ROS-I Enabling Innovation for Industry through Open Source

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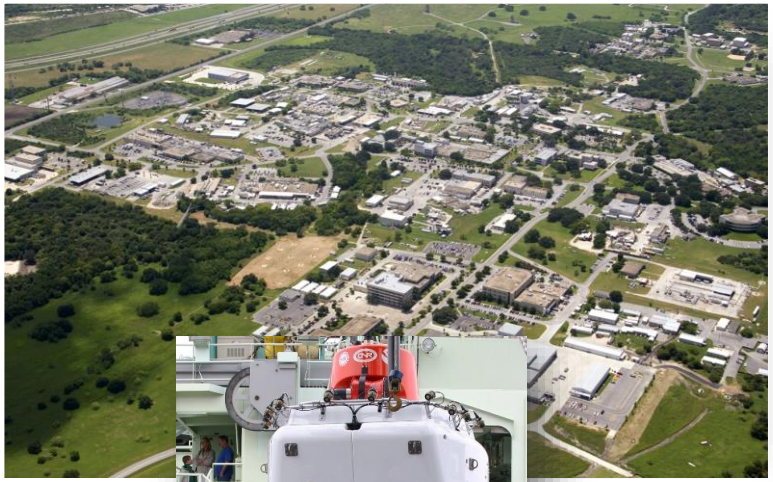
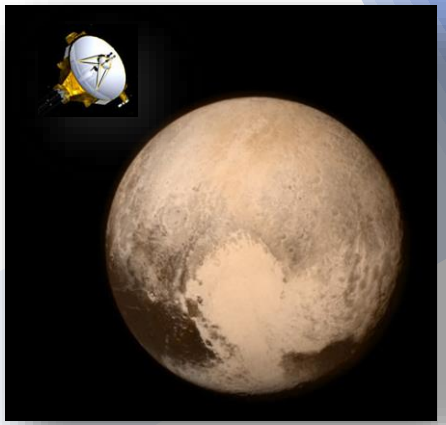
ROS-Industrial Consortium Program Manager

November 9, 2022

SwRI: Deep Sea to Deep Space





New Horizons, Pluto

Alvin submersible

Southwest Research Institute Characteristics

- Est. 1947
- San Antonio, Texas, USA
- Independent, Not for profit
- Applied RDT&E Services
- Natural Science and Eng.
- FY 2021 Revenue: $726M

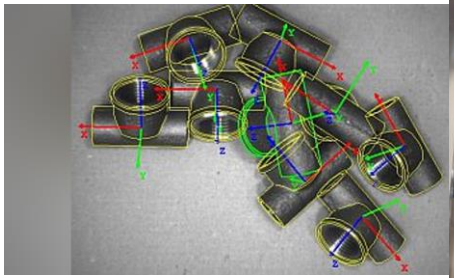
SwRI Advanced Systems Development

- Sharing information between multiple traditional industrial systems and tools
- Managing dynamic manufacturing environments
- Manage noise that is inherent to factories
- Reduce reliance on hard to find skill sets and accelerate operations where high mix/low lot is required
- Custom Mobile Robots
  - Bring the process to the part
  - Share information between systems
  - Improved agility
  - Multi-Process
  - Efficiently manage high mix of product

Reference: robotics.swri.org

Rapid Advancement & Industrial Challenges

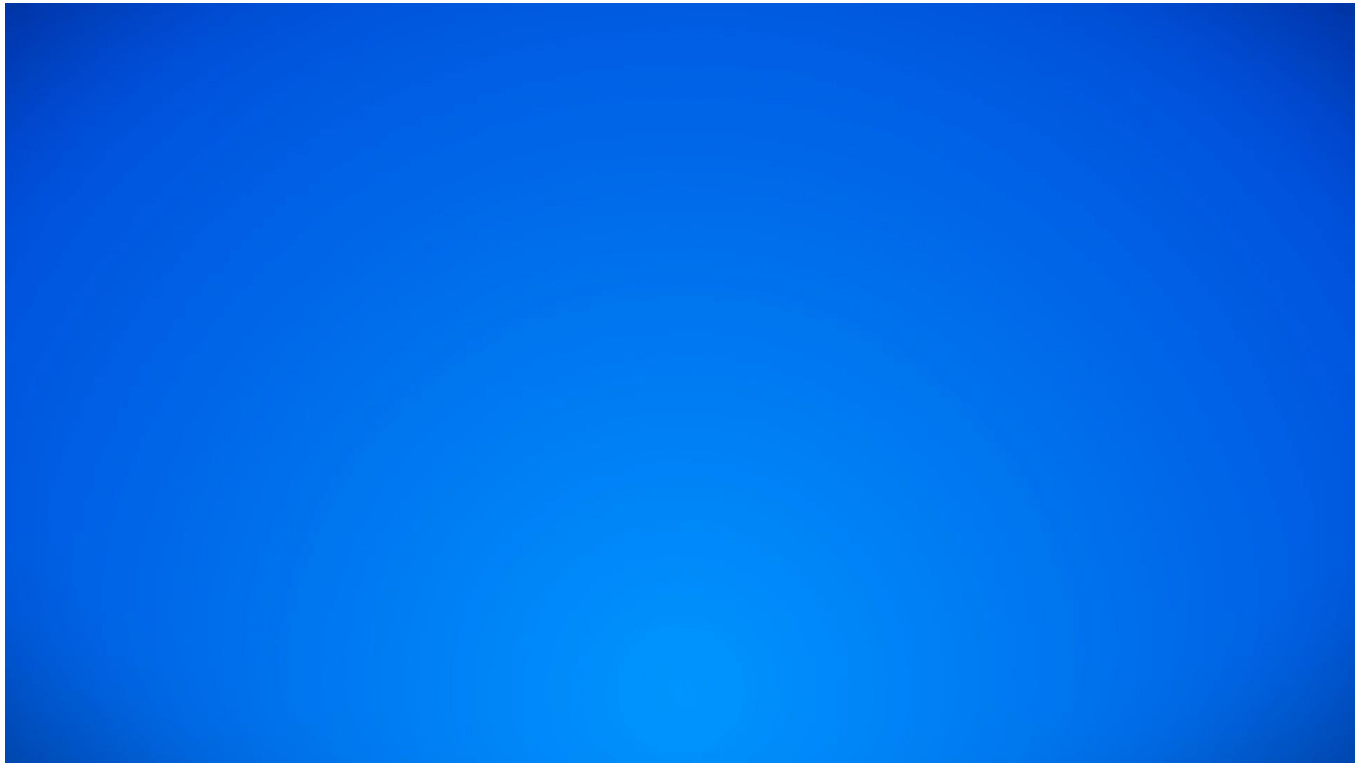
- Challenges with vendor lock/interoperability
- Not designed for unstructured environments
- Advances in vision
- Work with the operators



