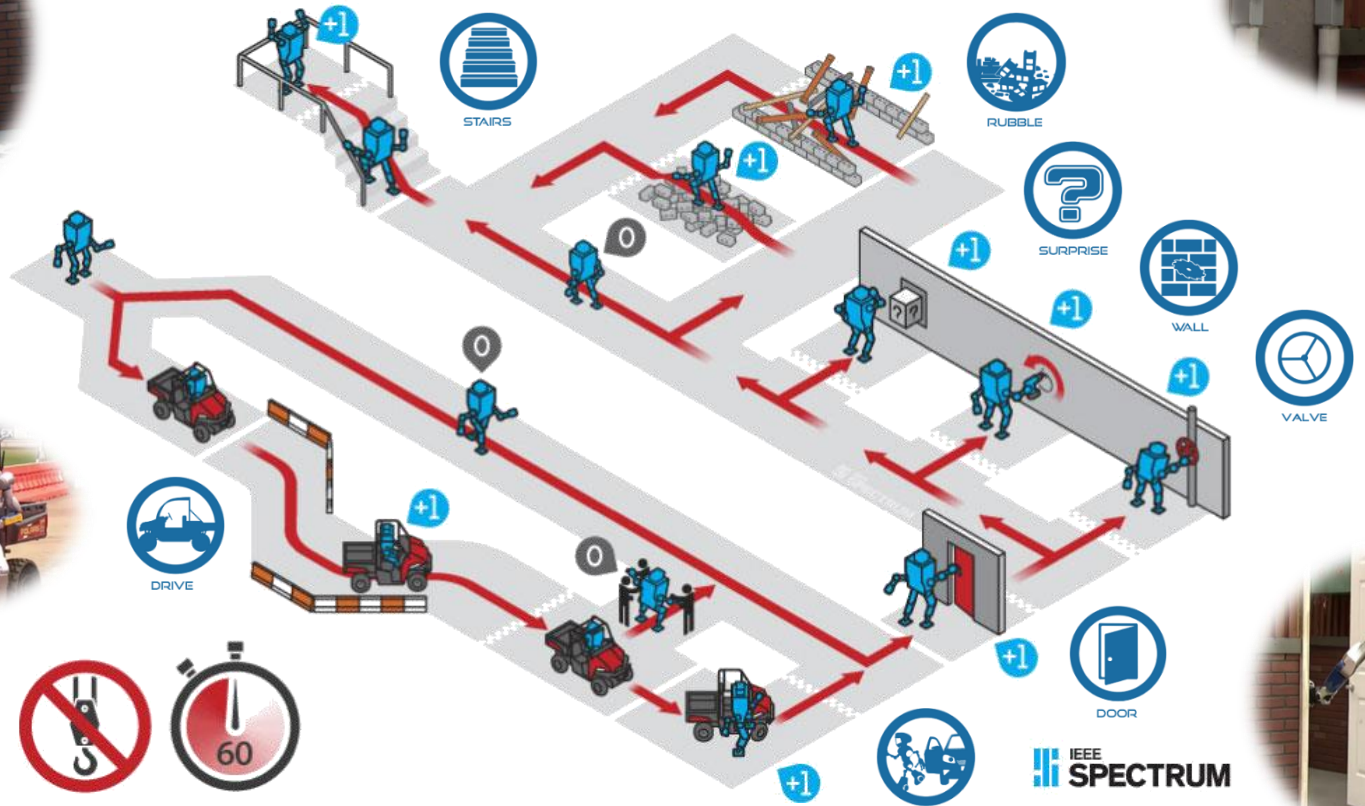
Artificial Intelligence (AI)



- Human out of the loop
- Only low-level tasks
- Difficult to combine them to achieve high-level task

Motivation

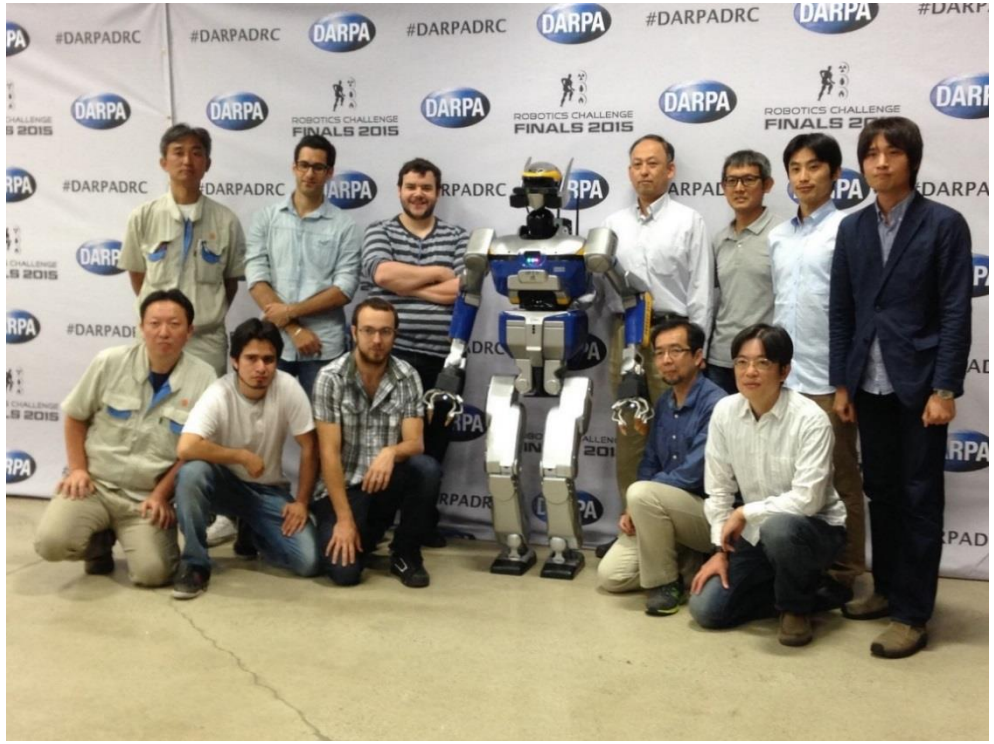
DARPA Robotics Challenge (DRC) Finals



Motivation

DARPA Robotics Challenge (DRC) Finals

- Team AIST-NEDO



Members: HRG (7), JRL (3), Kawada Industries (2)

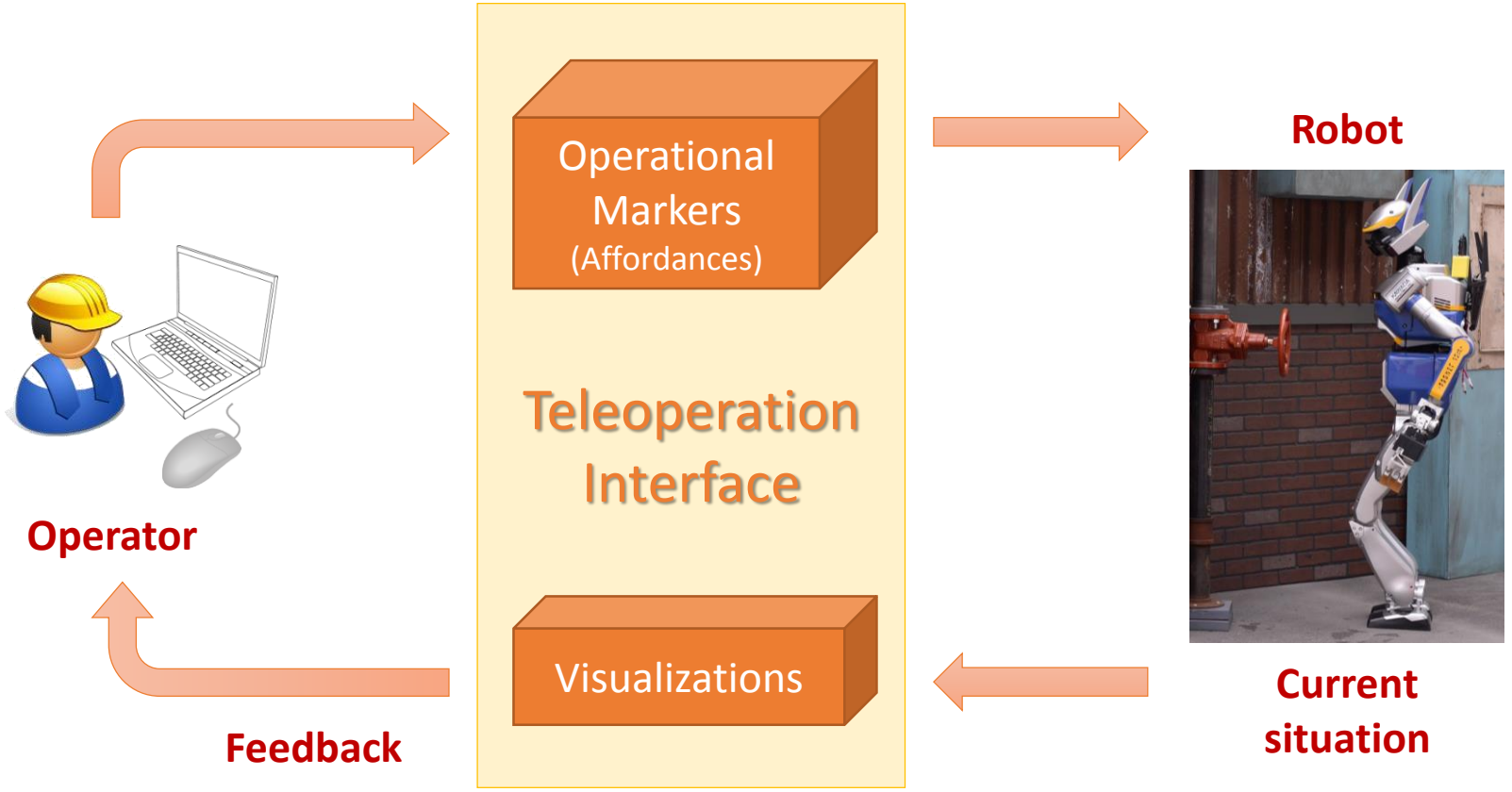
HRP-2改 (2015)
Improved **HRP-2** towards disaster response tasks

		HRP-2改
Dimensions	Height	1,710 [mm]
	Width	629 [mm]
	Depth	355 [mm]
Weight **including batteries**		65 [kg]
D.O.F.		32 D.O.F.
	Head	2 D.O.F.
	Arm	2 Arms × 7 D.O.F.
	Hand	2 Hands × 1 D.O.F.
	Waist	2 D.O.F.
	Leg	2 Legs × 6 D.O.F.

