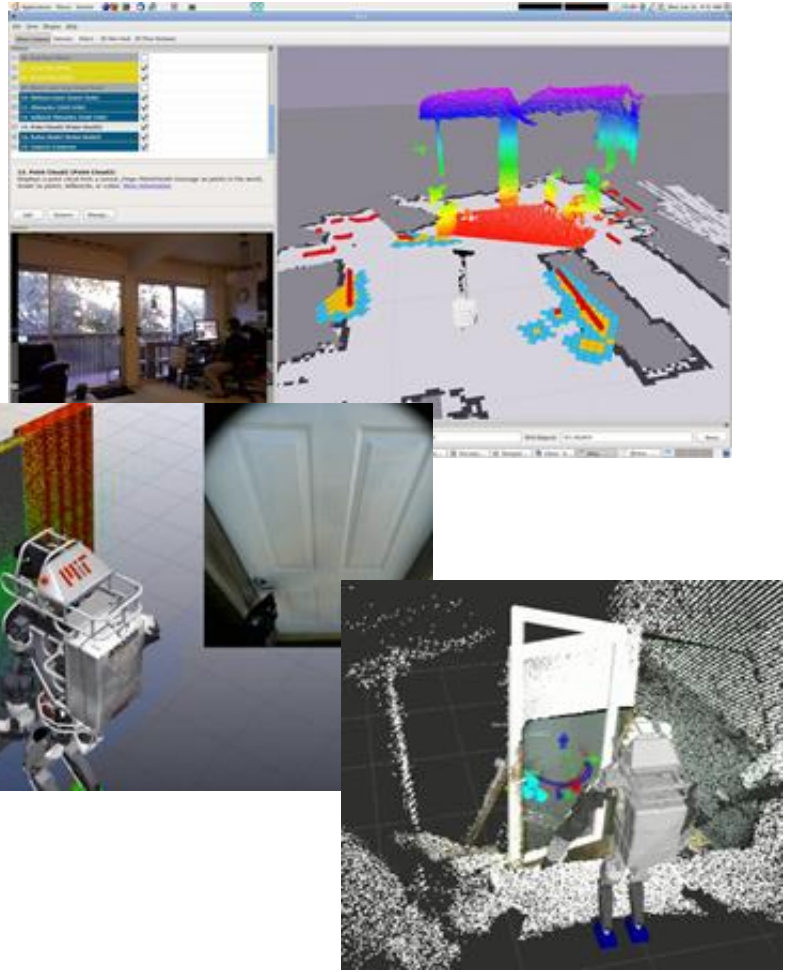
PHARAOH: An English-language procedure-based application framework for full or semi-autonomous robot operations

ROS-I Americas 2021
Stephen Hart (swhart@traclabs.com)

Rob Burridge presenting
TRACLabs, Inc.

Motivation

- Recent advances in interactive 3D user interfaces have revolutionized how humans program and work with robots to perform tasks.



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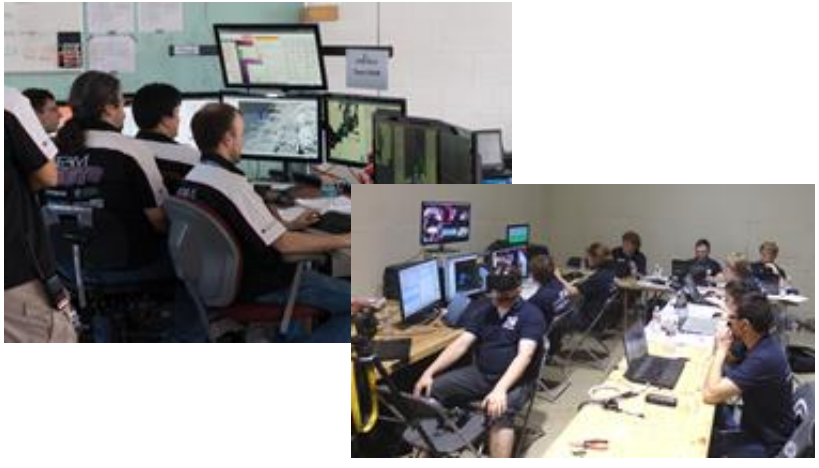
- Unfortunately, these “state-of-the-art” systems typically require a level of specialization that has kept these tools in the laboratory and research community.



vs.

Motivation

- Recent advances in interactive 3D user interfaces have revolutionized how humans program and work with robots to perform tasks.

- Unfortunately, these “state-of-the-art” systems typically require a level of specialization that has kept these tools in the laboratory and research community.

- Further, there is a vast mismatch between these tools and the traditional tools that direct humans to perform tasks or operate equipment during field operations.

TISSUE EQUIVALENT PROPORTIONAL COUNTER - ALARM PROCEDURE I
(MED OPS/2R - ALL/FIN) Page 1 of 6 pages

GROUND COMMUNICATIONS AVAILABLE

NOTE
1. The TEPC alarm is locally silenced using a switch on the Spectrometer. TEPC dose rate information may be read from the TEPC display.
2. The alarm LED will flash as long as the dose rate exceeds the setpoint. When the dose rate goes below the setpoint, the LED will go dark. There is no audible indication that the alarm condition has cleared.

1. Acknowledge Alarm
   Verify alarm LED – Flashing Red
   √Audio Alarm sw – 'OFF'
   Verify dose rate reading > 5 mrads/min.
2. Notify MCC-H
   Time of alarm.
   Initial alarm reading.
   LED status during alarm.

NOTE
1. The radiation ground support team is the primary means of assessing the radiation environment. N need to take special actions will be confir
2. Note the time when the alarm clears. Nor condition will clear in less than 15 minutes

3. Follow ground instructions.
4. When alarm clears
   Note the time when the alarm clears.
   Reset alarm.
   Verify alarm LED – Dark
   √Audio alarm sw – 'On'

NOTE
Transit through high radiation zones resulting solar proton events may occur at ~45-minute Alarm reinitiation may result from any subseq until the event subsides.

5. Acknowledge and clear alarms as they occur a Note timing and trends as directed in steps 1 a

23 AUG 00 175

RIGGING EQUIPMENT SECTION 1B

SAFETY

- Slings & Rigging Inspected PRIOR TO USE
- Objects in eyelets of synthetic slings DO NOT exceed 1/3 the length of the eyelet
- Objects in eyelets of wire rope slings DO NOT exceed 1/2 the length of the eyelet
- The D/d Ratio of any attached rigging equipment to the Wire Rope is 25:1
- The included Angle of the slings attaching to the hook DOES NOT exceed 90°
- Sharp Edge Protection
- Shield and protect slings and rigging against chemical exposure and extreme heat
- Safety notified 5 days prior to all lifts

SLINGS

- SYNTHETIC
- CHAIN
- WIRE ROPE
- WIRE MESH

SLING CONFIGURATION & CAPACITY

- Vertical: _____ [Vertical is within 0° to 5° to be 100%]
- Basket: _____ [Wire Rope Slings require D/d of 25:1]
- Choker: _____ [Starting @ approximately 75% of Vertical]

Number of Slings: _____

- 2 Leg Bridle
- 3 Leg Bridle
- 4 Leg Bridle
- More than 4 Leg Bridle
- Tag Line

SHACKLES

- Shackles are at 100% of capacity when slings are from 0° to 5° of vertical
- Shackles are at 70% of capacity when the included sling angles are from 12° to 90° of vertical
- Shackles are at 50% of capacity when the included sling angles are from 91° to 120°

Number of Shackles: _____
Shackle Capacity: _____

EYEBOLTS

- Non-shouldered eyebolts are at 100% of capacity when the slings are from 0° to 5° of vertical
- Non-shouldered eyebolts are NOT recommended with sling angles more than 5° from vertical
- Shouldered eyebolts are at 100% of capacity when the slings are from 0° to 5° of vertical
- Shouldered eyebolts are at 70% of capacity when the sling angles are from 6° to 45° of vertical
- Shouldered eyebolts are at 50% of capacity when he sling angles are from 46° to 90° of vertical

- Shouldered
- Non-shouldered

Eyebolt Capacity: _____ (lbs.)