ROS-I


ROS Qt Creator Plug-in
CAD to ROS
Developer Tools
Mobile Manipulator
Sorting
Scan-N-Plan
Applications
Hardware Interfaces
Yaskawa
Universal Robots
ABB
Fanu
Staubli
Industrial 3D Sensors
Intel® RealSense™
IFM
Pepperl & Fuchs
IDS® Ensenso
Photoneo
Sick
ROS industrial
Bridges
CANopen®
EtherCAT®
Ethernet/IP™
PROFINET®
Human Interfaces
ROS/2
Calibration

10 years strong



Tech Vision Supported by Industry

- **ROS-Industrial Consortium** acts as an ecosystem where different players – end-users, equipment providers, system integrators, institutes of research and training partners **come together to advance and proliferate Open Source robotics**

Strategy for Development

MoveIt

TESSERACT

DART
Dynamic Animation and Robotics Toolkit

DRAKE
Model-Based Design and Verification for Robotics

Environment Layer (MoveIt, Tesseract, Dart, etc.)

Messages, Topics

ROS 1 / ROS 2 / Middleware Layer

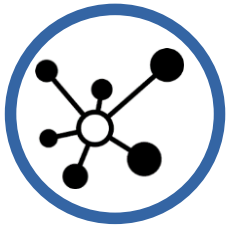
Build ROS1 or ROS2, these are independent

Independent of ROS

Collision Detection

Motion Planners

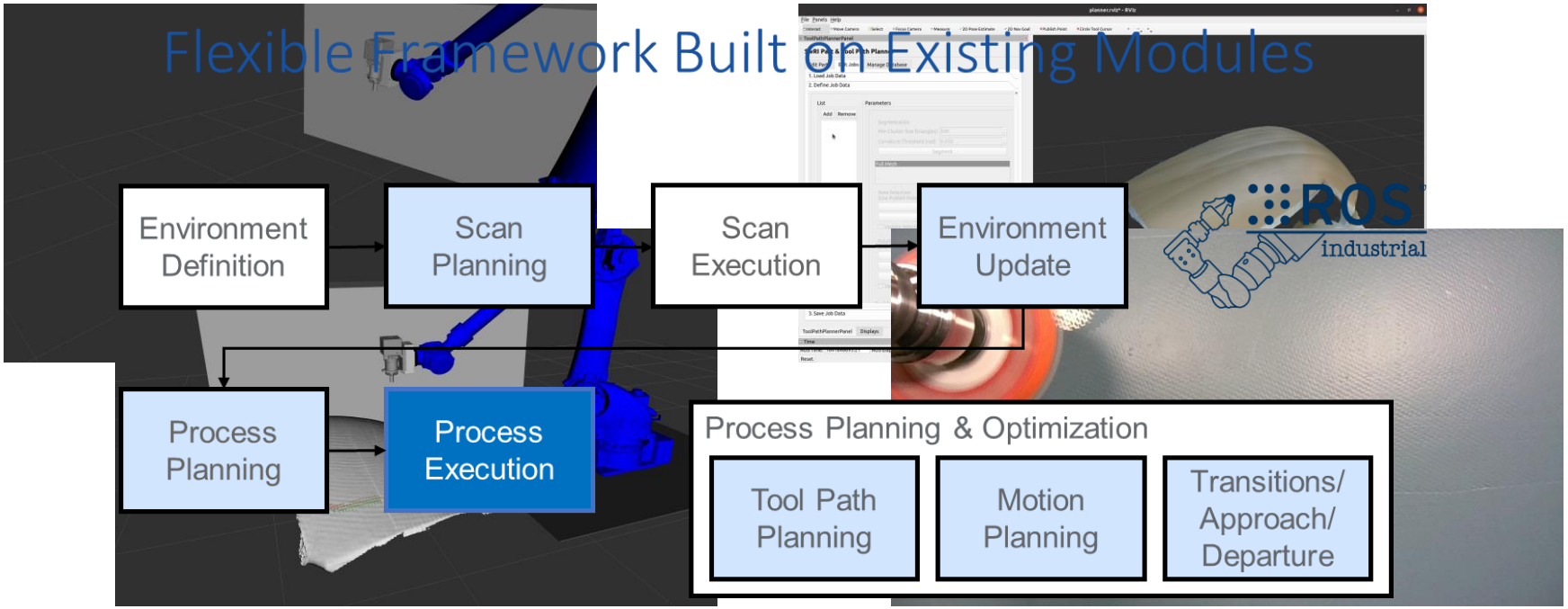
Kinematic Solvers



Connectivity Structure

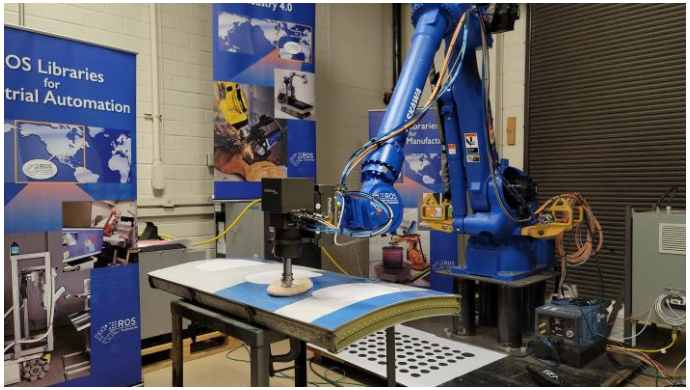
Continue to support deployed end-user ROS1 systems with new capabilities as they are developed even if for a ROS2 solution