Teleoperation system
Objective

- Practical in disaster response
  - Semi-autonomous behavior
  - Flexibility
  - Low-bandwidth
  - Low-cost availability
- Competitive in DRC
  - Parallel development
    - Simulation

Teleoperation system
Overview



Teleoperation Interface

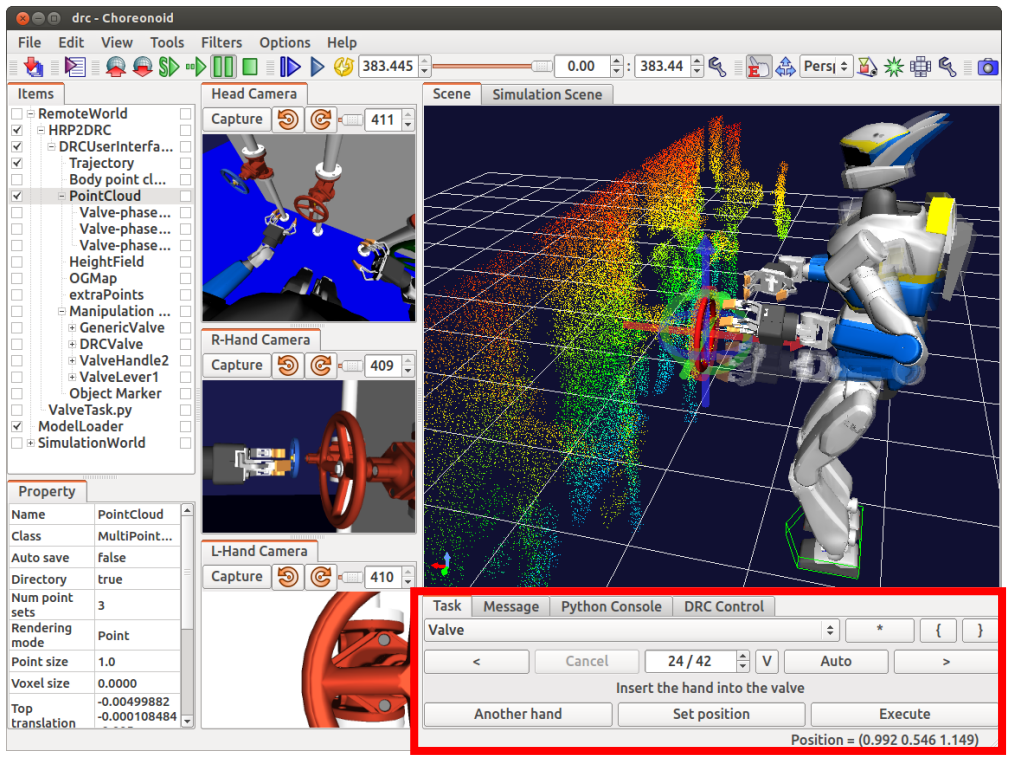
- Choreonoid (www.choreonoid.org/en/)
  - Integrated robotics **GUI** environment
  - Allows users to add **plug-ins**
  - Robot control (**RT-Middleware**)
  - Dynamics **simulation**

[Nakaoka_SII2012]

Teleoperation Interface

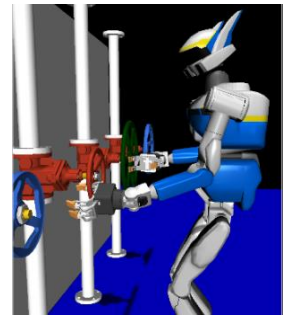
- Teleoperation **plug-in** [Nakaoka_Humanoids2015]
  - Visualizations
  - Operational markers
  - Task sequencer

Operator



Real Robot

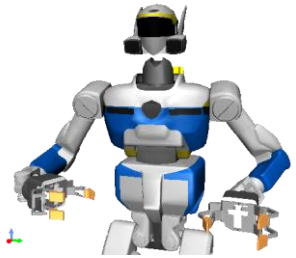
Simulation



Teleoperation interface
Basic components

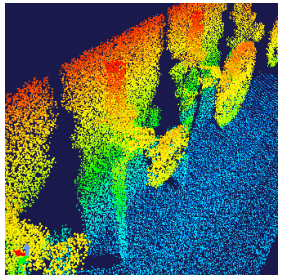
- Visualizations

[Nakaoka_Humanoids2015]