HOOK

Included angle to the hook DOES NOT exceed 90°

- Latch required
- Latch removed in the open position
- Latch removed in the closed position

MASTERLINK

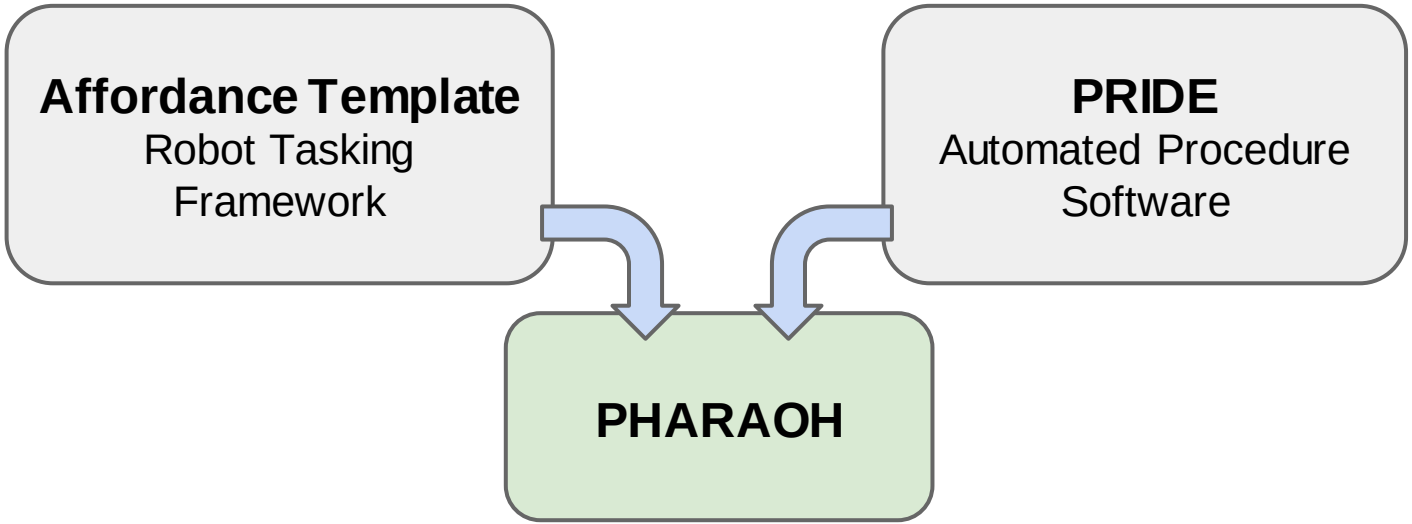
Masterlink Capacity: _____

SWIVEL HOIST RING

Torque value: _____
Swivel hoist ring capacity:

Purpose of this work

We aim to bridge the gap between state-of-the-art **robot application tools** and mission-appropriate **procedure execution software** to enable the use of complex robot systems in real-world field operations.



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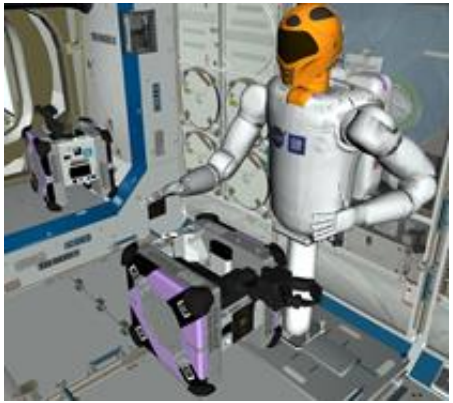
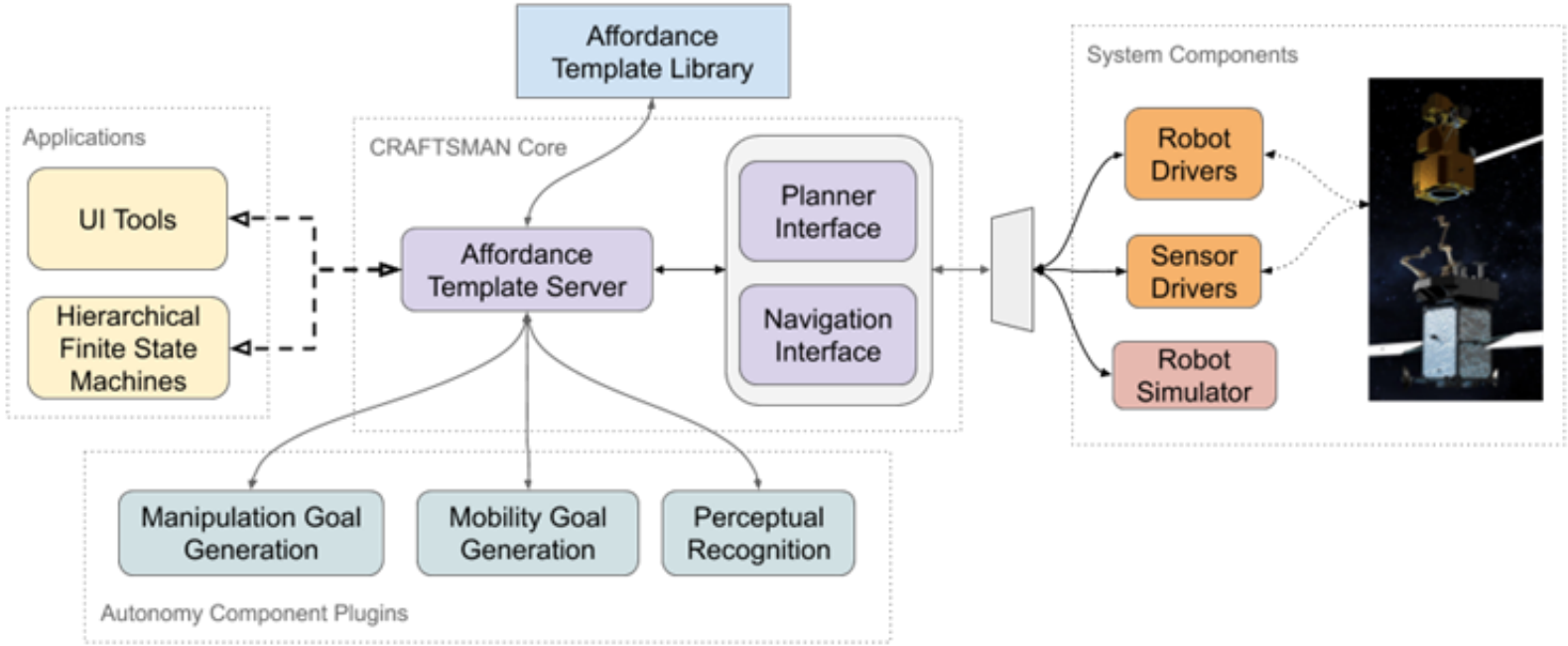


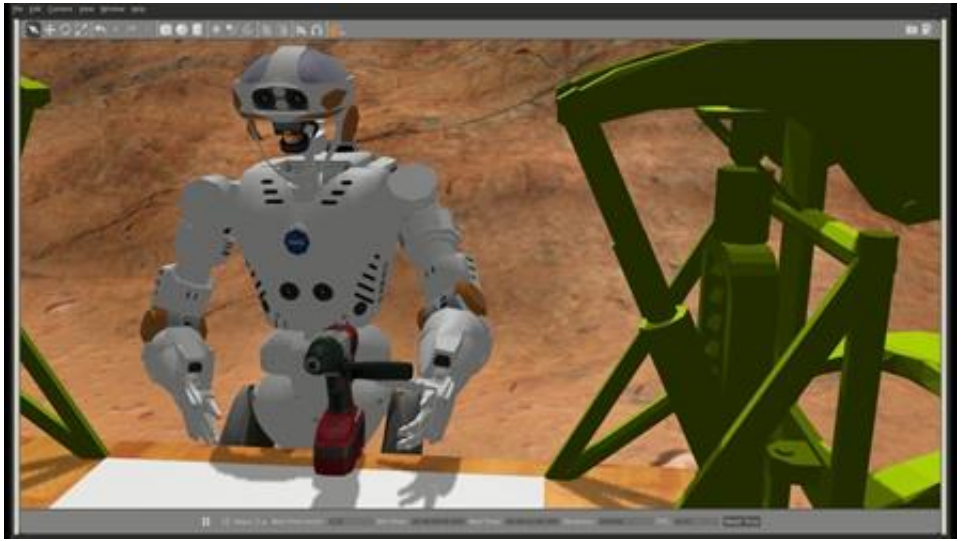
The CRAFTSMAN Software Tool-Suite

CRAFTSMAN is a **ROS-based** framework for developing advanced, sensor-driven, robotic applications for use with a wide variety of robots.