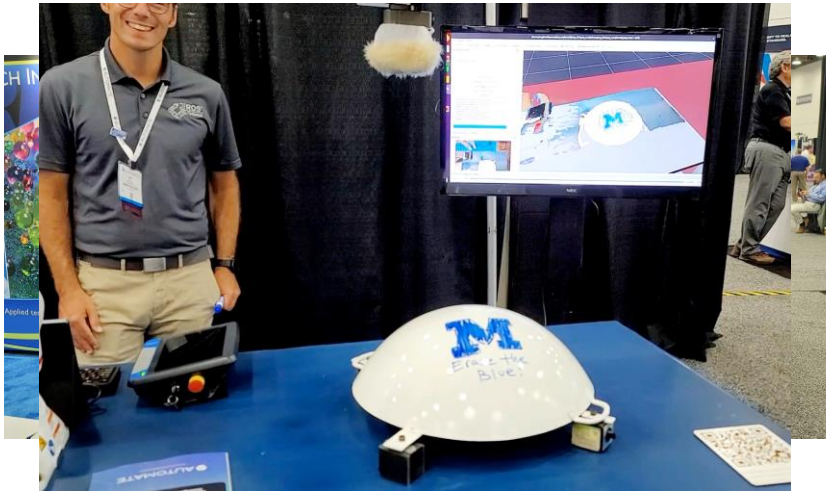
Adaptive surface finishing framework



https://github.com/ros-industrial/industrial_reconstruction

Teaching Application



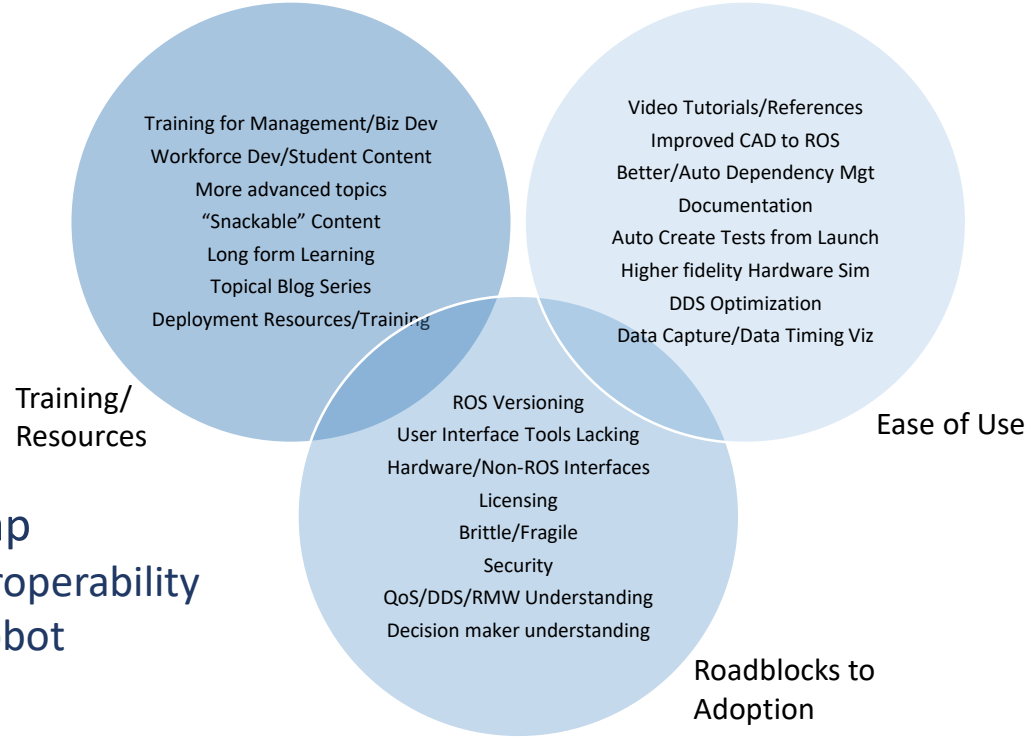


https://github.com/ros-industrial-consortium/scan_n_plan_workshop

Developers' Meeting Overview: https://youtu.be/GgTxvIaekjE

Shaping a Roadmap - Feedback

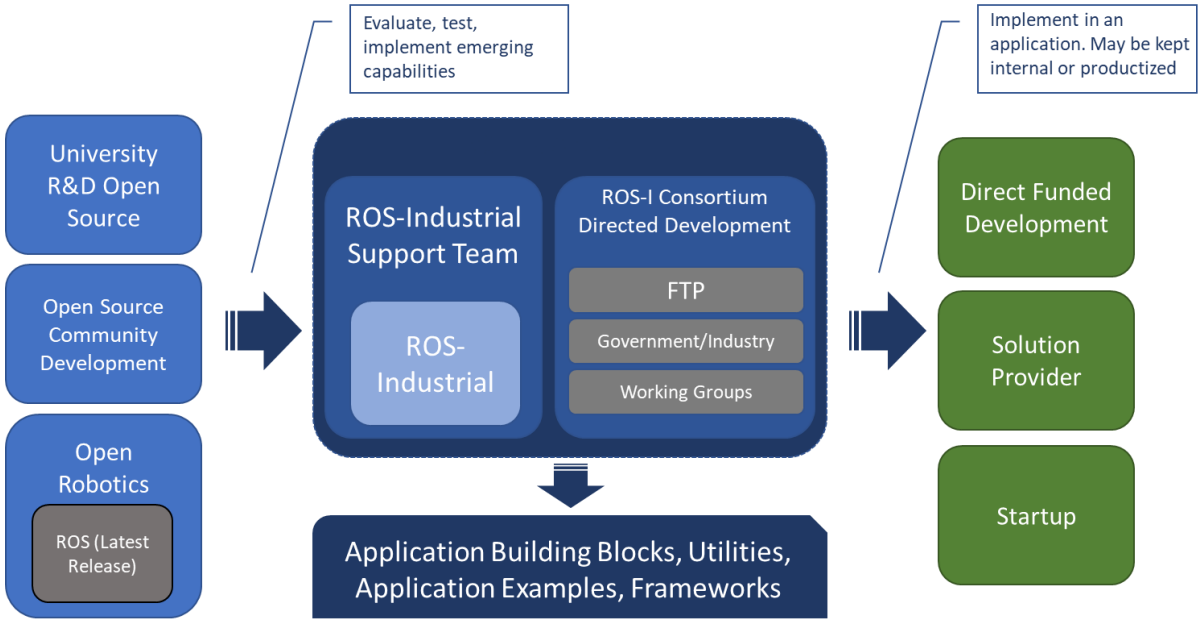
- Workshops over last handful of years providing feedback
- Long list of challenges
  - Developers
  - Decision Makers
  - Mfg Engineers
  - Tech Stewards
- Feedback on various areas
- Affinitize and update roadmap
  - Capture ROS 2/Version/Interoperability
  - Reference back to roles in robot ecosystem



