Flexible Framework for Quantitative Reachability Analysis

SOUTHWEST RESEARCH INSTITUTE®

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INTELLIGENT SYSTEMS

swri.org

Agenda

- Background
- Existing solutions
- REACH
- Results Metrics
- Framework
- Plugins
- Example
- Future work
- Relevance

Background

- Industrial robotic systems designed to perform specified task(s)
  - Opposed to some robotics applications where new use-cases are researched on existing hardware
- Considerations for robotic system design
  - Workspace size
  - Workspace constraints
  - Workpiece geometry
  - Robot size
  - Robot configuration
- **How to evaluate concepts to objectively?**

Background

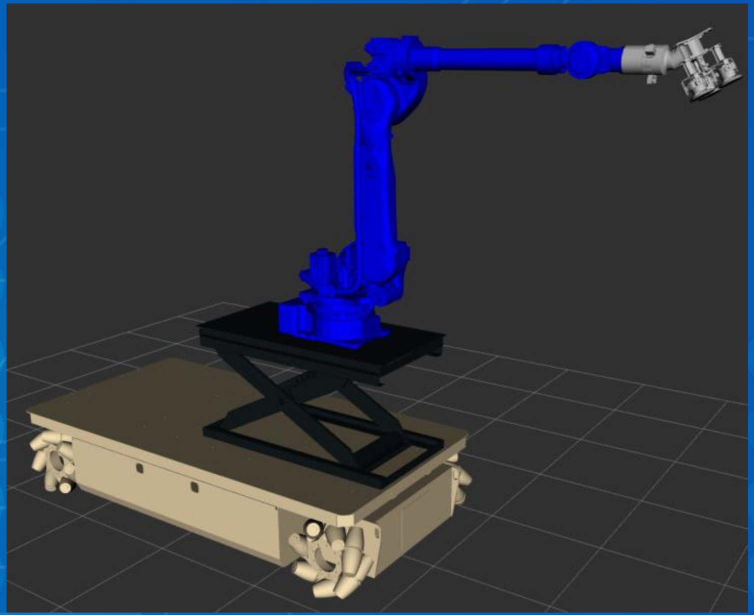
- What do we want?
  - A design that:
    1. Can reach an acceptable area on a workpiece with a given tool(s)
    2. Has the most flexibility for accommodating new parts/processes and/or changes to the environment
    3. Stays as far away from collision with the environment as possible
  - To understand:
    - How changes to system configuration affect the goals defined above
    - How the robot system will reach desired points