CRAFTSMAN Capabilities

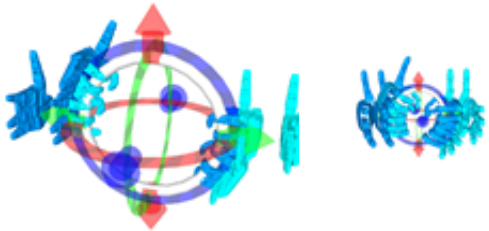
- Suitable for teleoperation, shared autonomy, and full automation
- Matured through multiple deployments in industrial and NASA contexts
- Supports a wide variety of advanced motion planning techniques and features
  - Cartesian and Joint motion
  - collision free paths (OMPL)
  - tolerance/constraint based parameterization
  - plan optimization
  - multiple levels of safety checking
  - coordinated motion planning among multiple manipulators and robots
  - integrated mobile manipulation
  - grasp planning



Affordance Templates

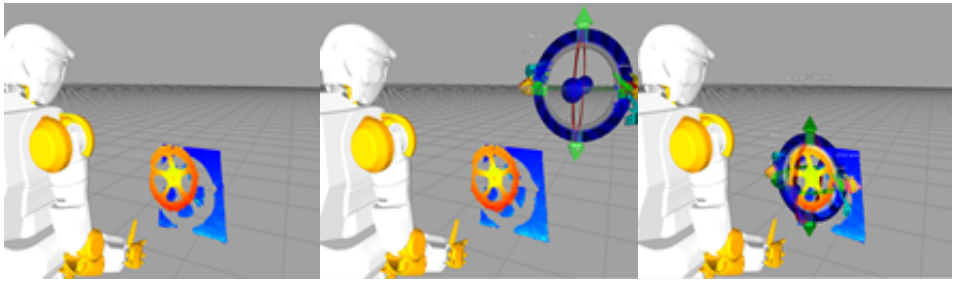
- Interactive 3D task programming and execution framework
  - “Object”-oriented task encoding
  - Inherent generalization across *robots*, *tasks*, and *environments*
  - Used on Robonaut 2, Valkyrie, Atlas, Industrial Robots, etc.
- Supports different levels of *shared* and *full* autonomy
  - Authoring, monitoring, and interacting/supervising
- Intuitive graphical tools to set or adjust task parameters and get feedback from the robot

task transferability between robots

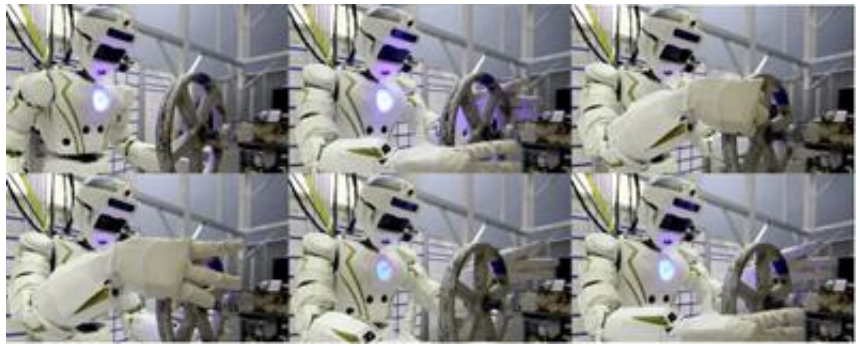


adjustable to task context

ROS

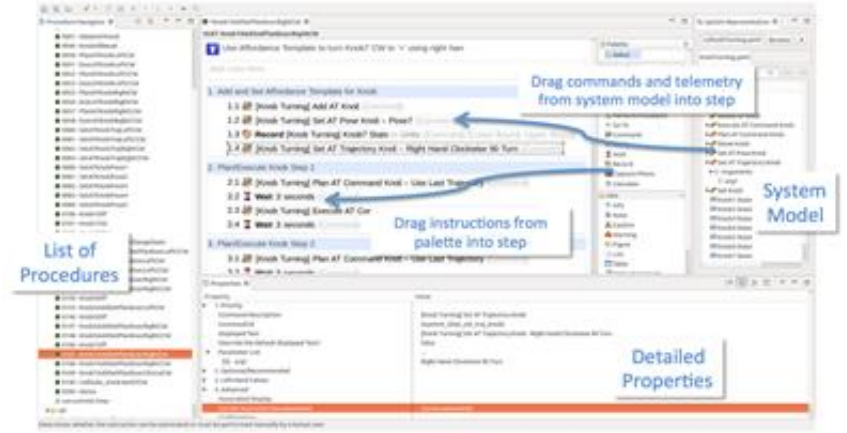


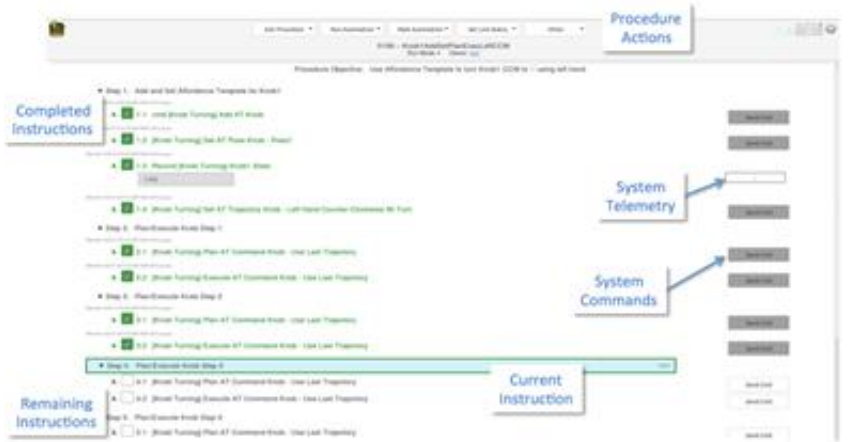
operator registers templates to run-time sensor data



PRIDE – Electronic Procedure Automation Software

- Procedure **authoring** and **execution** IDE designed for NASA and service-sector *human* field operations
  - Sub-procedures can be composed hierarchically
  - Text-based, cross-platform, web front-end supports intuitive usage by trained operators





http://traclabs.com/projects/pride/

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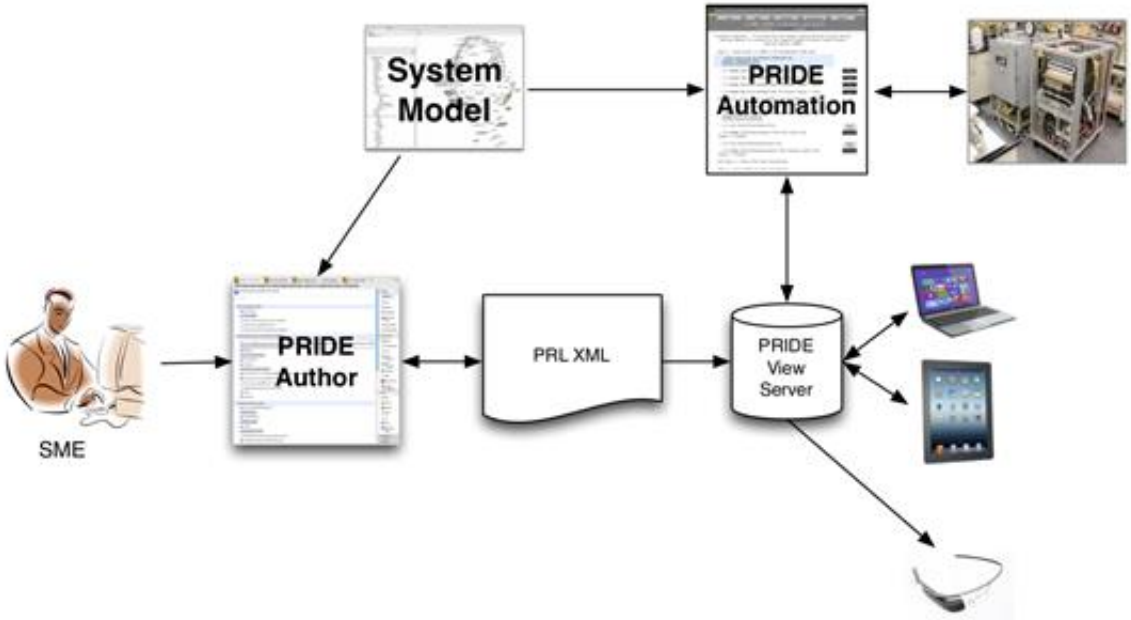
- **Telemetry** and **control** can be integrated into procedures via custom System Models
  - Increased automation and gathering of performance metrics