Continue to foster collaboration

- In person conferences, training events, meetups
- Write ups and additional broader reach collaborative initiatives beyond the ROS community
  - American Welding Society
  - Founders' Society of Americas
  - Coaters' Association
  - Remanufacturing Industries Council
  - Manufacturing Innovation Institutes

How to get capability on the floor

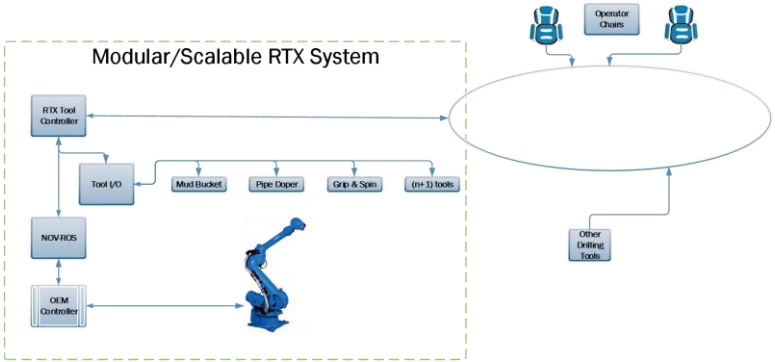


ROS industrial

Manufacturing USA®

- Continued opportunity to leverage MII network for tech transition
- Many examples of Government/Industry partnerships that refine capabilities
- Startups can leverage for de-risking/scaling

Delivering new products



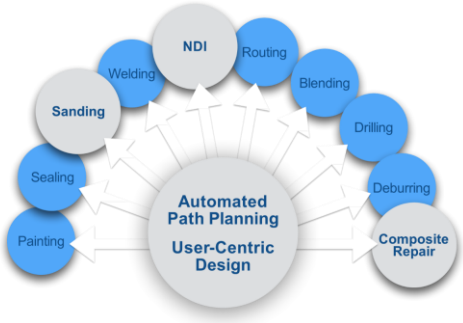
NOV RTX Productized

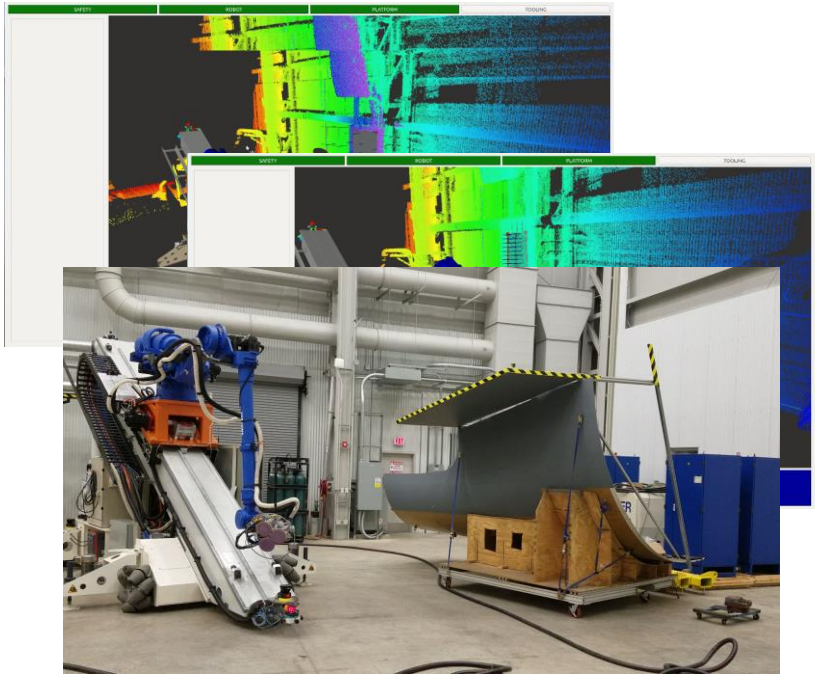
- modular and scalable system that can be put on any rig network
- Framework for all path planning and collision avoidance is NOV-ROS
- Prototype integration of scene awareness and people detection into RTX system
- Productization of all end effectors nearly complete
- Roadmap for other functions/end effectors ongoing

NOV Keynote from RICA 2022 Annual Meeting:
https://youtu.be/WQZJnv5BR48?list=PLXUpEXjGC63weFXogyQrAOS45a62nVM8L

Agility and Scan-N-Plan

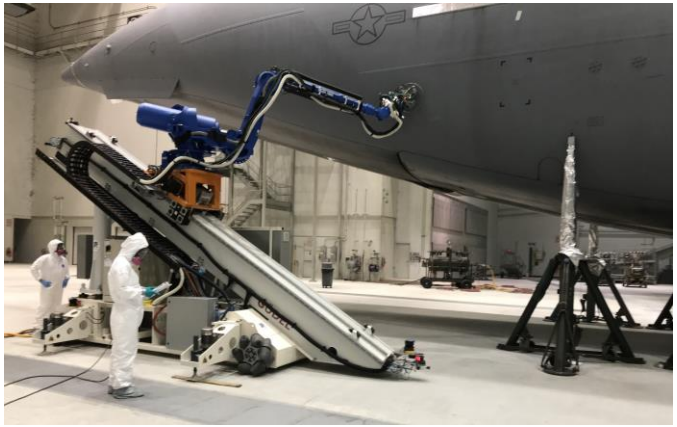
- Agility in Aerospace Applications Platform & Framework
- NCDMM led Air Force Research Lab Program to Realize human in the loop agile capability for depots





Extensibility Example

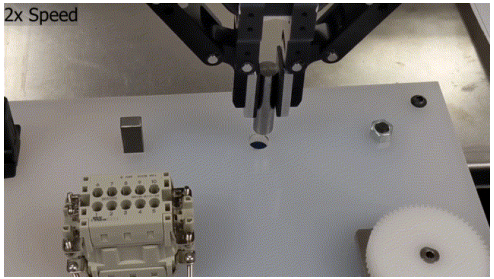
- Recent success taking a developed application framework (A5) and extending it to new platforms and processes
  - ARM Institute Sponsored
    - https://arminstitute.org/project-highlight-mobile-autonomous-coating-application-for-aircraft-sustainment/
    - https://arminstitute.org/project-highlight-autonomous-coating-with-realtime-control-and-inspection/
- Demonstrated adaptability to new hardware and improved existing tools and developed new capabilities