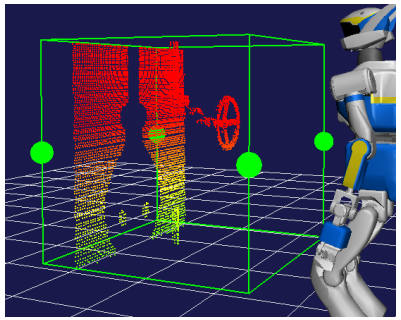
3D model of the robot

Camera Images

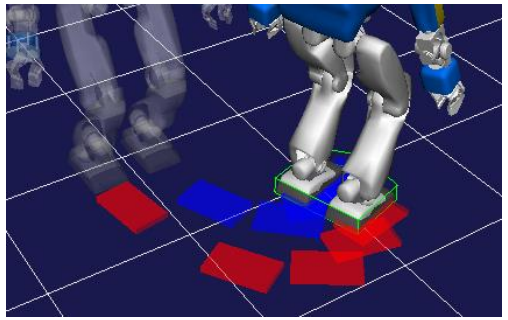


Point cloud

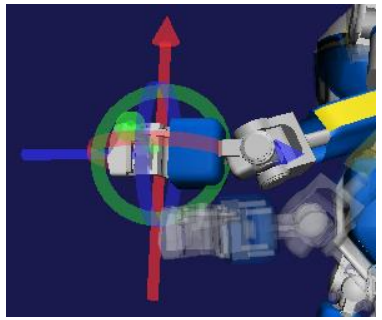
- Operational markers



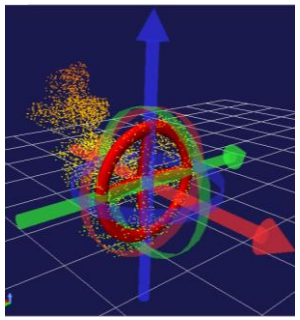
Measurement marker



Walk destination marker

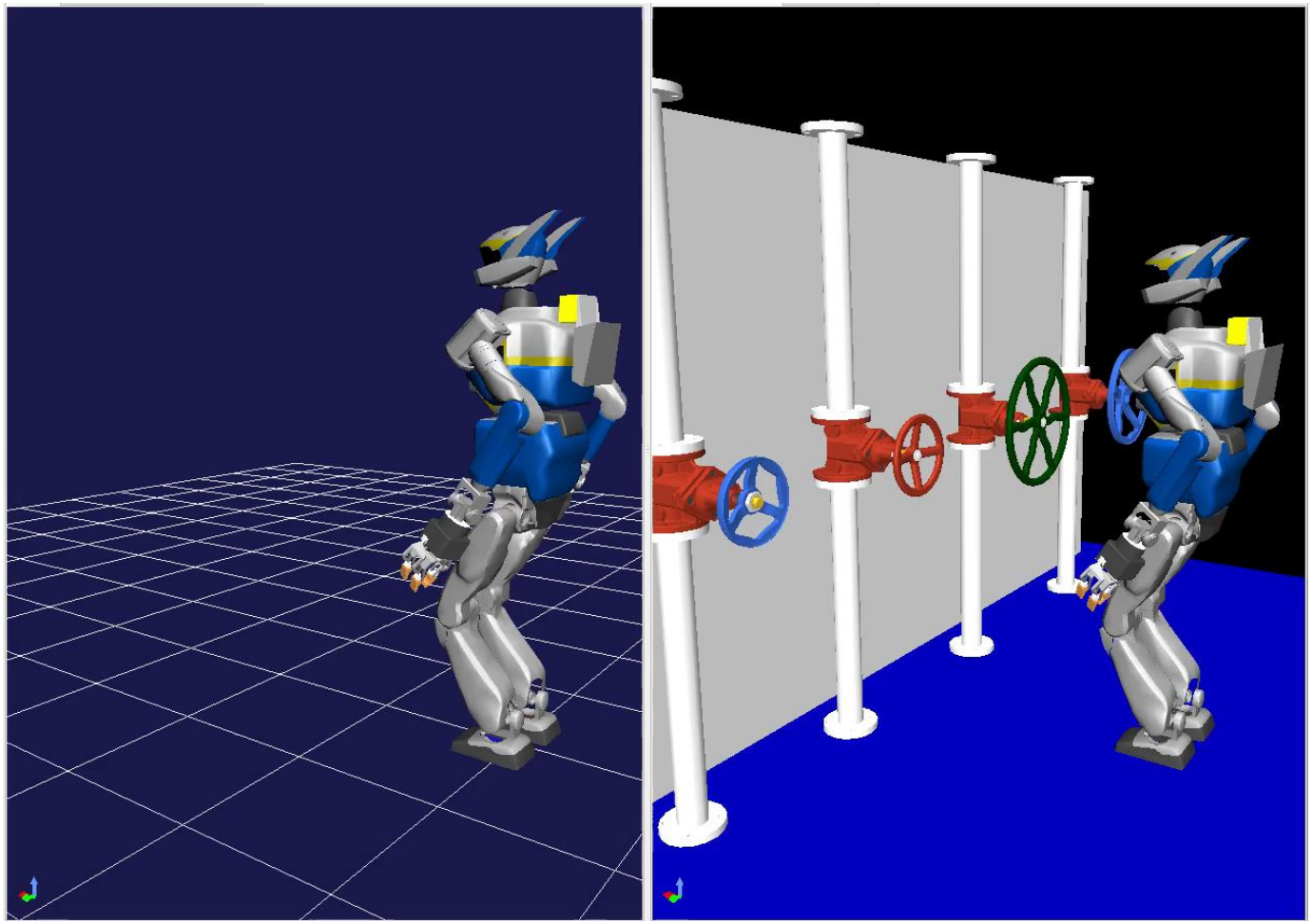


Body part marker

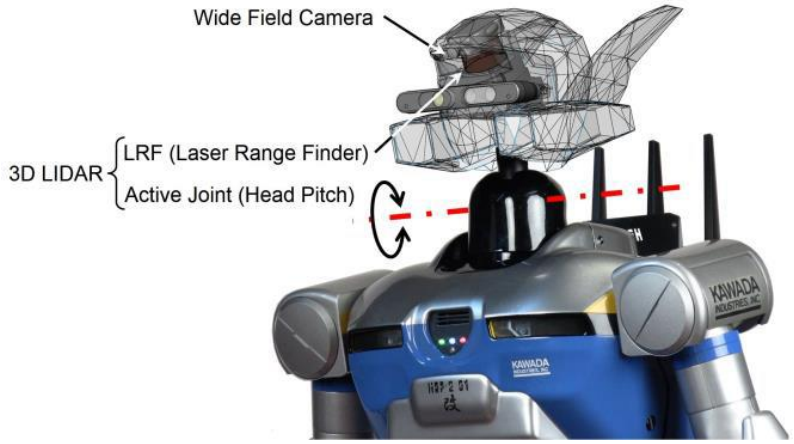


Manipulation marker

Measurement marker

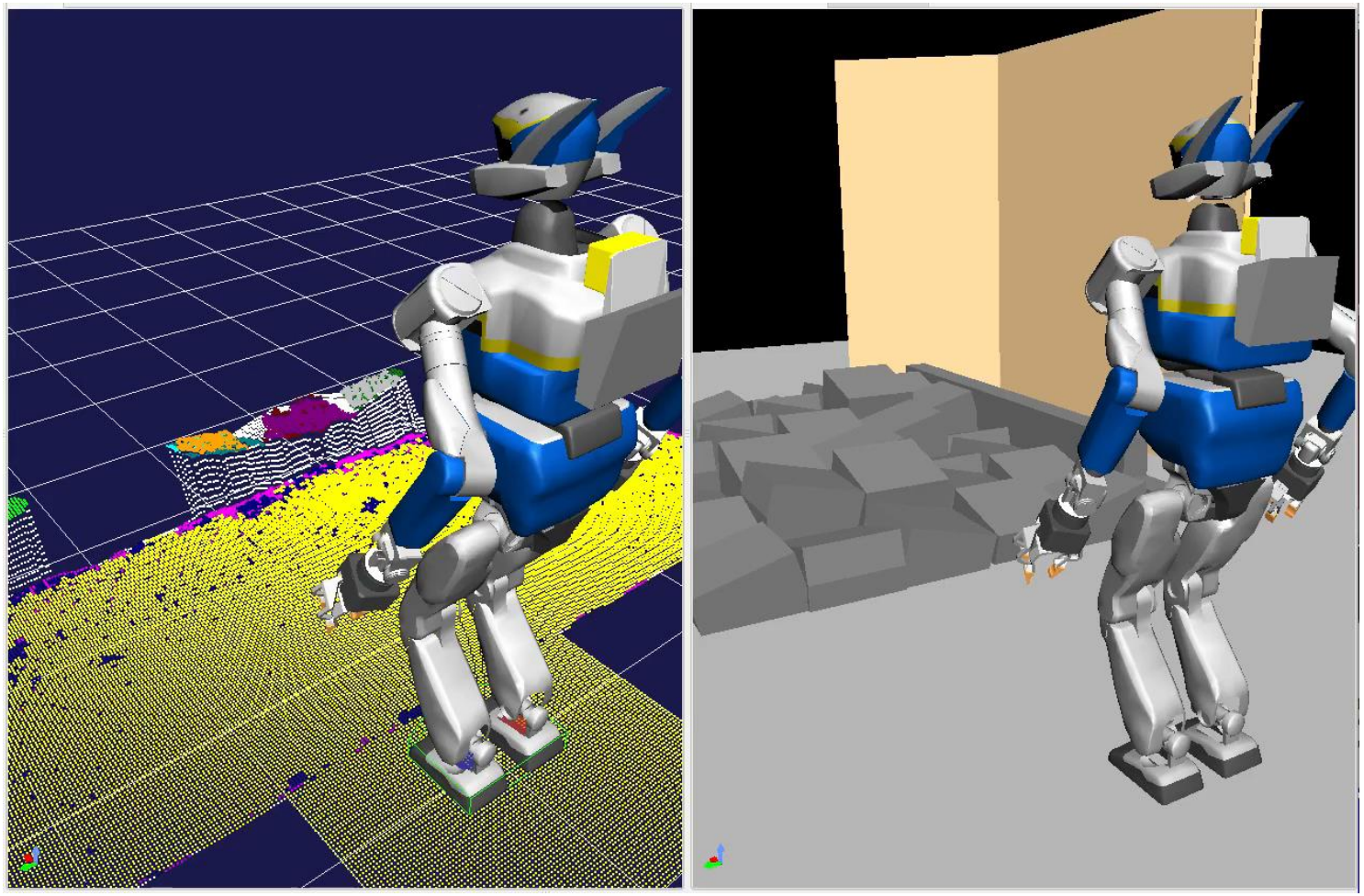


Interface [Nakaoka_Humanoids2015] Simulation



- Calculate span of the head pitch
- Only information of region of interest

Walk Destination Marker



Interface [Nakaoka_Humanoids2015] Simulation

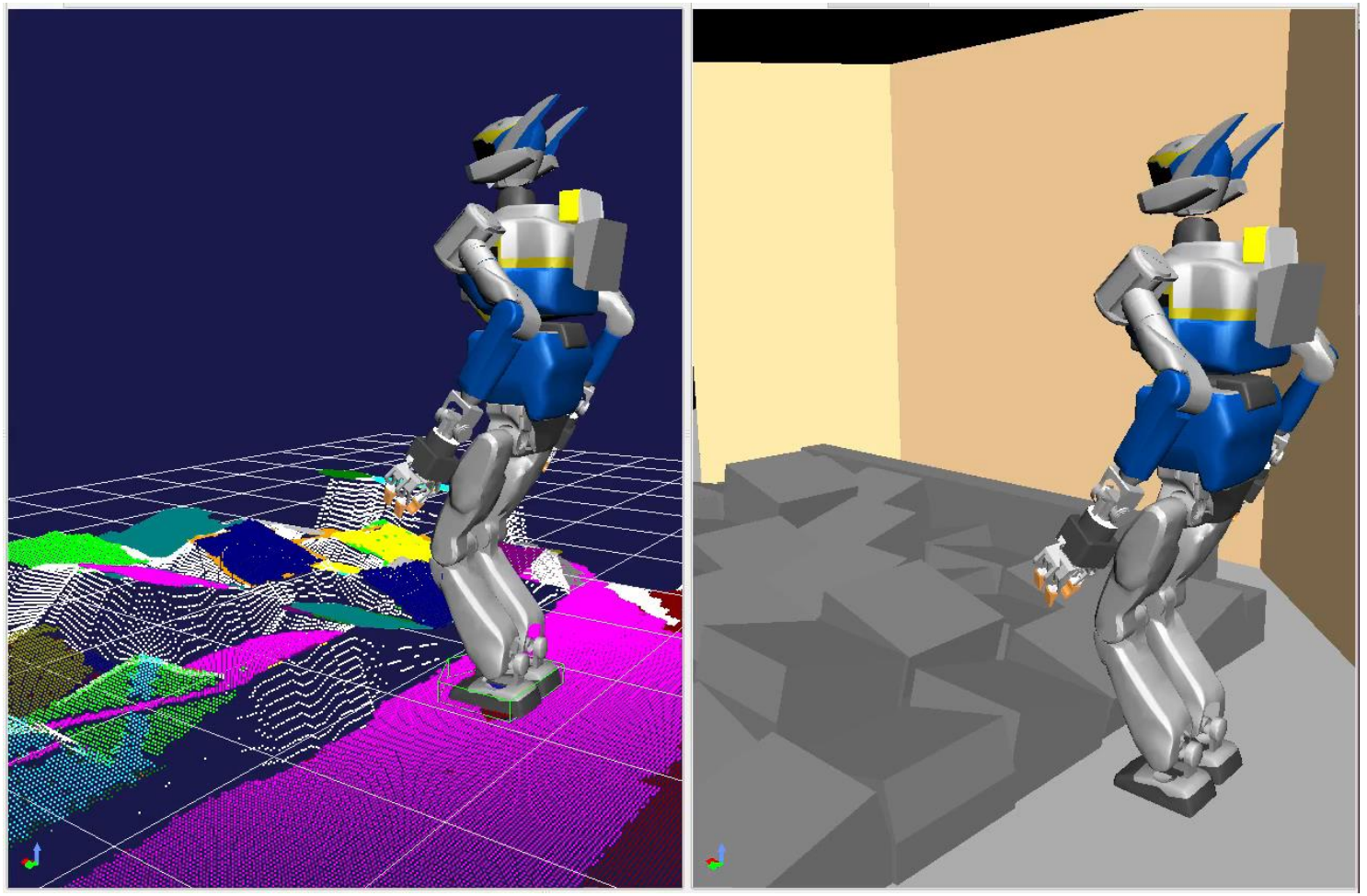
- Footstep planner with collision avoidance