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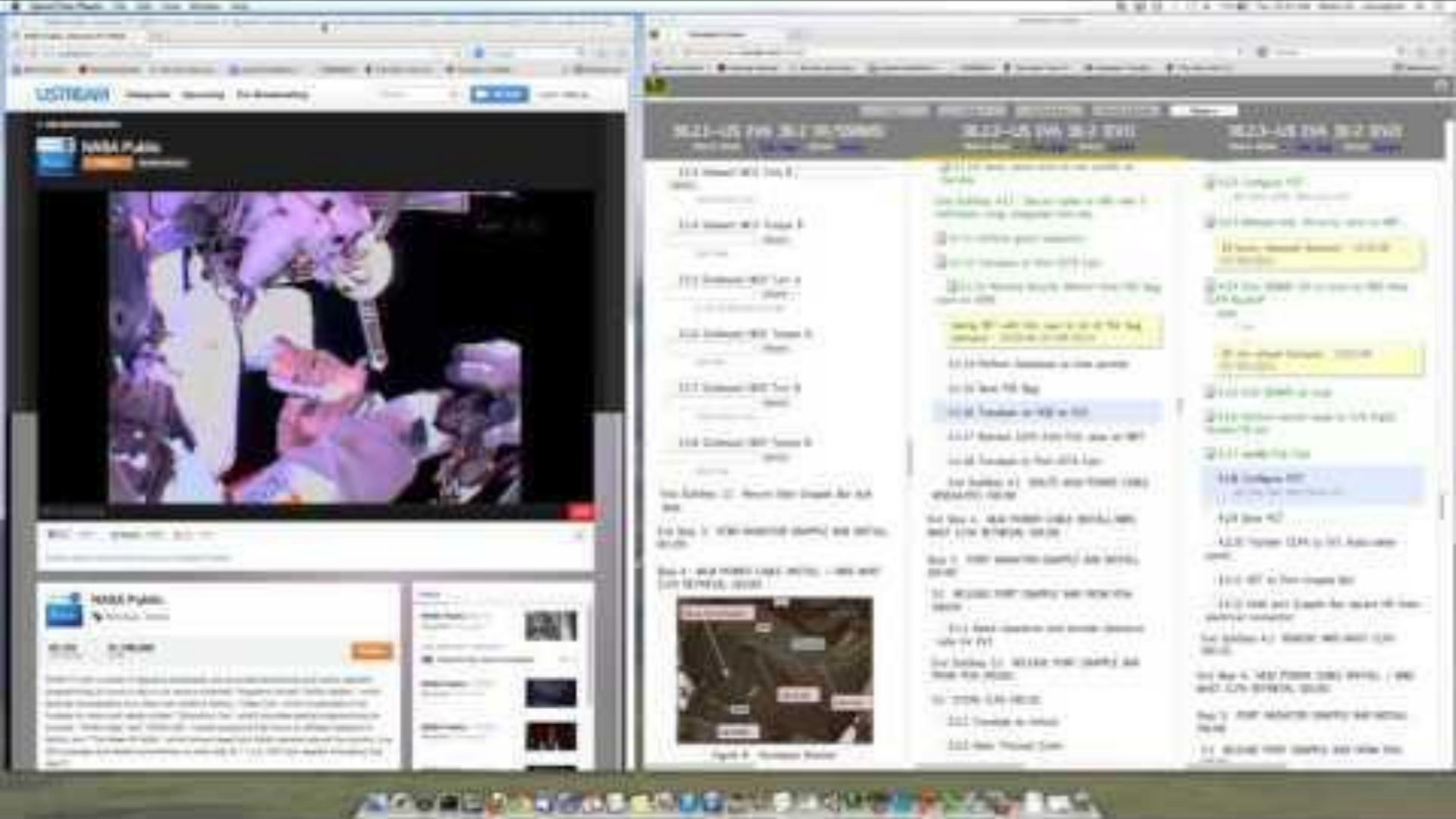

USTREAM
NASA Public

PHARAOH: Using PRIDE to Control Robots

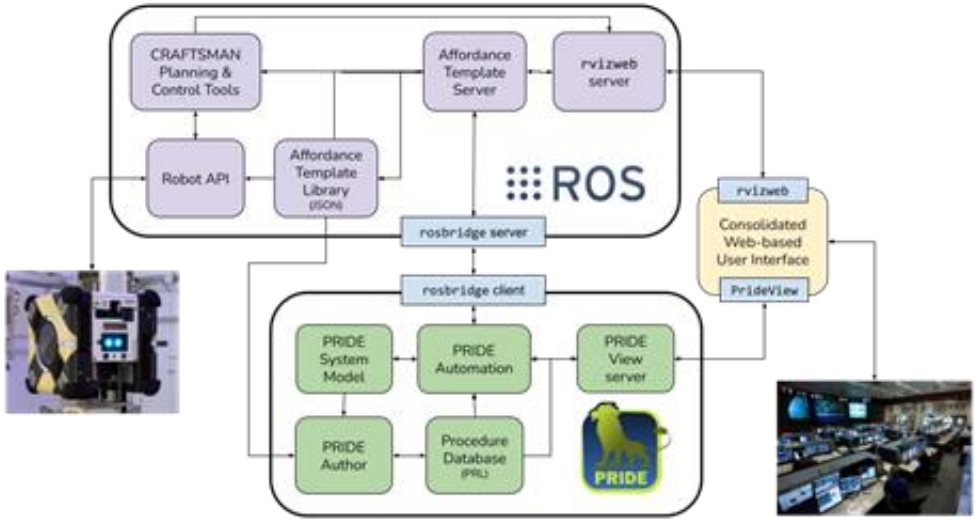
- **P**rocedure-**H**andling **A**rchitecture for **R**obots **A**nd/**O**r **H**umans

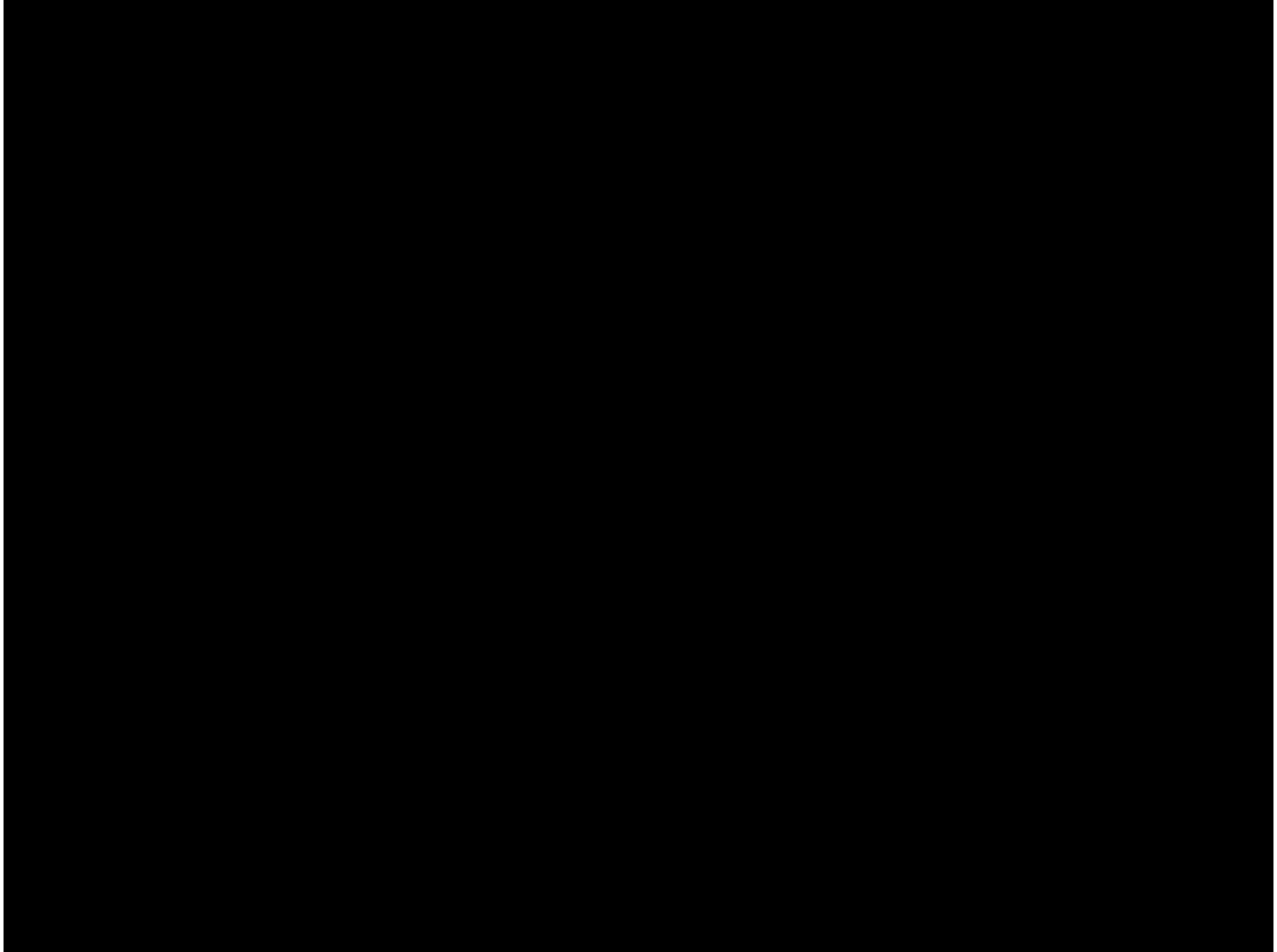
- Create a PRIDE **System Model** to interface with the Affordance Template ROS API