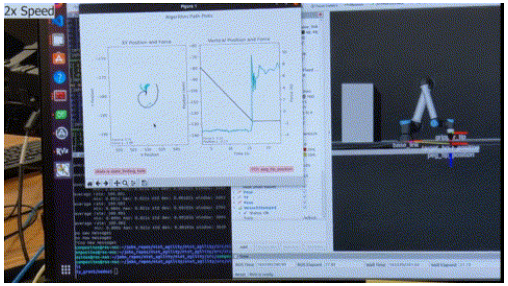


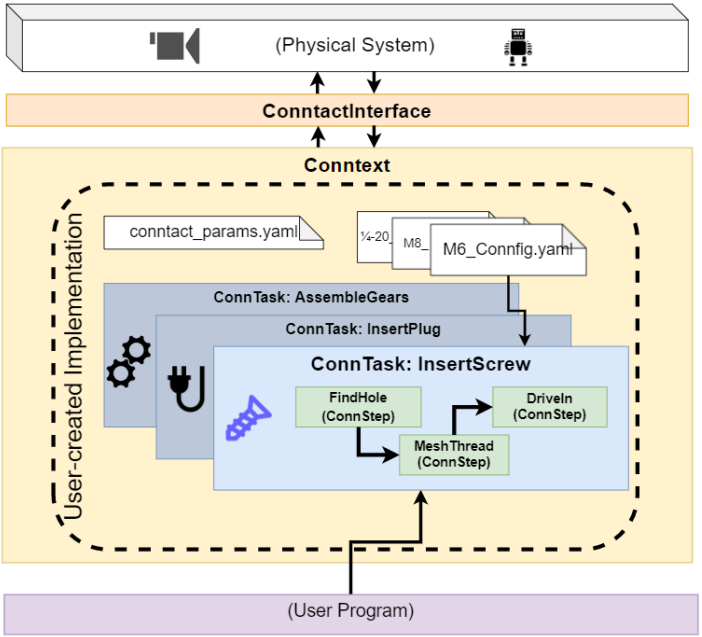
Extensibility Result

Agility in advanced assembly applications

- The ConnTact Assembly Framework
  - Ability to enable researches to simply implement and test learning algorithms to test extensibility
  - Supported by NIST and the Agility Working Group



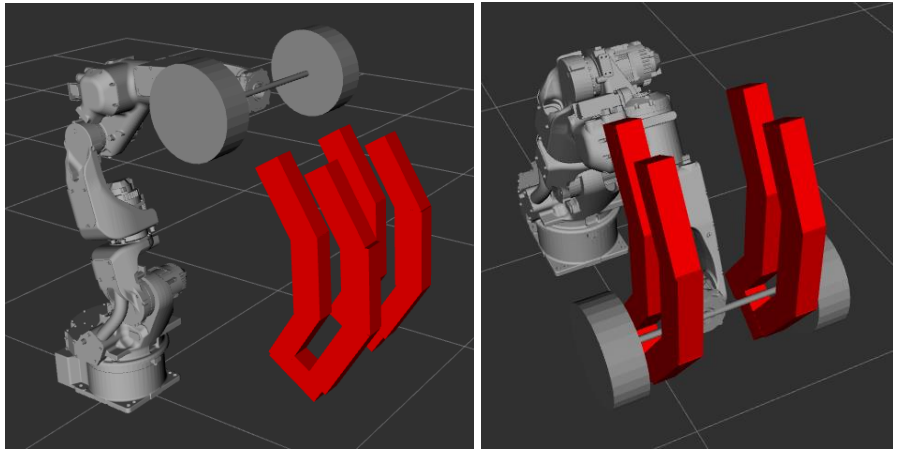




https://github.com/swri-robotics/ConnTact

Reinforcement Learning as a seed

- Reinforcement learning as a seed for optimization-based motion planning
  - Confined space
  - Generating motion plans computationally intense
  - Apply existing search-based motion planning applications to improve training times
  - With the actor network learning from trajectories generated from graph search techniques, the weaknesses of the motion planners comes into play
    - TrajOpt long times to generate valid trajectories & OMPL algorithms such as RRT are non-deterministic.
    - Supervised only is not feasible
  - Train the actor network on examples provided by the motion planners then switch to training the network through standard reinforcement learning exploration methods
  - Use output as a seed for the optimization framework



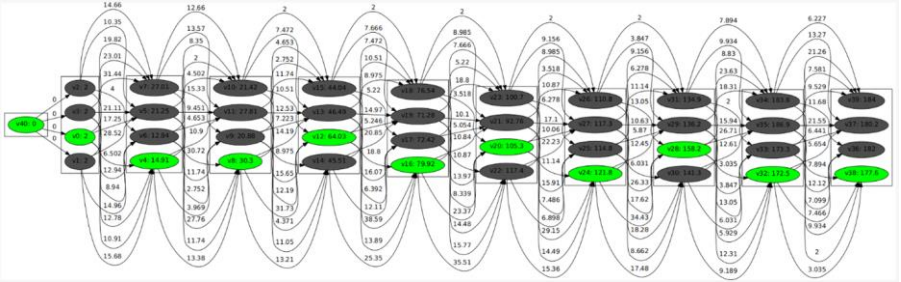
https://rosindustrial.org/news/2021/8/24/behavior-cloning-for-deep-reinforcement-learning-trajectory-generation

https://github.com/tesseract-robotics/trajopt

TESSERACT

Improving Large Volume Motion Planning

- Extra degrees of freedom in large robots like rail systems or mobile bases increase work volume
- Intros challenges in process planning; the limitation of the “useful” motion of a robotic system that is constrained by the application at hand
- The new improvements in process planning allow for branching “depth first” searches, which will quickly find a solution for every position in the trajectory, instead of search “breadth first” to find the optimal configuration at each pose