  [Nakaoka_SII2014]

- 3D Occupancy Grid Map (OGM) used to represent obstacles
  - OctoMap

  [Hornung_AuRo2013]

Walk Destination Marker

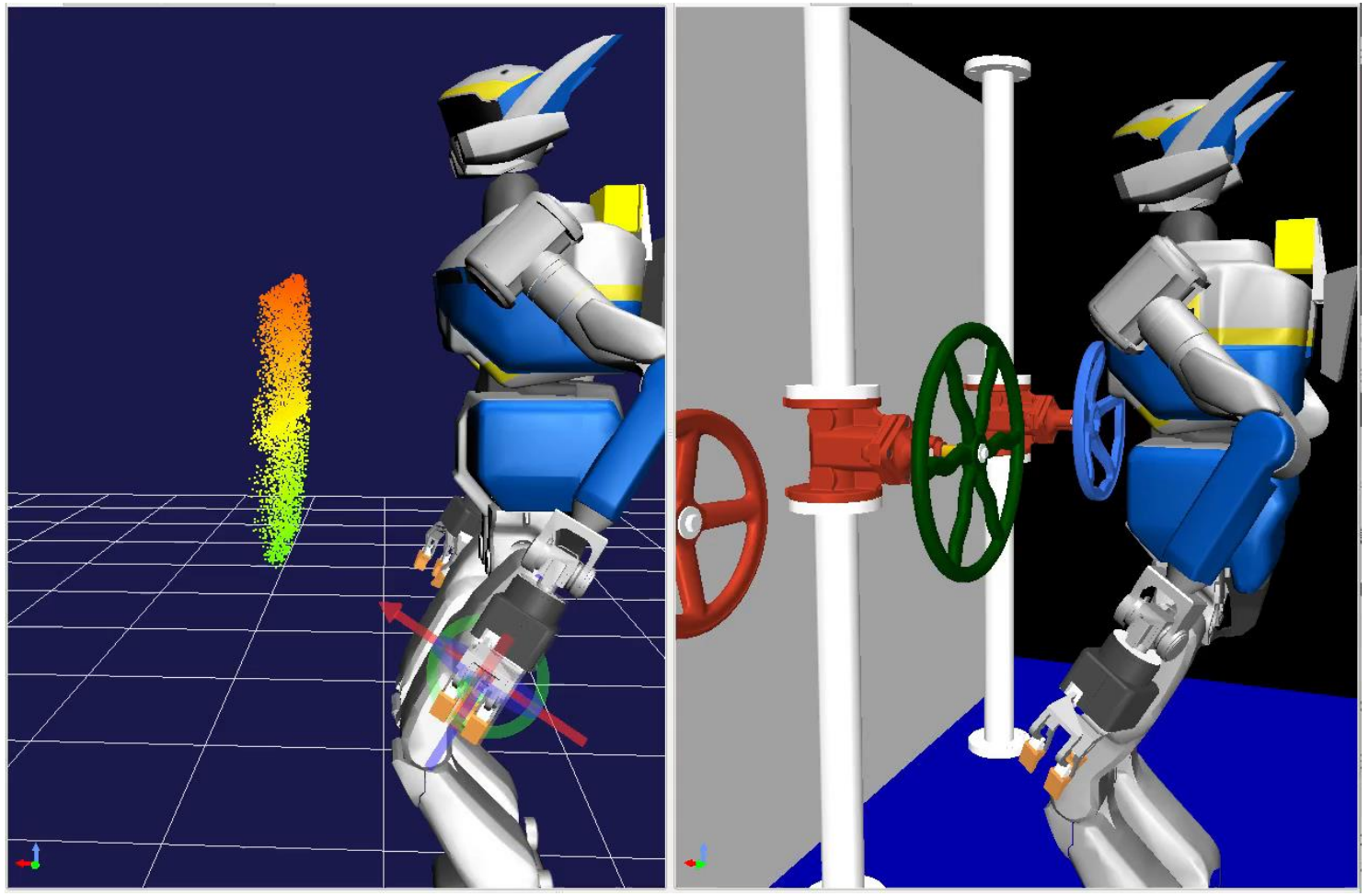


Interface [Nakaoka_Humanoids2015] Simulation

- Height Field (HF)
  - Plane segmentation applied to the point cloud
  - Clusters with similar inclination
- Balance control
  - Divergent Component of Motion (DCM)-based
  - PID of the DCM error
  - Modifies desired ZMP

[Morisawa_SII2014]

Body Part (Hand) Marker



Interface [Nakaoka_Humanoids2015] Simulation

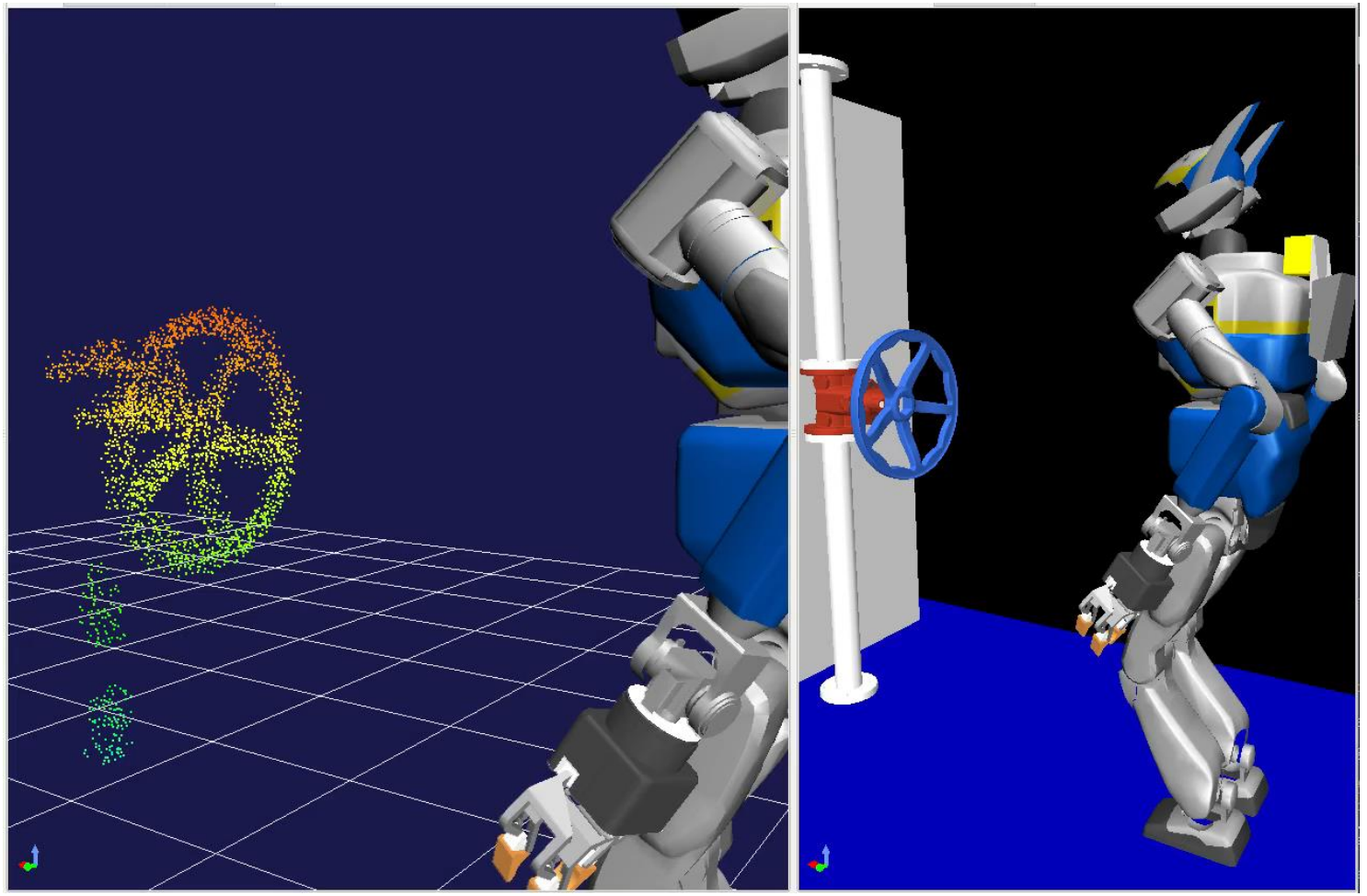
- Reaching pose
  - Prioritized whole-body inverse kinematics

[Kanoun_TRO2011]

- Collision avoidance
  - Small sphere to each point of the point cloud
  - Body parts approximated by spheres and capped cylinders
  - Resulting sequence shown by “ghostly” key postures

[Kanehiro_IROS2012]