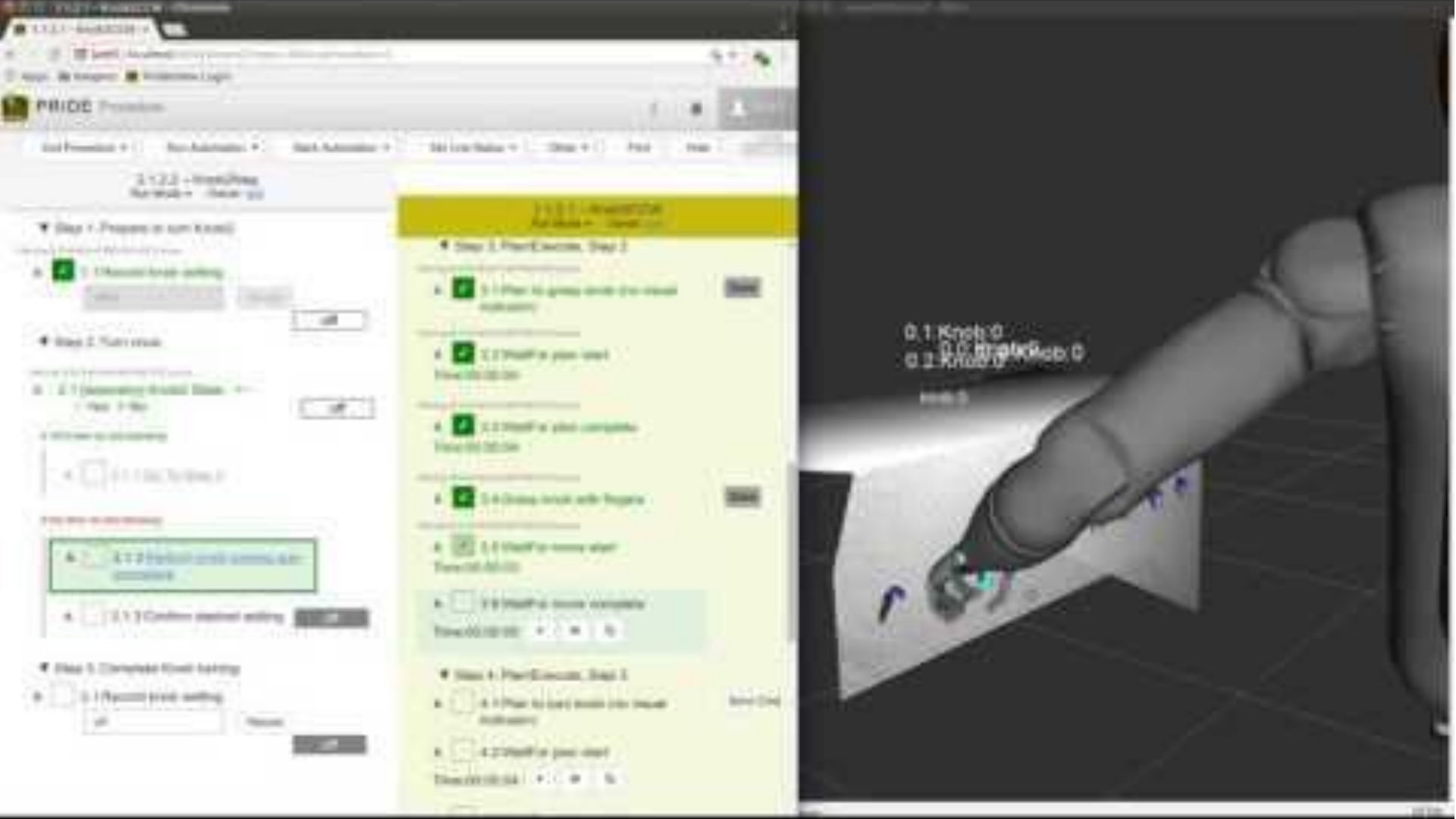
- Automate AT program flow:
  - Adding/Deleting
  - Planning/Executing
  - Setting strategy

- Walk an operator through adjusting AT task goals in 3D interface
  - Example: “Use 6-DOF arrows to register the virtual knob model to the 3D sensor data”

- Gather performance statistics during operation
  - System data
  - Timing
  - Success/failure rates
  - Manual vs. automated steps



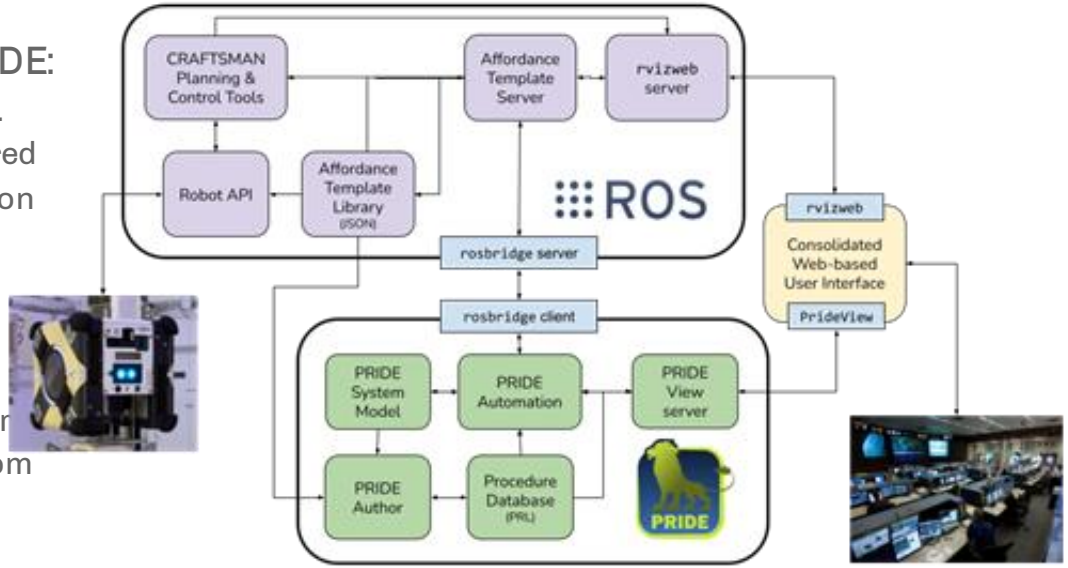



PRIDE

Affordance Template PRIDE Integration

- To accommodate Affordance Templates in PHARAOH, it is now possible to load AT JSON files **directly** as PRIDE System Representations.

- CRAFTSMAN capabilities needed in PRIDE:
  1. Locate an item of interest (a display object).
  2. Choose a trajectory that specifies the desired display objects, navigation, and manipulation task.
  3. Navigate to a position that facilitates the chosen trajectory's manipulation task.
  4. Do the chosen manipulation task.
  5. Desiderata that are required by the softwar for AT usage but can possibly be hidden from the user.



Affordance Template PRIDE Integration

- A simplified ROS Service API was created for the AT server code that allows a **single** point-of-entry between PAX and CRAFTSMAN.

```
uint8 LOAD=0
uint8 UNLOAD=1
uint8 PLAN=2
uint8 EXECUTE=3
uint8 CLEAR=4
uint8 LOCALIZE=5

string template_name
string trajectory_name
uint8 command_type # One of the constants above
bool navigation
string identifier # Used for planning, executing, and clearing plans
string precondition # Only needed for planning
string display_object
---
bool success
string result_message
string identifier
```

Affordance Template PRIDE Integration

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- New PAX Telemetry and Control Java components were added to communicate with this API.