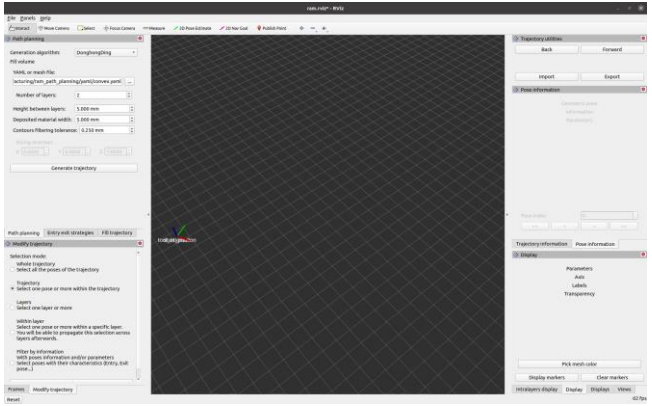
Full Dijkstra graph find the optimal path throught he graph by exploring every edge

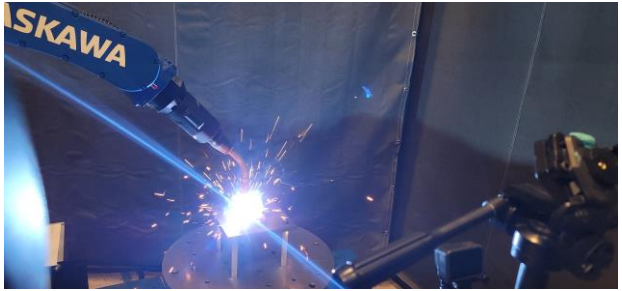
Typical rail based system with large volume

https://github.com/swri-robotics/descartes_light

Coming up - Open Additive Framework

- Open Flexible Additive Framework
- Merging of computational physics-bases analysis with planning

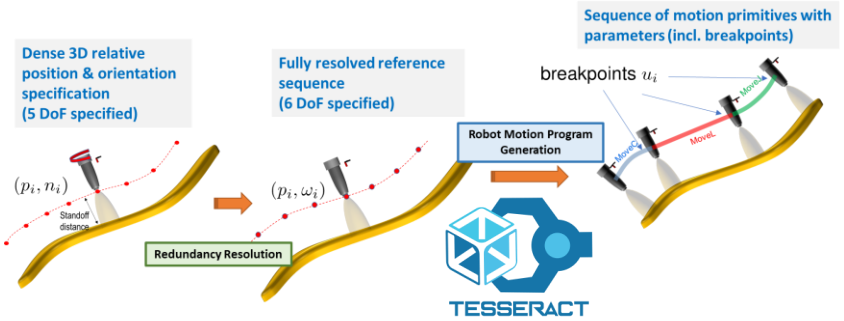




Write Up: https://rosindustrial.org/news/2022/8/23/an-open-framework-for-additive-manufacturing Video: https://youtu.be/rxkLyYaazII

Optimized tool path for tracking accuracy and velocity

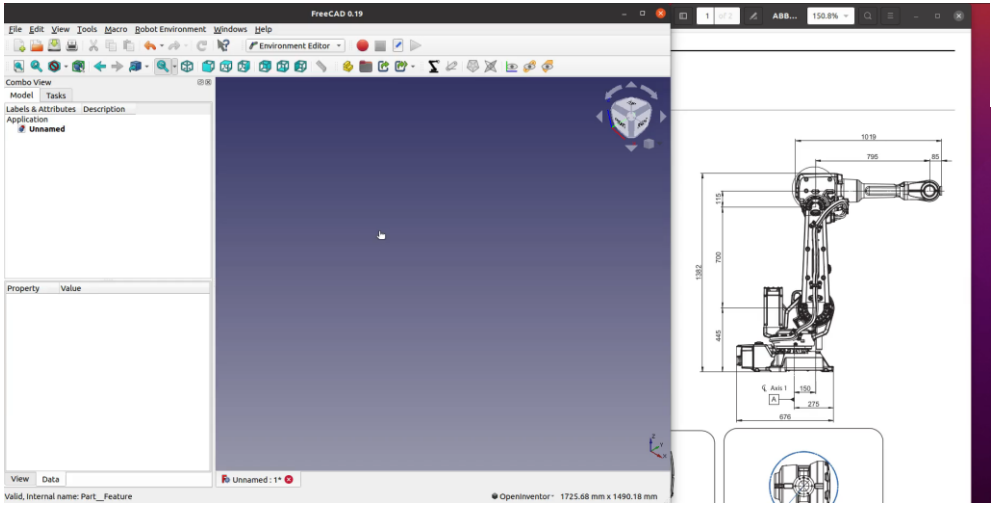
- ARM Institute project led by Rensselaer Polytechnic Institute (RPI) with GE, SwRI, and Yaskawa
  - Realized through pose optimization with redundancy resolution
  - Greedy motion primitive fitting (MoveL to MoveC)
  - Adjust blending zones and waypoint position based on trajectory error
  - Outputs for consumption into motion planner – plug-in to Tesseract



Error Stats	Avg Error (mm)	Max Error (mm)	Min Error (mm)	Std Error (mm)	Avg Angle (rad)	Max Angle (rad)	Min Angle (rad)	Std Angle (rad)
Curve 1	0.0021	**0.163**	0.00038	0.03	0.0016	0.0061	0.00008	0.0014
Curve 2	0.094	**0.436**	0.0054	0.073	0.0027	0.0117	0.0005	0.0023

https://arminstitute.org/projects/optimized-robot-motion-program-for-tracking-complex-geometric-paths/

Addressing manufacturing voice

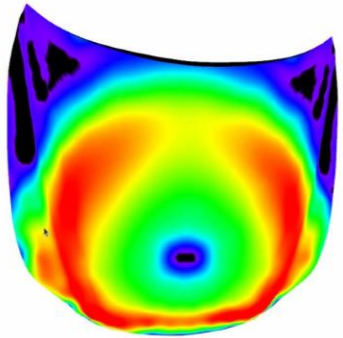


SWORD

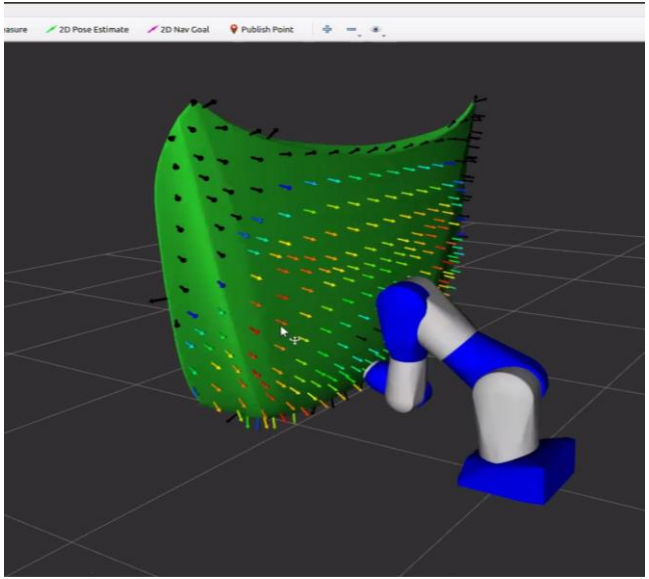
Starting Beta Testing with ROS-I Members