Manipulation (Object) Marker

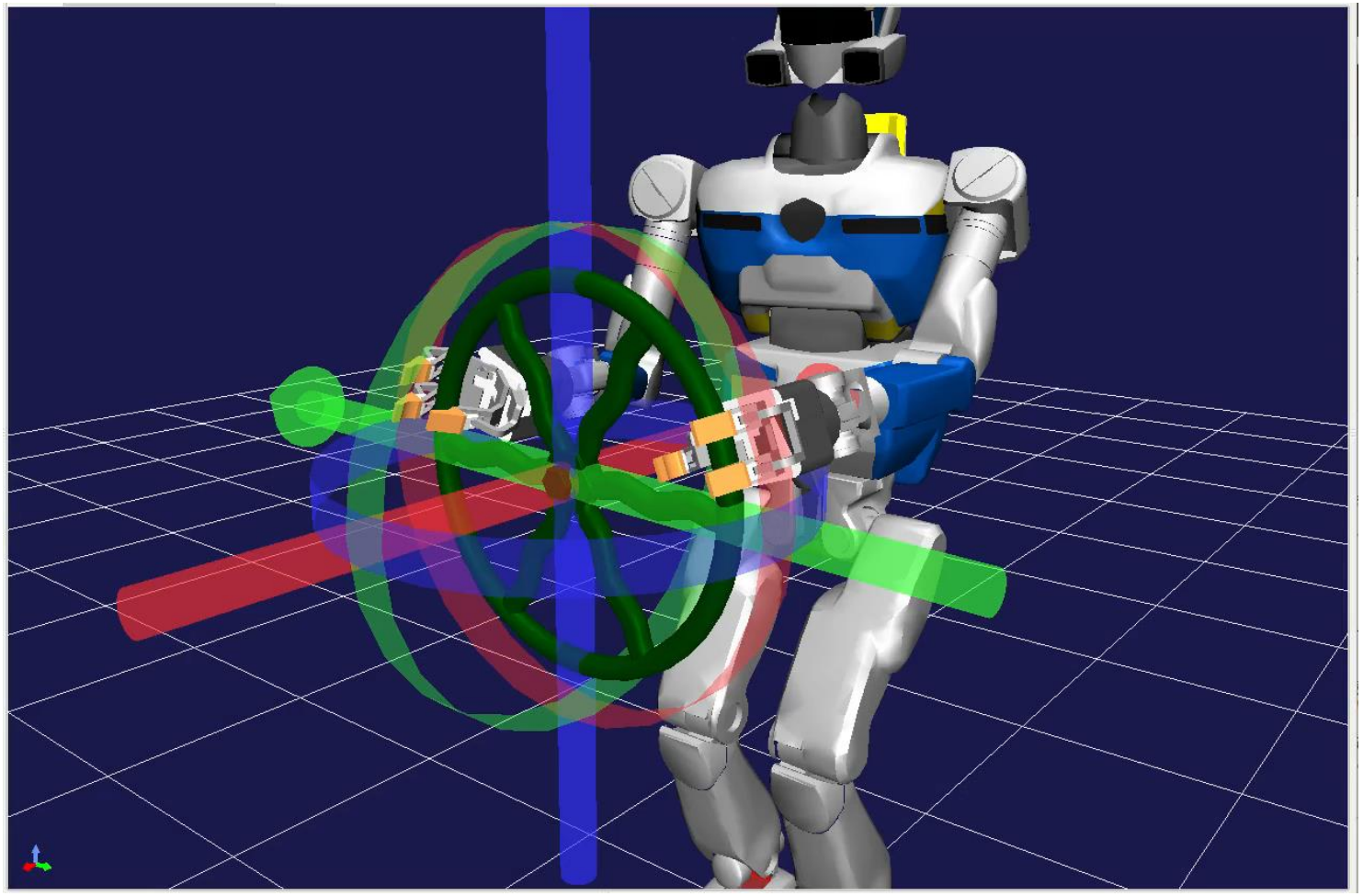


Interface [Nakaoka_Humanoids2015] Simulation

1. **Object representation and recognition**

- Automatic alignment
  - Iterative Closest Point (ICP) algorithm
  - Point Cloud Library (PCL)

Manipulation (Object) Marker

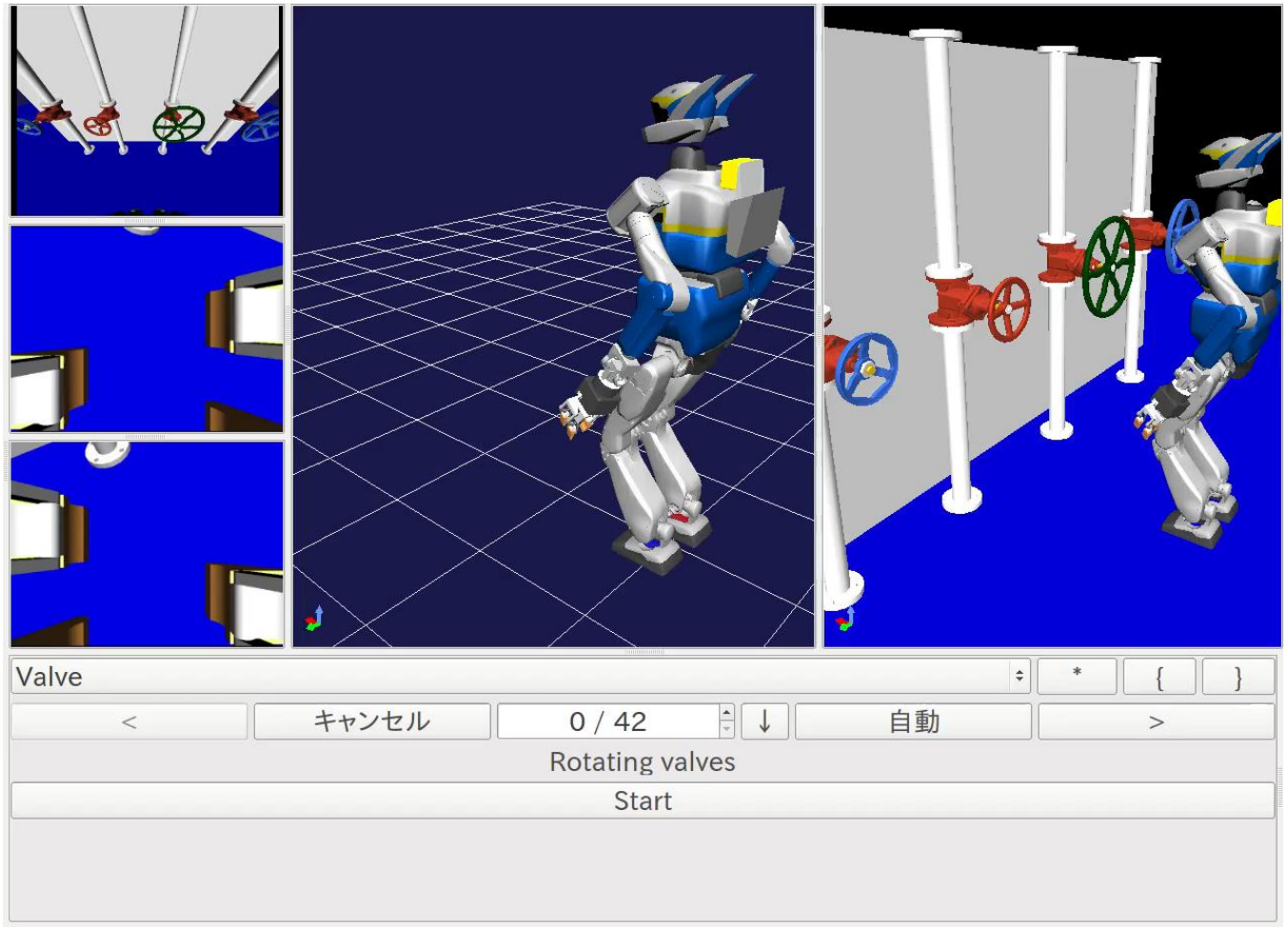


Interface [Nakaoka_Humanoids2015]

2. Generation of hand trajectories

- Manipulation
  - One hand or both
  - Planned sequence shown by “ghostly” key postures

Task Sequencer

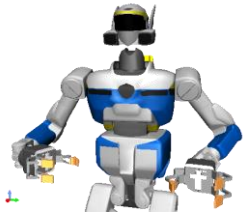


- Interface for **simplifying** and **automating** task operations
  - Reduce burden on the operator
- Characteristics:
  - Stepwise execution (or “auto”)
  - Manual intervention
  - On-the-fly updating

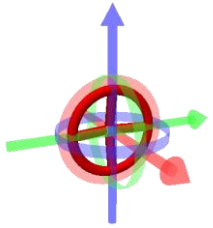
Interface

[Nakaoka_Humanoids2015], [Nakaoka_ARSO2017]

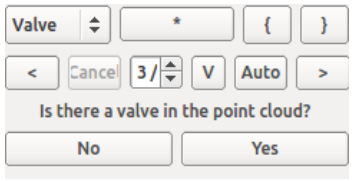
Communication System



Robot status



Marker status



Marker status, Commands

Operator

Choreonoid (Front-end)

Input
Visualization

Operator Control Station (OCS)

Continuous
bidirectional
9600 bps

Degraded
unidirectional
300 Mbps

Choreonoid (main)

Recognition
Planning

Field Computer (FC)

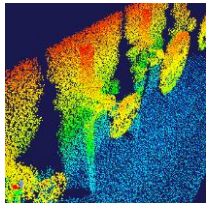
High-speed
wireless
connection

Robot

Onboard
Computer

[Nakaoka_Humanoids2015] [Cisneros_AR2016]