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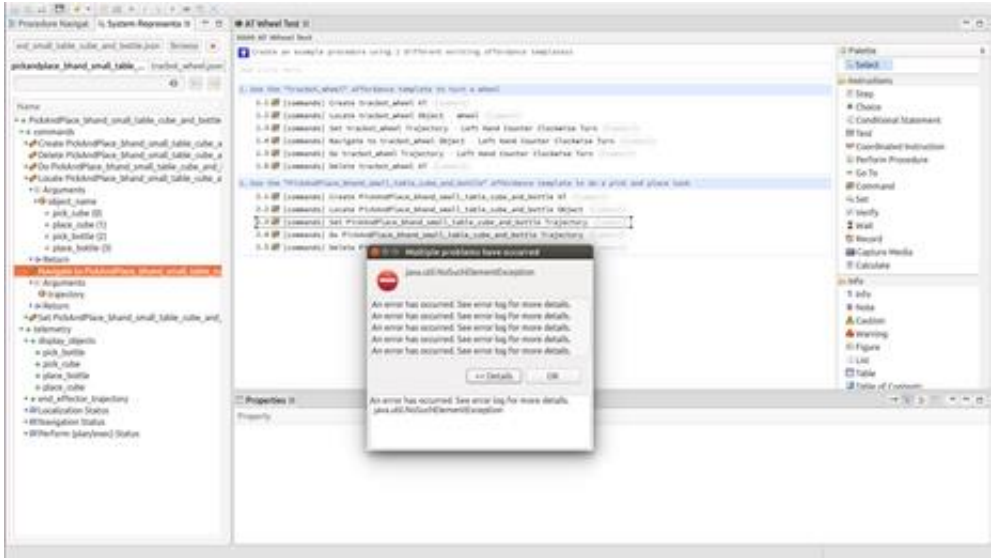

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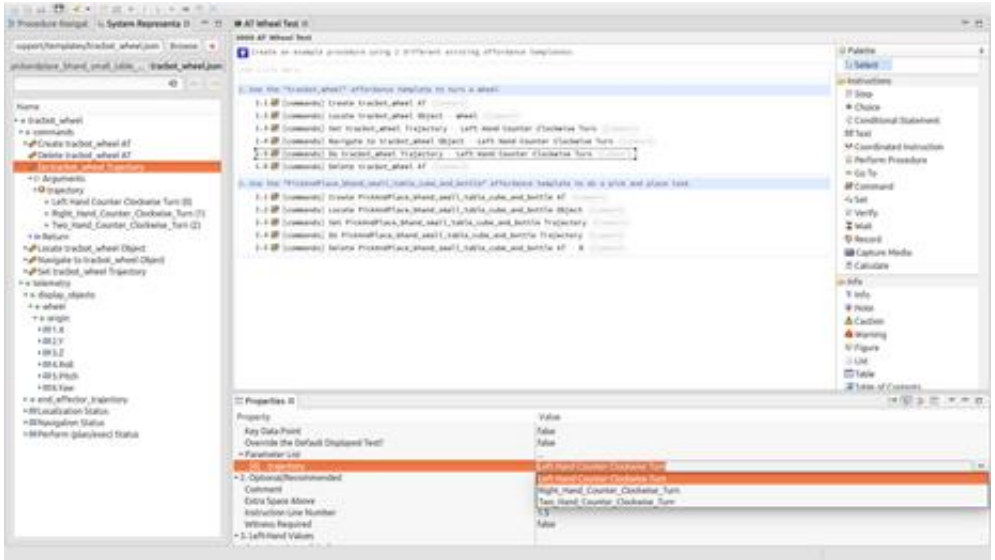
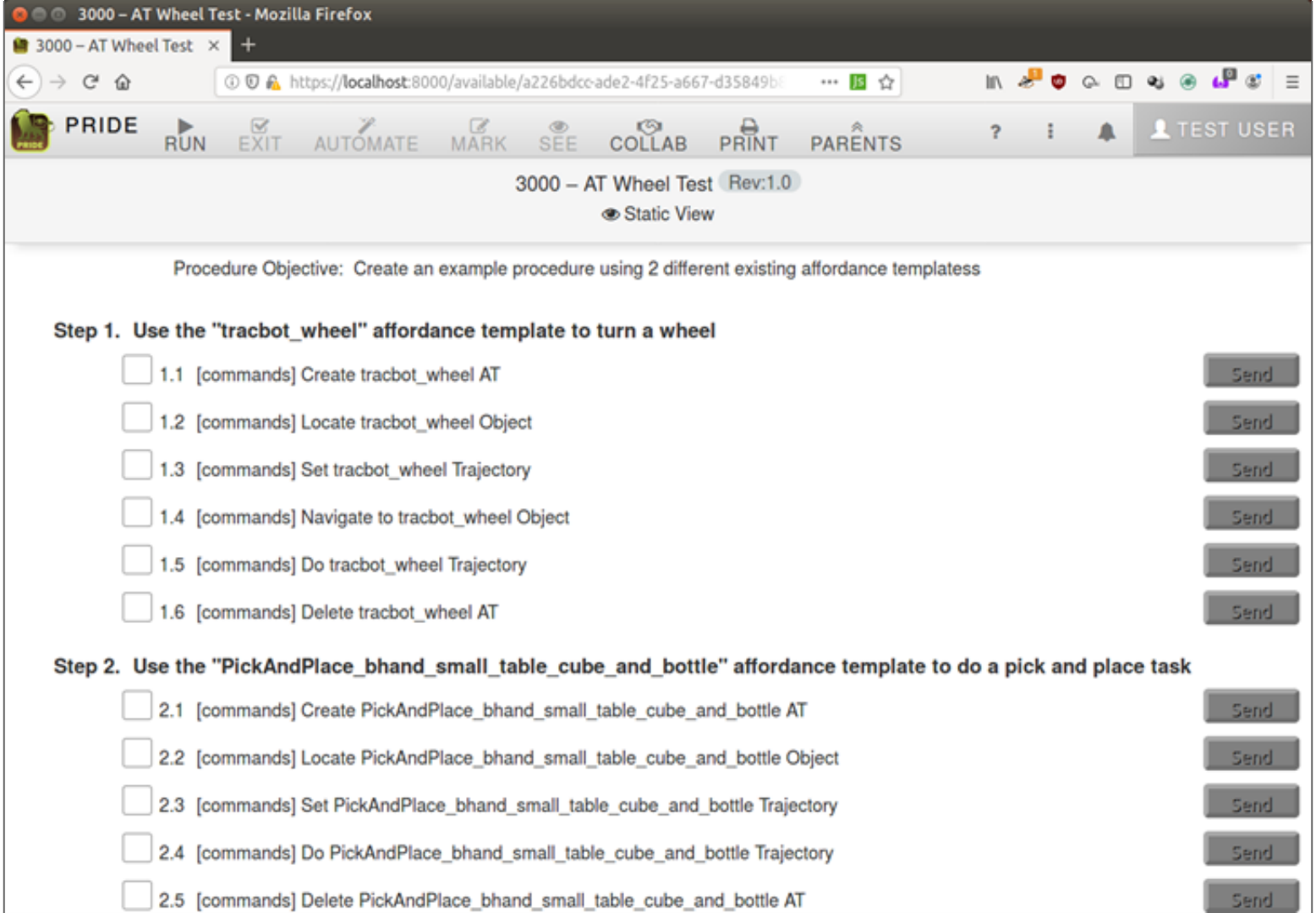
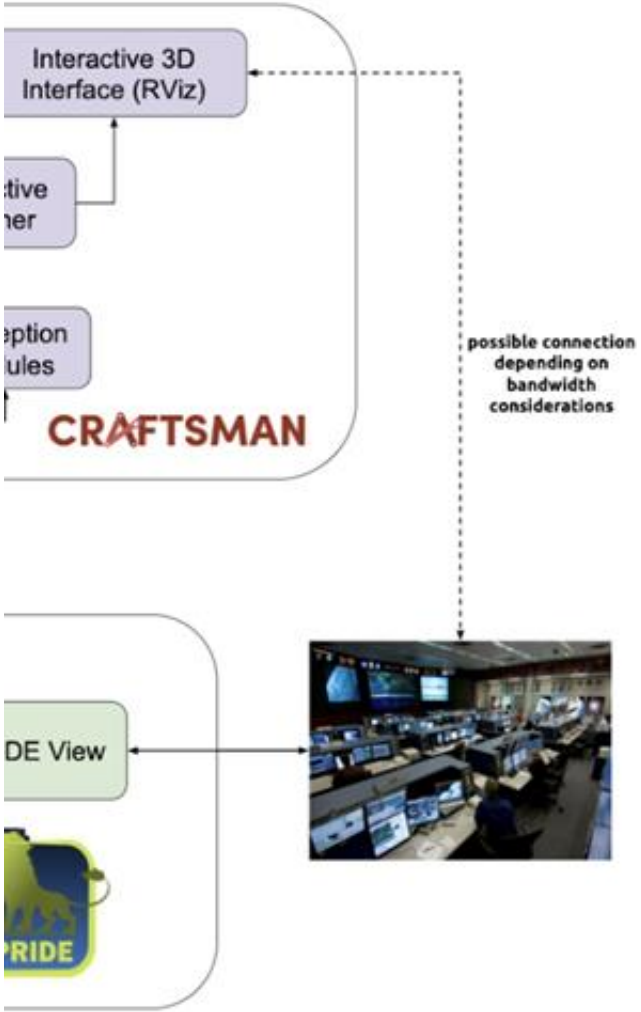