Quantitative Robot Reach Analysis

Updates on the Reach Repository - The REACH repository is a tool that allows users to visualize and quantitatively evaluate the reach capability of a robot system at a given base position for a given workpiece. See the ROSCon 2019 presentation and video for a more detailed explanation of the reach study concept and approach.



Heat map for reachability – coming soon!



Heat map scoring of waypoints on a mesh – pose quality – new metrics! – available now!

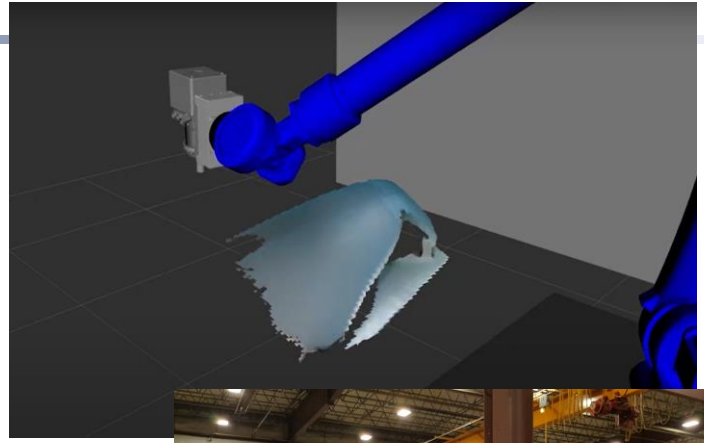
https://github.com/ros-industrial/reach

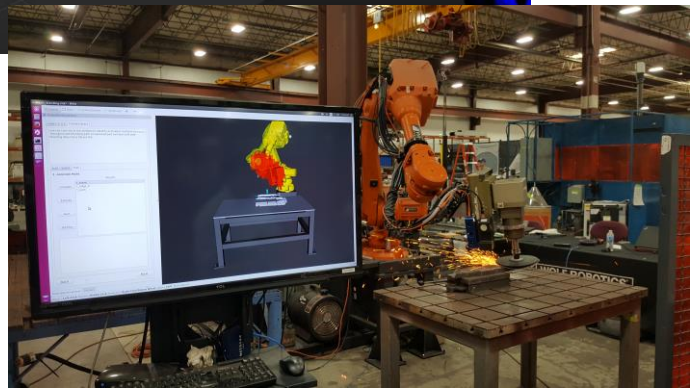
Resources for the Community

- ROS-Industrial
  - Home: rosindustrial.org
  - Documentation: wiki.ros.org/industrial
  - Code: https://github.com/ros-industrial; https://github.com/ros-industrial-consortium
  - Training: http://ros-industrial.github.io/industrial_training/
  - ROSin: http://rosin-project.eu/
- Upcoming Events (https://rosindustrial.org/events-summary/)

Thank You!

- Provide feedback
- Seek out ways to collaborate
- Engage your supplier/partners on ROS use
- Reach out if you need help





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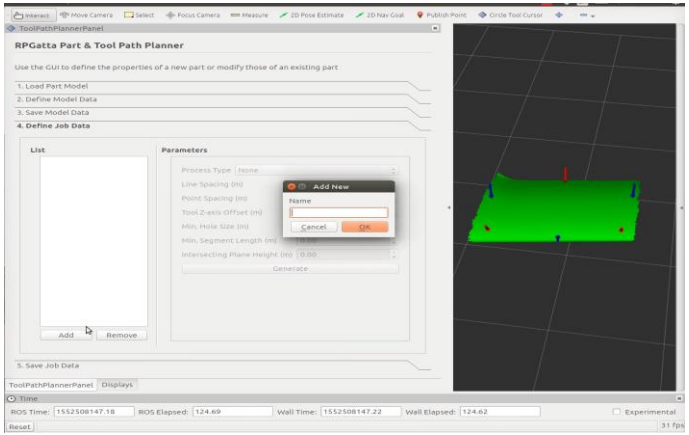
Reference

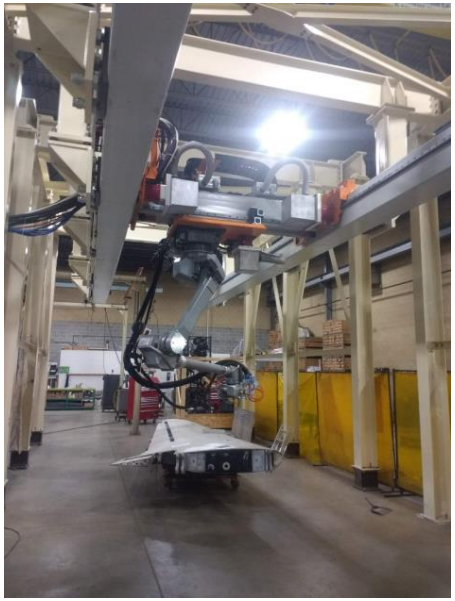
Supporting the community

- ROS 2 Technical Steering Committee (TSC)
  - Represent industry/consortium for core ROS 2 topics/roadmap etc
  - Garner support for working groups that are important to industry
- (Hardware) Interfaces Working Group
  - Working group to identify interfaces that include the semantics
  - Identify industrial standards that have good references
  - Open to everyone: https://discourse.ros.org/t/hardware-interfaces-working-group-recurring-meeting/24847/1
- Acting on Roadmapping from Industry Members & Broader Industry
  - Inform future capability development & tools to support adoption

Deployment example case studies

- Remanufacturing
  - Arbitrarily located parts
  - Multi-process
  - Stringent Requirements