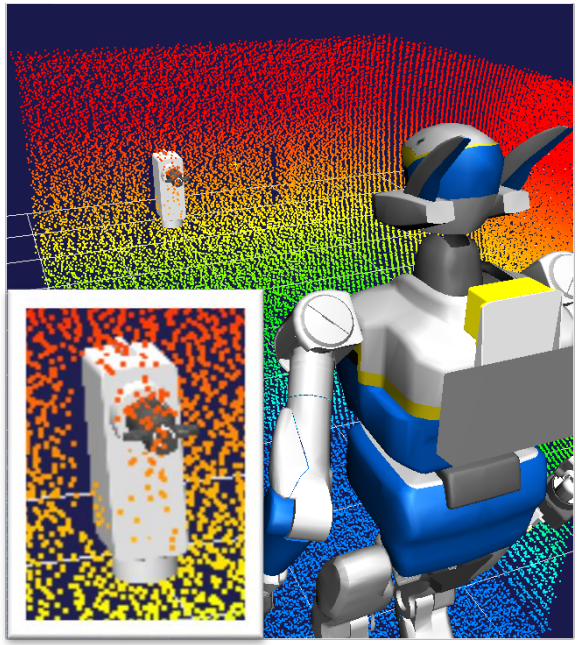
Camera
images



Point
cloud

Effective Teleoperated Manipulation

- Problems
  - Partially unknown environment
  - Teleoperated with limited communication
  - Noisy sensing (inaccurate point cloud)
  - Controller error (steady-state error)
  - Race against time
- Effective and practical general strategy
  - Fast semi-automatic identification
  - Visual information for fine refinement
  - Force sensors to correct identification
  - Task-based motion parametrization



Effective Teleoperated Manipulation
Problems

- **Race against time**
  - A huge bottleneck to improve the speed is actually the time spent by the operator

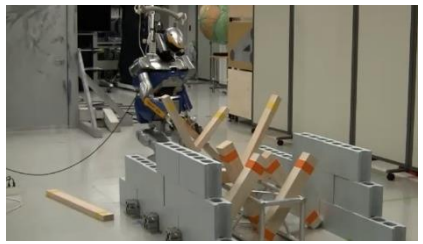


TABLE II: Teams that completed the plug task.

Team	Place	Task time	Eff. time	Insert. adjust.
KAIST	1	11:01	2:18	14
IHMC Robotics	2	6:31	2:32	8
Tartan Rescue	3	18:33	3:21	17
NIMBRO Rescue	4	8:16	2:29	16
WPI-CMU	7	5:07	1:42	7
AIST-NEDO	10	16:34	1:34	3

[Cisneros_Humanoids2015]

TABLE II: Time analysis of the Debris Task.

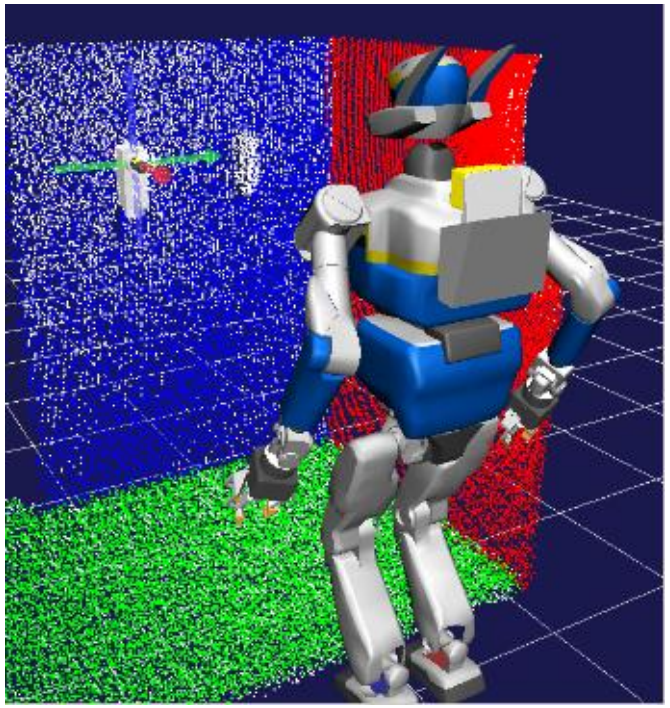
Concept	Tot. time [min:s]	Type	Time p/operation [s] μ	σ	min	max
Robot motion	6:15.0	Measurement	5.8	1.3	4.1	8.0
		Walking	6.6	2.8	3.1	11.9
		Upper-Body	3.4	1.9	1.0	8.6
Computer processes	1:59.4	Alignment	4.0	4.5	0.4	16.7
		Others	2.3	0.9	0.2	5.3
Used by operator	6:06.2	Identification	5.1	1.1	3.5	7.5
		Walk dest.	14.3	6.5	8.8	26.1
		Others	3.1	2.2	0.4	9.7

[Cisneros_Humanoids2016]

Effective Teleoperated Manipulation

Practical strategy

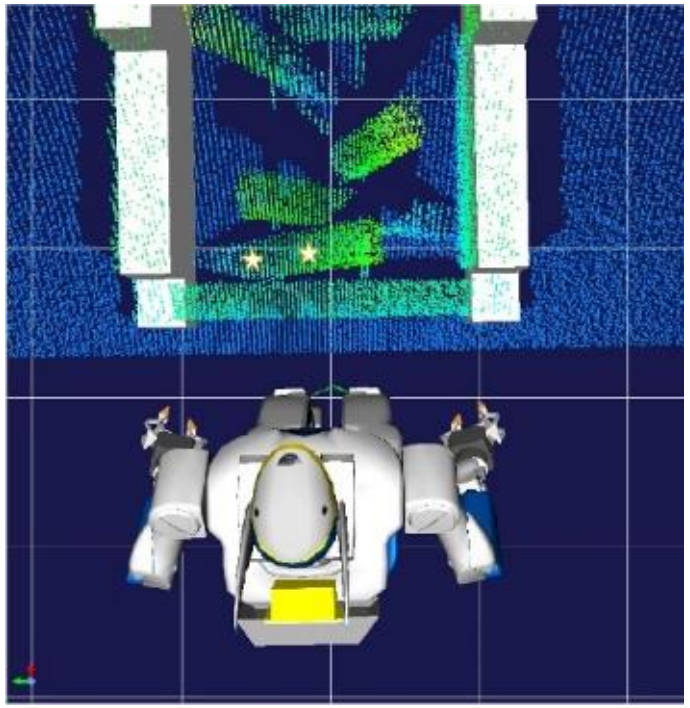
- **Fast semi-automatic identification**
  - User input that requires no precision → fast
  - Initial guess using *a priori* knowledge
  - Automatic refinement
    - ICP



Plug task

Socket-plug identification

[Cisneros_AR2016]



Debris task

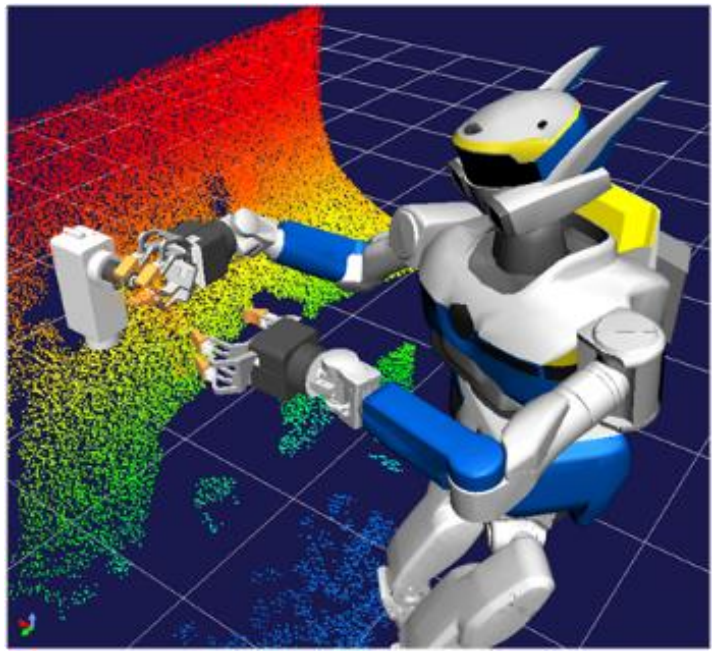
Debris identification

[Cisneros_Humanoids2016]

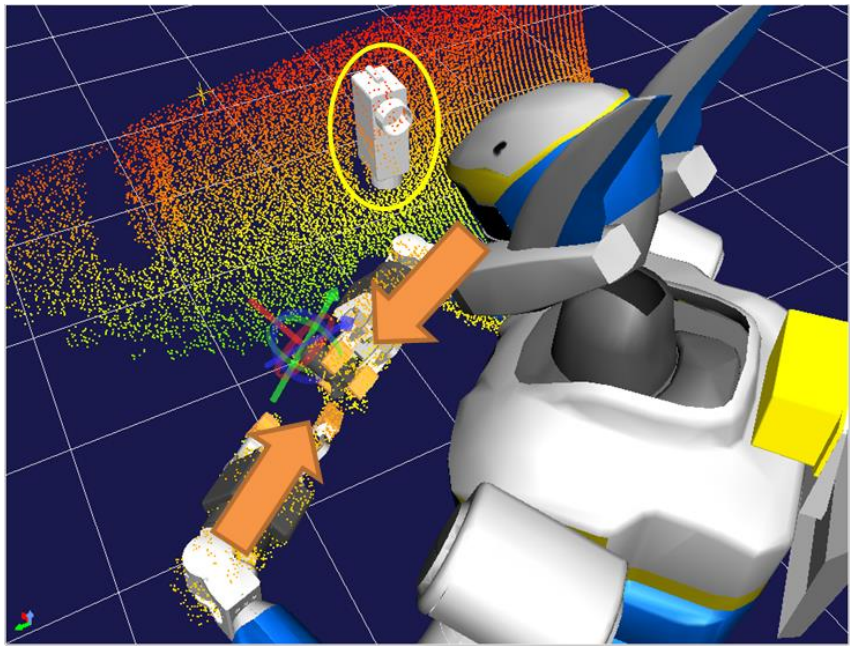
Effective Teleoperated Manipulation

Practical strategy

- **Visual information for fine refinement**
  - Pre-reaching
  - Use camera information only for fine refinement