3000 – AT Wheel Test - Mozilla Firefox
3000 – AT Wheel Test
https://localhost:8000/available/a226bdcc-ade2-4f25-a667-d35849b
PRIDE
RUN
EXIT
AUTOMATE
MARK
SEE
COLLAB
PRINT
PARENTS
TEST USER
3000 – AT Wheel Test Rev:1.0
Static View
Procedure Objective: Create an example procedure using 2 different existing affordance templatess
Step 1. Use the "tracbot_wheel" affordance template to turn a wheel
1.1 [commands] Create tracbot_wheel AT
1.2 [commands] Locate tracbot_wheel Object
1.3 [commands] Set tracbot_wheel Trajectory
1.4 [commands] Navigate to tracbot_wheel Object
1.5 [commands] Do tracbot_wheel Trajectory
1.6 [commands] Delete tracbot_wheel AT
Step 2. Use the "PickAndPlace_bhand_small_table_cube_and_bottle" affordance template to do a pick and place task
2.1 [commands] Create PickAndPlace_bhand_small_table_cube_and_bottle AT
2.2 [commands] Locate PickAndPlace_bhand_small_table_cube_and_bottle Object
2.3 [commands] Set PickAndPlace_bhand_small_table_cube_and_bottle Trajectory
2.4 [commands] Do PickAndPlace_bhand_small_table_cube_and_bottle Trajectory
2.5 [commands] Delete PickAndPlace_bhand_small_table_cube_and_bottle AT
Send

Consolidated User Interface

- In general, we can not presume robot operators will have a ROS-enabled Ubuntu computer for communication with their robots.
- A goal of the PHARAOH work has been to enable a more platform-independent and lightweight User Interface that provides the necessary components without sacrificing capabilities.
- Although Unreal and Unity based approaches were initially pursued, the complexity of ROS integration and multi-platform compatibility proved intractable from a maintenance and development standpoint.



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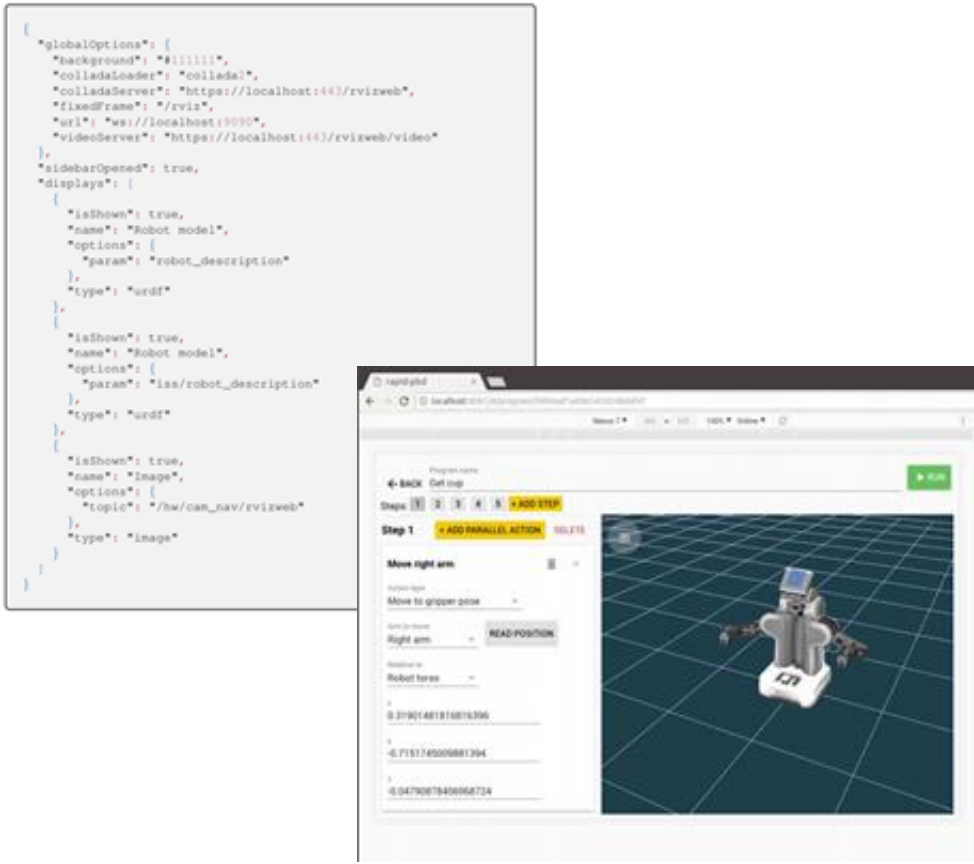
- We ultimately settled on consolidating the `rvizweb` utility with a web server that “consolidated” PrideView and the web-based Rviz.



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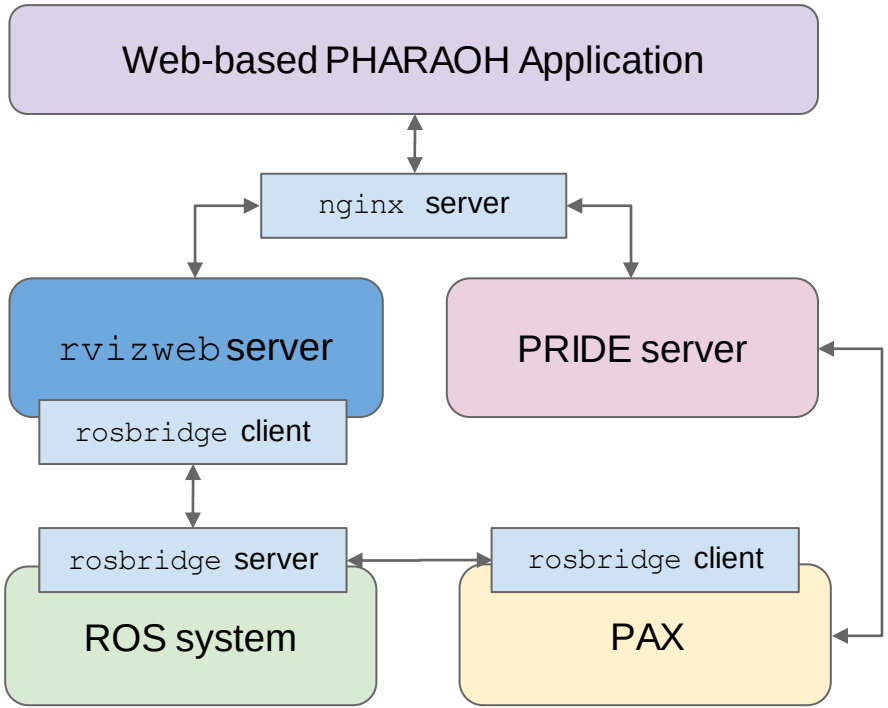
- `rvizweb` uses `rosbridge` to communicate with web-based applications and provides a JSON-configurable RViz-like UI with the same core situational awareness capabilities.



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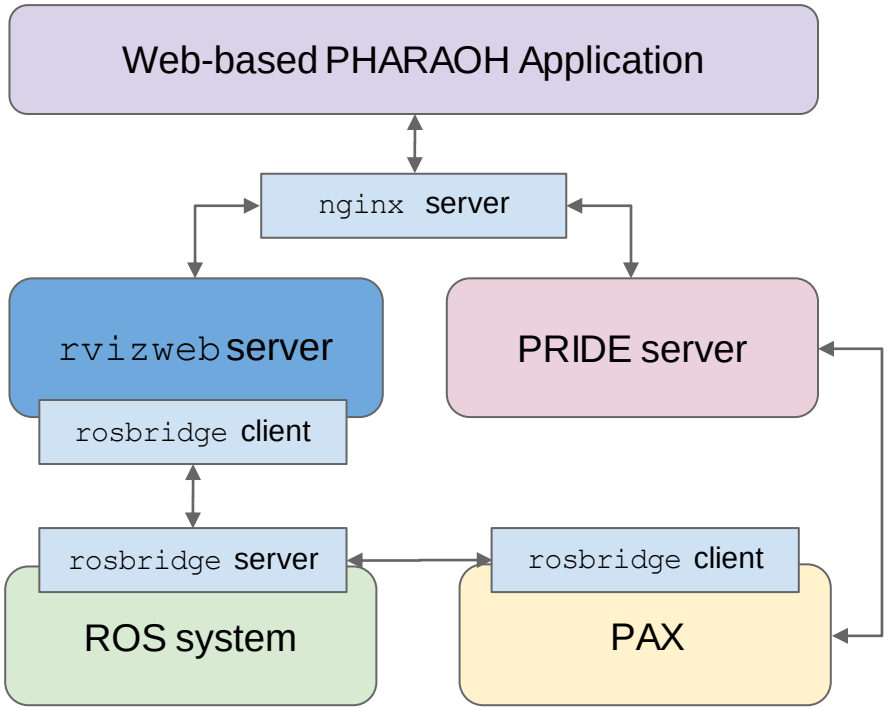
- `rvizweb` uses `rosbridge` to communicate with web-based applications and provides a JSON-configurable RViz-like UI with the same core situational awareness capabilities.
- Using nginx, we created a web-based front end that integrates, side-by-side, Pride View and `rvizweb` to provide a single PHARAOH front end.