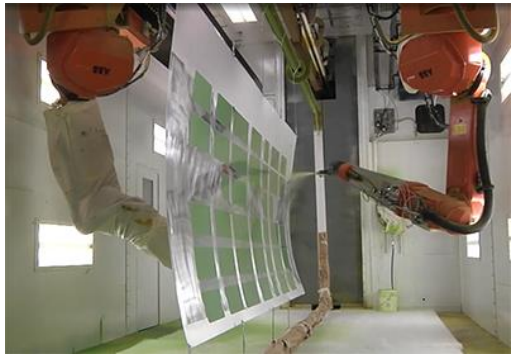


Common Framework to support 3 different systems

- Chemical Stripping
- Grit Blast
- Sanding

Industrial deployment for high mix paint

- 2014 deployment of ROS-based system by Spirit AeroSystems
- The Scan-N-Plan approach is particularly effective for these types of conditions:
  - Highly variable part mixes where hand programming is impractical
  - No CAD part models available
  - Flexible or deformable parts, making pre-programming impossible
  - Part-to-part variability that is difficult to accommodate with static programming
  - Applications requiring flexible part fixturing or no fixturing at all
- Spirit has numerous deployments and an internal team versed in leverage of ROS-based tools for solution development
  - Inspection tasking and tracking across final assembly
  - Composite sanding

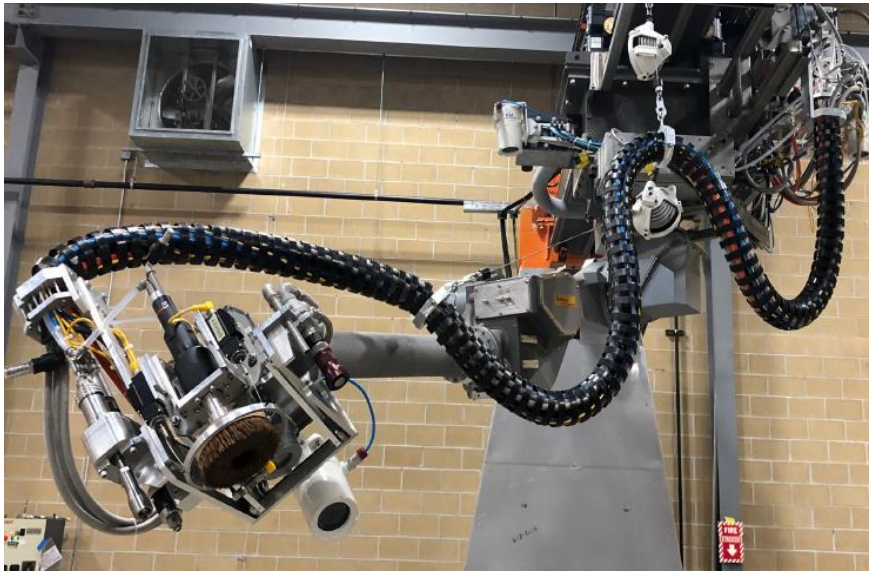


real-time robot trajectory planning use 3D scan data to register a part and create a robot trajectory on the fly

Lessons learned & new capabilities

TESSERACT

- Modeling System Constraints
  - Festooning
  - DC Joint Exclusion Zones
  - Configuration
  - Limit Robot Extension
  - Numerical Rounding
  - Error Recovery
- Dynamic/Conditional Tasking
  - cpp-taskflow
- Realtime Path Planning
  - GPU accelerated planning/checking



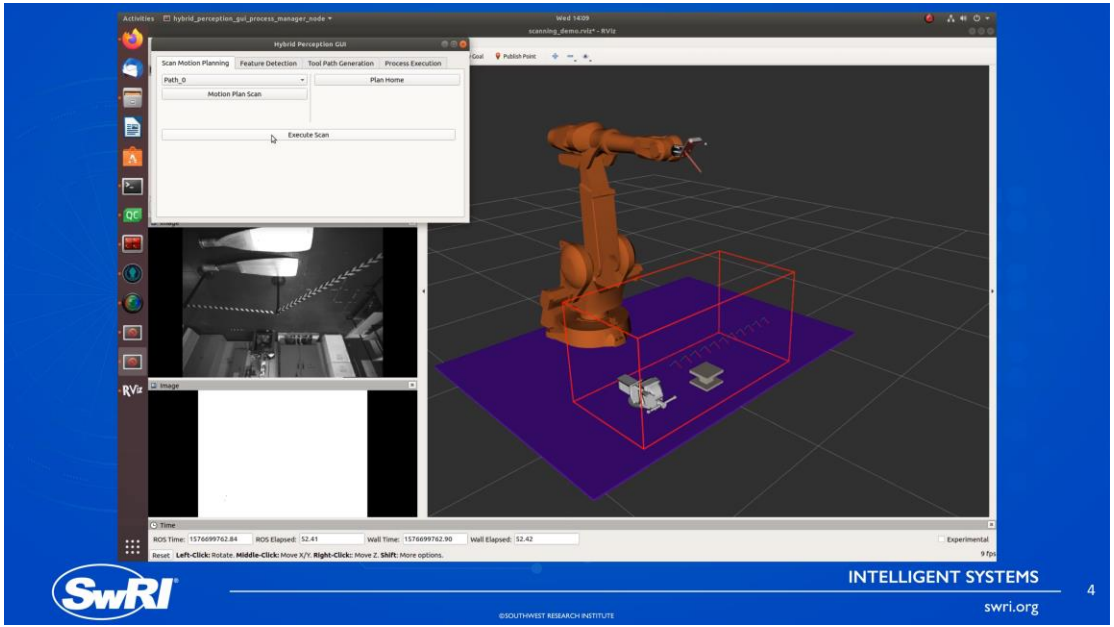
Additional Challenges – solution provider challenged with talent retention, software framework complexity

Take aways

- Open source is a key enabler for new capability to be realized in industrial solutions
- Extensible well architected frameworks can provide launch points for new solutions in numerous domains
- There are opportunities to inform and engage with advanced capability developers to align capabilities with needs in the materials joining community
- There are key roles to be filled to address skills, sustainability, and growth of these foundational capabilities on shop floors

On the fly feature identfication

- Annotating 3D data with output from 2D classifiers
- Semantic Segmentation



https://rosindustrial.org/news/2020/6/11/hybrid-perception-systems-for-process-feature-detection