Plug task
Check alignment



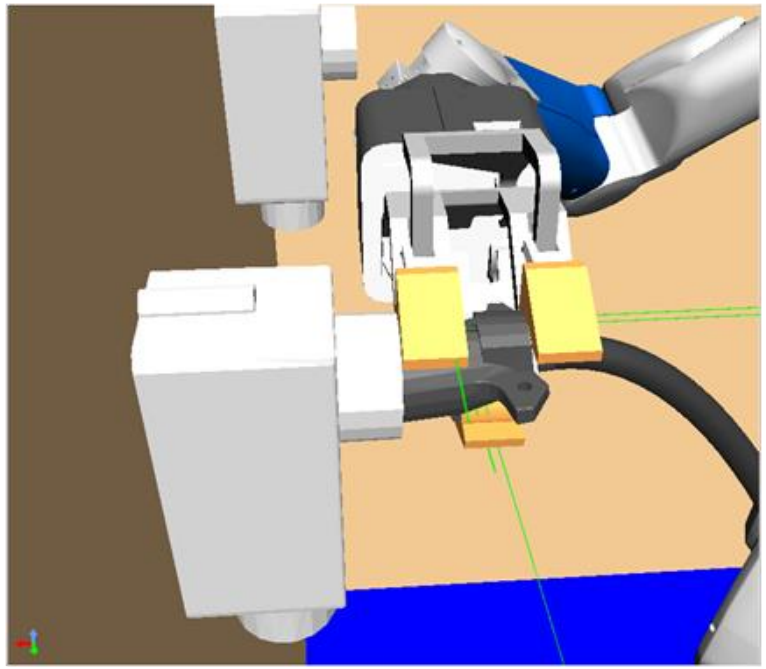
Plug task
Check relative pose of the plug

[Cisneros_AR2016]

Effective Teleoperated Manipulation

Practical strategy

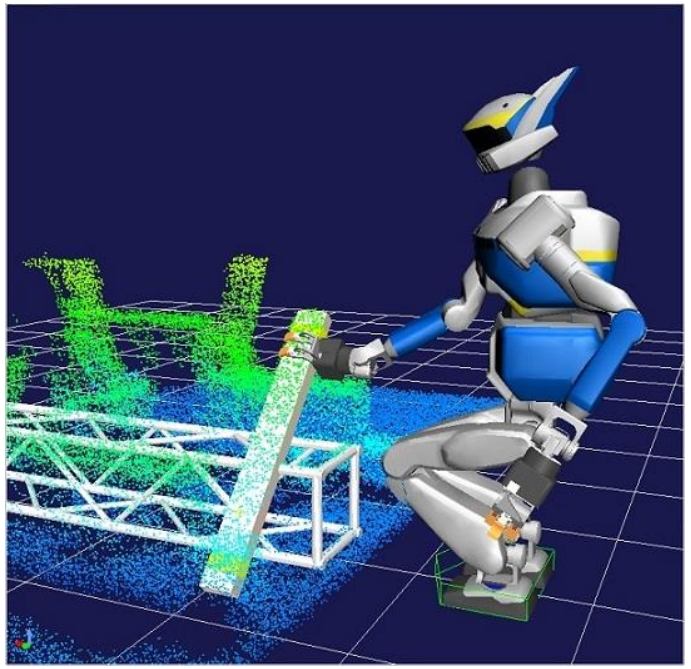
- **Force sensors to correct identification**
  - Stop until touching (sensed force)
  - Separate if required
  - Recalculate task state



Plug task

Grasp small plug

[Cisneros_AR2016]



Debris task

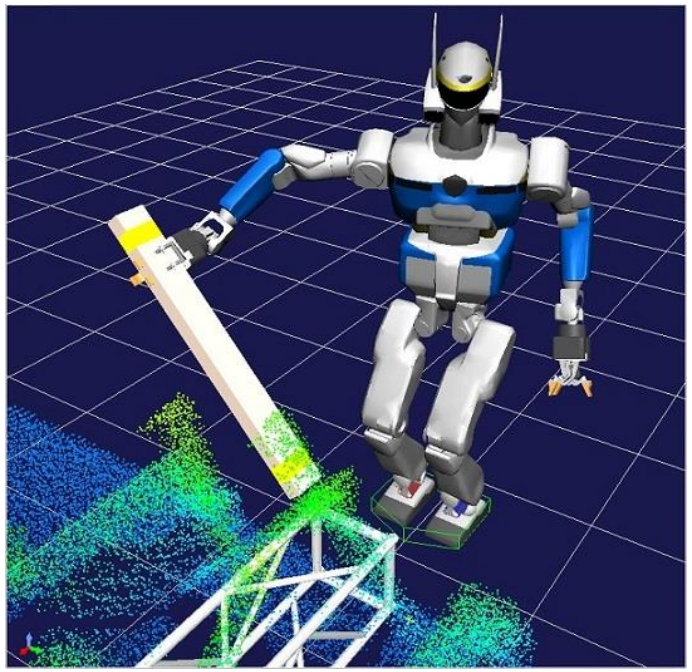
Approach until touching

[Cisneros_Humanoids2016]

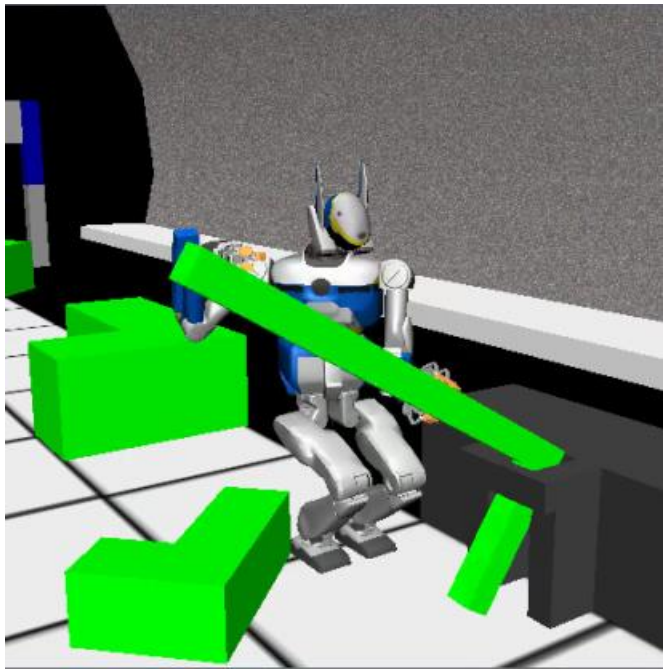
Effective Teleoperated Manipulation

Practical strategy

- **Task-based motion parametrization**
  - Calculate motion based on current state to perform sub-task automatically
  - Reduce burden for operator



Debris task
Simple removal



Debris task
Complex removal

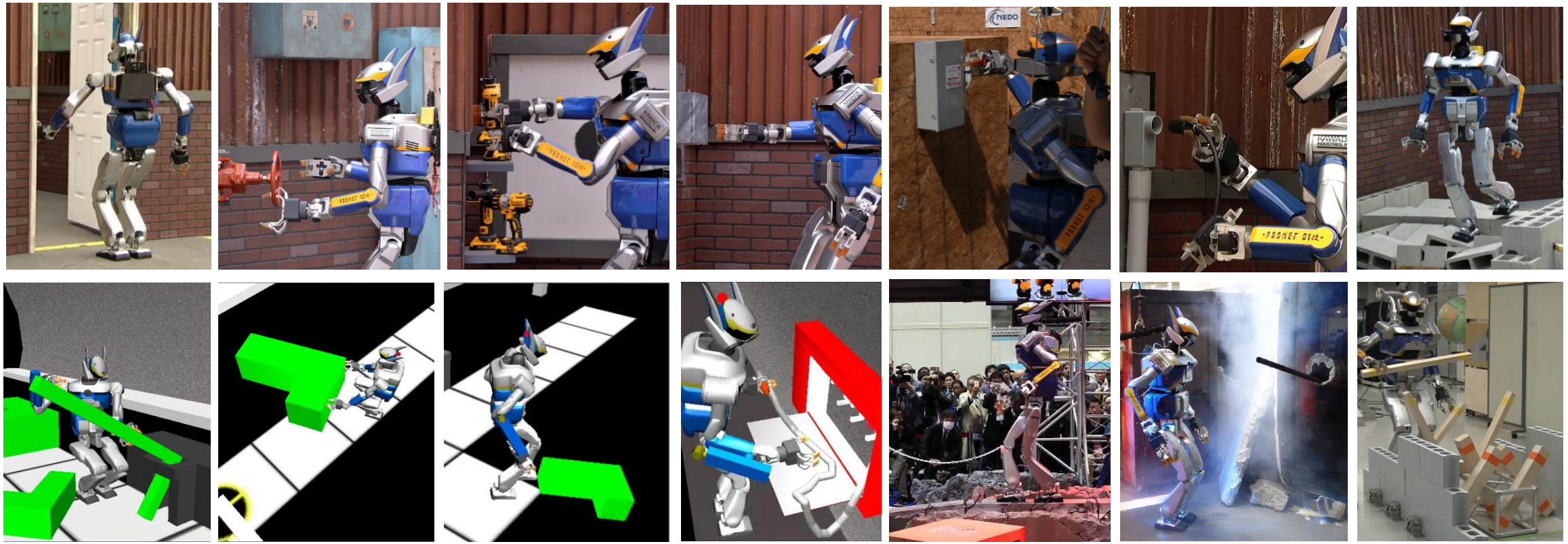
[Cisneros_Humanoids2016]