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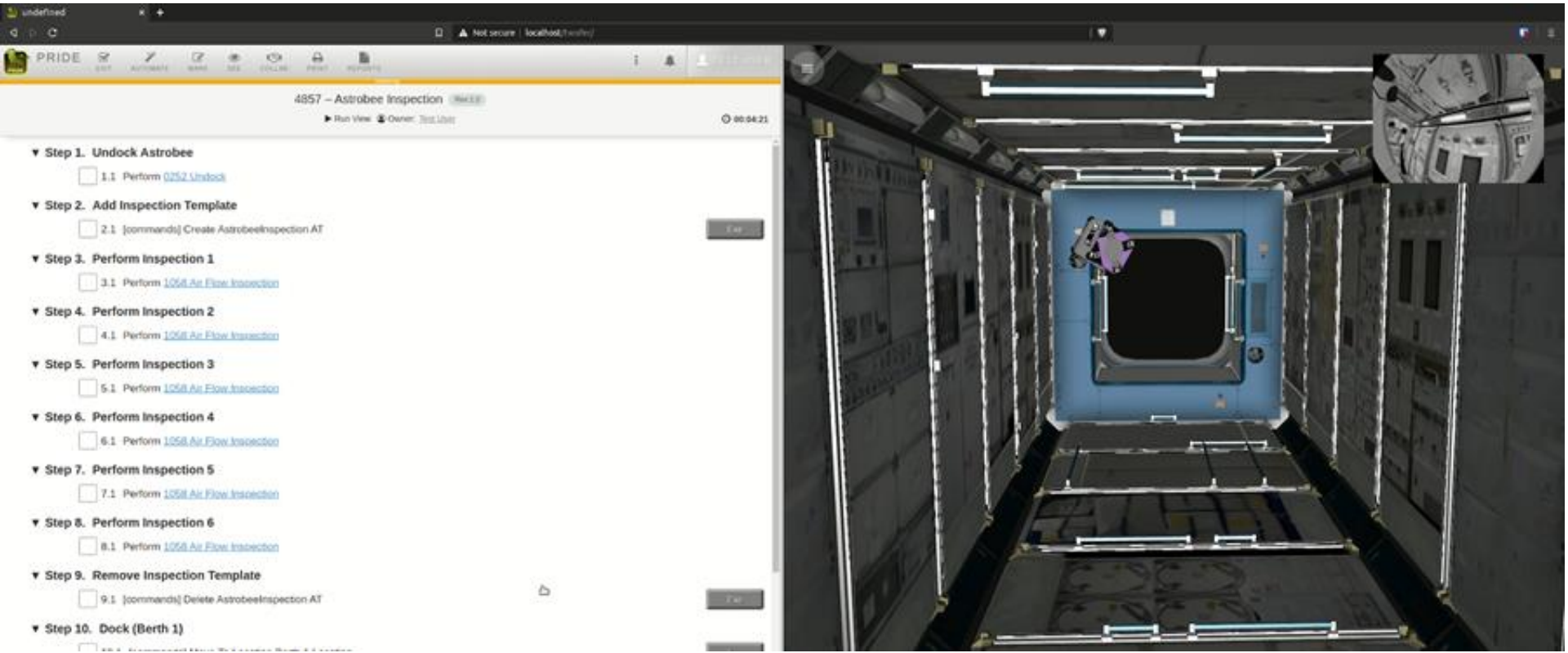
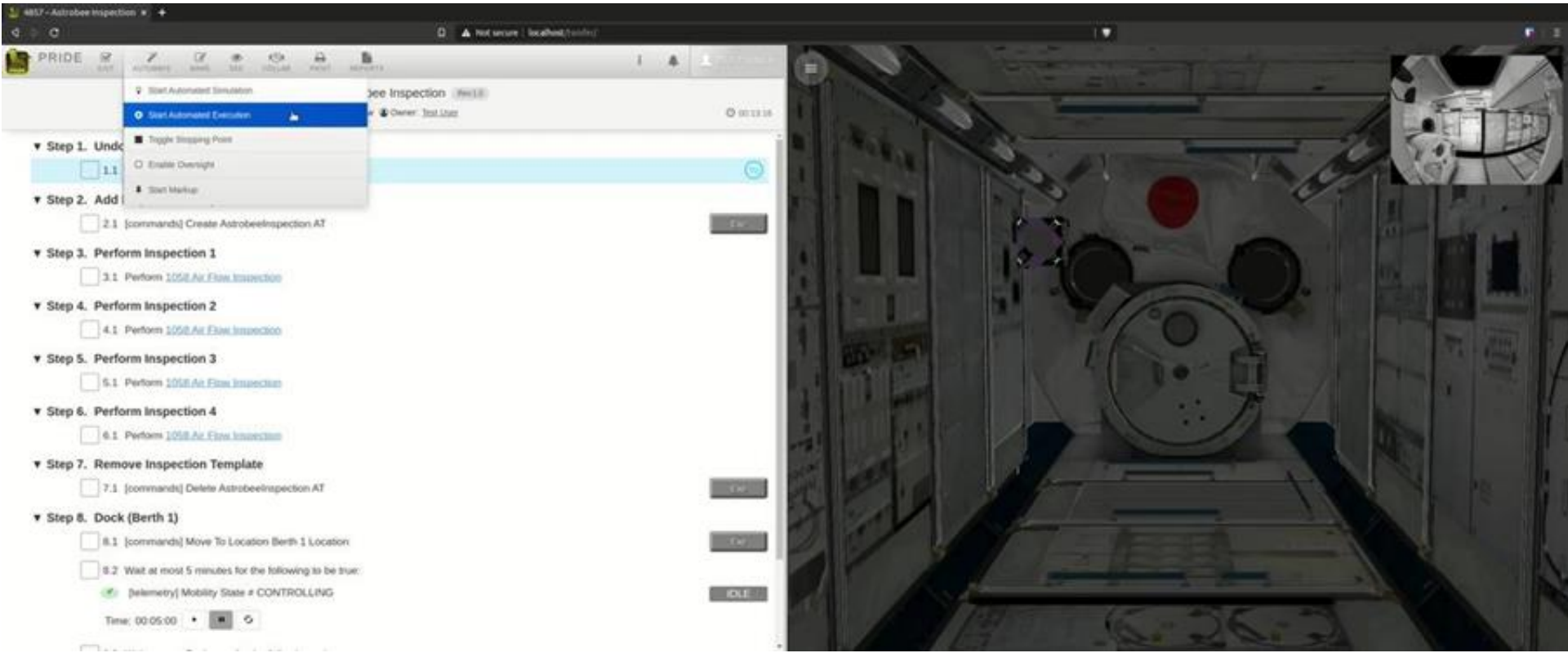


PHARAOH Demonstrations



Not secure | localhost:8000/viewer/cdb0a0f9-3bc7-4a92-89cd-970bd92b74f6?mode=g...

Apps | Timesheets | time | Webex - TRAC... | astrobee

PRIDE

3206 – ISS Ventilation Maintanence Rev 1.0

Guided View | Owner: Test User | 00:00:10

Figure 4. R2 Right Vent Scraping AT

▼ 9.5.4 Clean Up After Removal

CAUTION

Return Robonaut to its ready position

9.5.4.1 [commands] Delete sock_removal AT — Done

9.5.4.2 [commands] Locate r2_helper Object backward — Sensing...

Command Settings

Arguments

+ + object_name Add a comment to this line + : **backward**

Results

▼ Step 10. Go to beginning of procedure

10.1 Go To Step 4. Monitor CO2 Levels

Gazebo

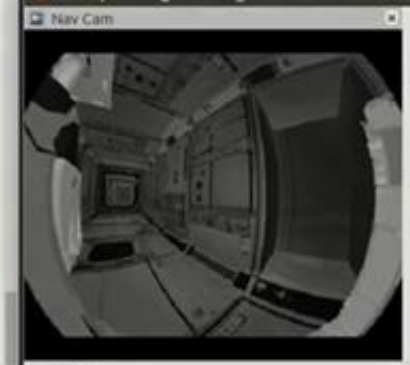
Real Time Factor: 0.93 Sim Time: 00 00:18:27.293 Real Time: 00 00:19:17.852 Iterations: 113474 FPS:

performed for: 11 h

Time

pharaoh_astrobee_r2.rviz* - RViz

Nav Cam



Reset

31 fps

The End