Effective Teleoperated Manipulation

Examples

Effective Teleoperated Manipulation

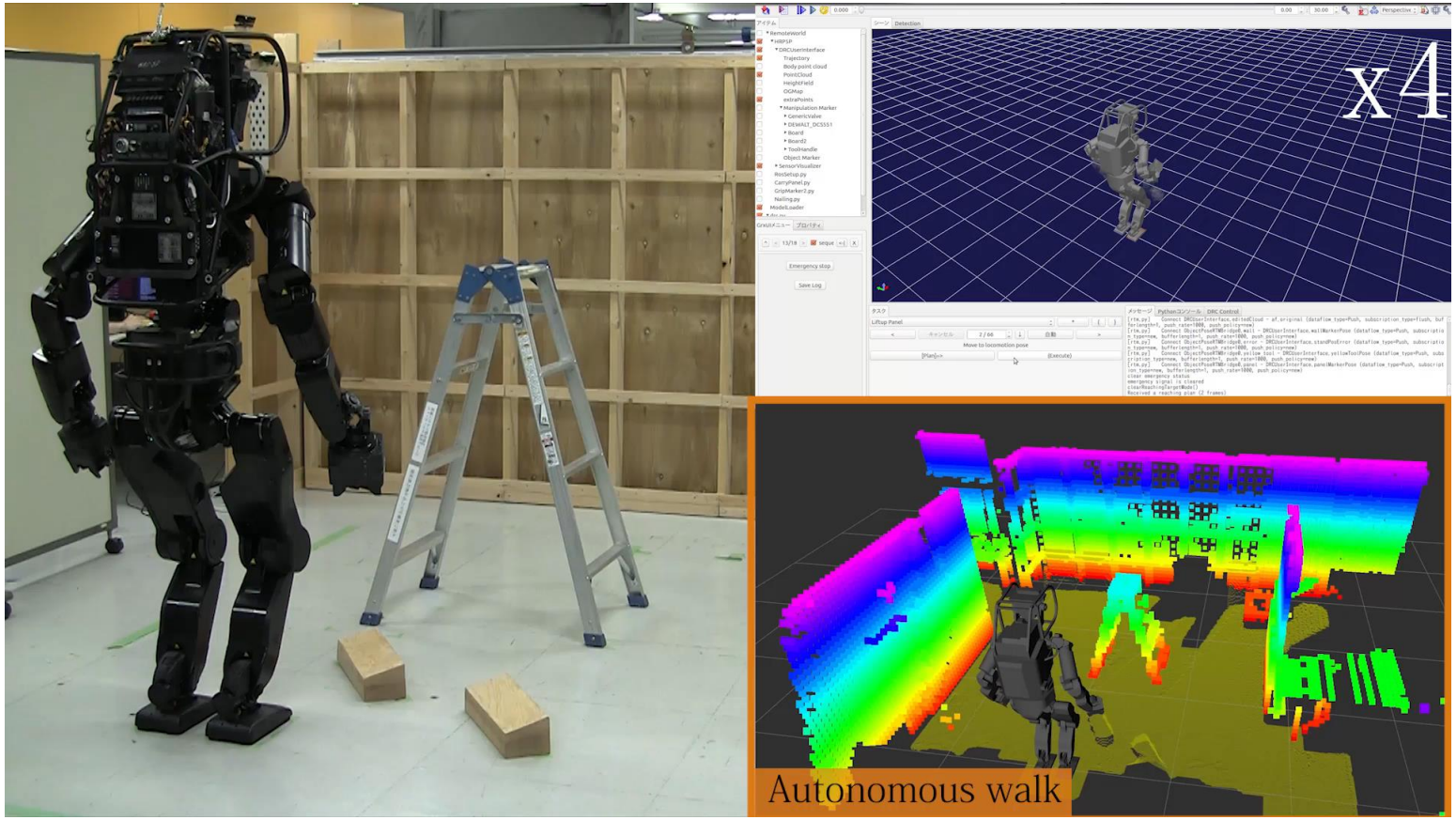
Examples



Perception based locomotion system

Improved semi-autonomous teleoperated locomotion

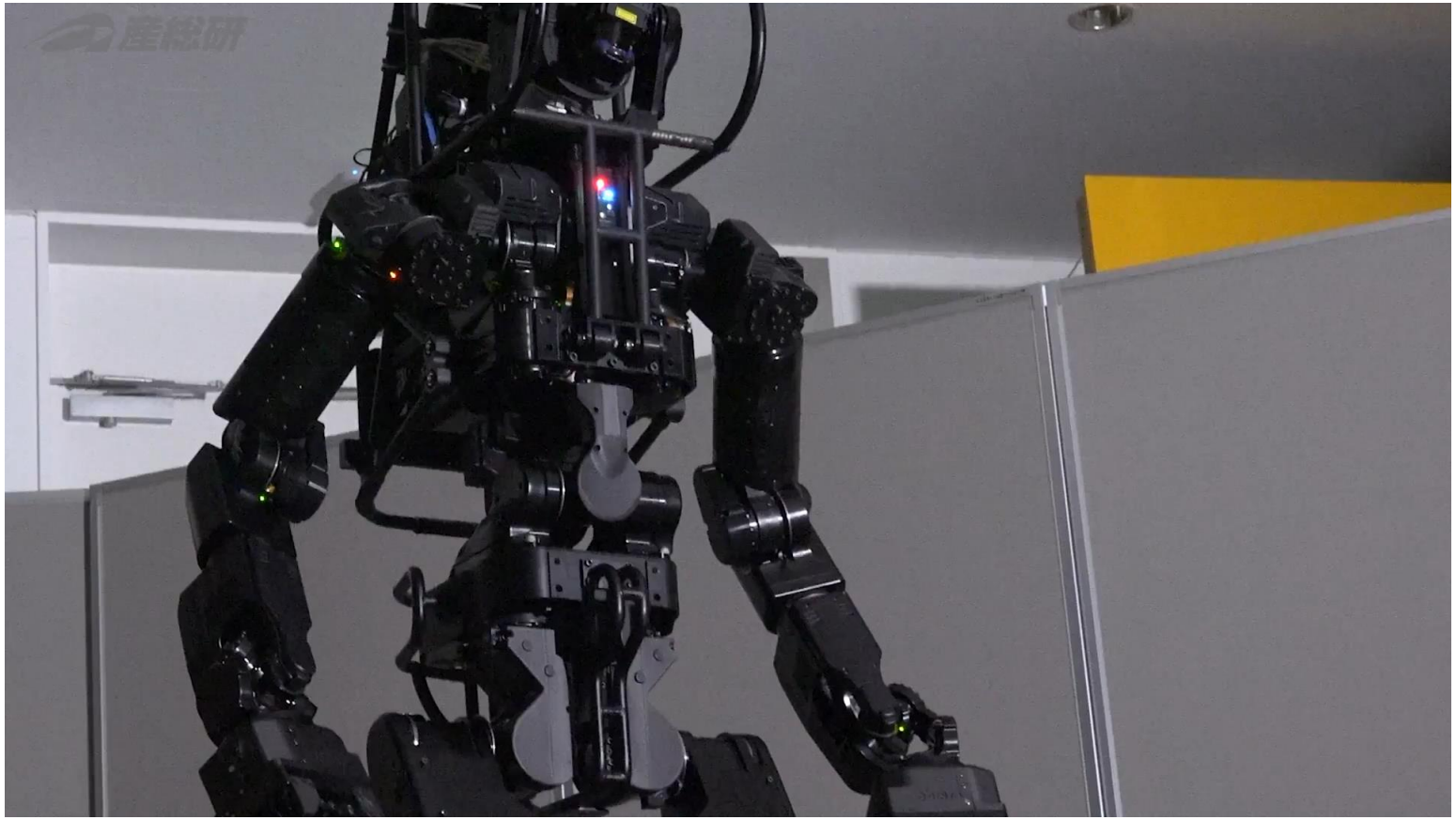
- **Localization**
  - Odometry fusion based on a particle filter
- **Environmental memorization**
  - Occupancy grid map
    - Collision avoidance
  - Height field
    - Landing state
    - Waist height estimation



[Kumagai_IROS2018]

Plaster board installation by HRP-5P

- Our newest demo
- The plaster board is 11 kg (not easy to carry)
- We have been working on improving the speed
  - Perception
  - Automating the task
  - Approximately 8 min (still 8 times slower than a human)



https://www.youtube.com/watch?v=ARpd5J5gDMk

Challenges

- More transparent interface
  - Allow to input values
- 3D measurement robust to lightning conditions
  - Noise leading to unexpected collisions
- More advanced recognition techniques [WIP]
  - We can only recognize preloaded objects
- Simulation of more complex environments
  - Discrepancies between simulation and experiment
- Fault recovery
  - Although possible, difficult to overcome unexpected situations

Conclusions

- Our teleoperation system is practical, although it needs improvement
  - Intensively used to develop tasks
- Autonomy
  - Achieved by the task sequencer
  - Depends on the object recognition capability
- Flexibility
  - Combination of task sequencer and interactive manual operations
- Low-bandwidth
  - Small amount of data (except for the images and point cloud)
- Low-cost availability
  - Only PCs, allowing parallel development

Questions?