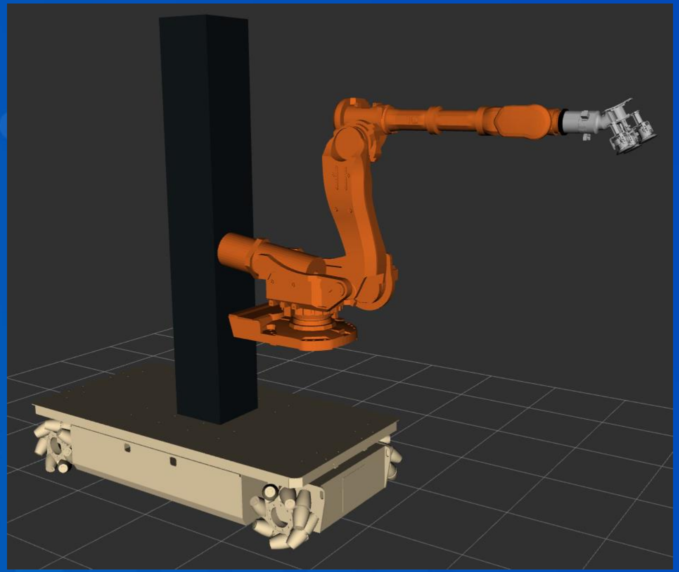
SwRI Examples

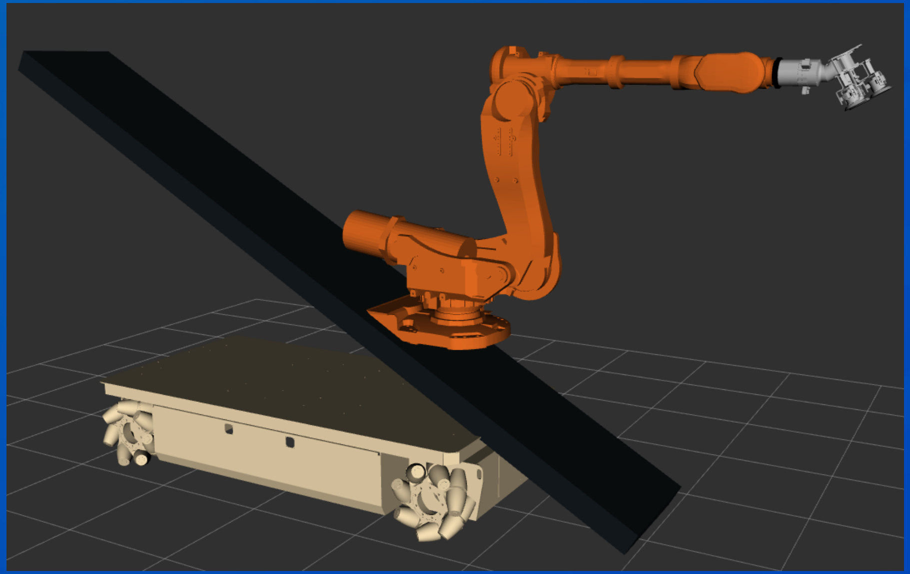
- Laser De-paint Robot
  - Must reach ~90% of area on mid-size aircraft (e.g. Boeing 737, Airbus A320)
  - Proposed configuration: 11+ DOF
    - 8+ DOF manipulator
    - 3 DOF mobile base

SwRI Examples

- Military Aircraft Maintenance Robot
  - Must service ~50% of area on C-17 aircraft
  - Tool Z-orientation free
  - Proposed configuration: 10+ DOF
    - 7+ DOF manipulator
    - 3 DOF mobile base

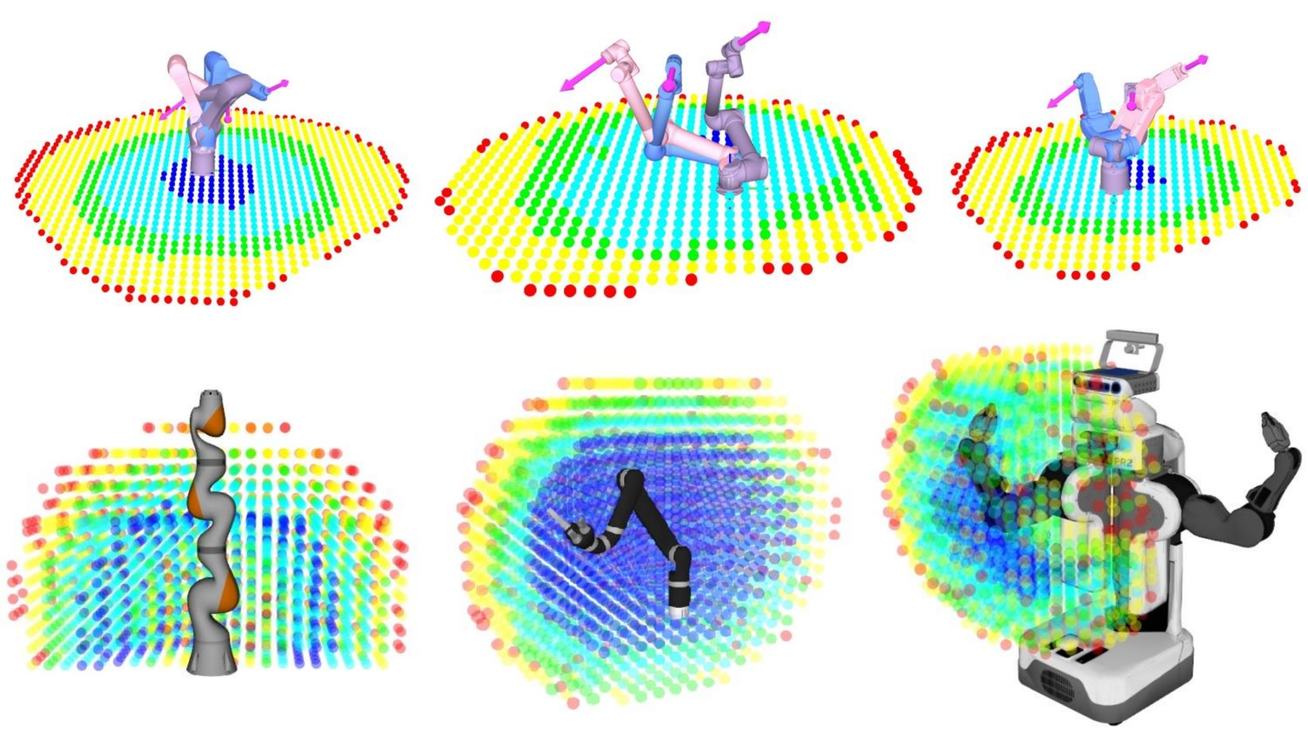






Existing Solutions

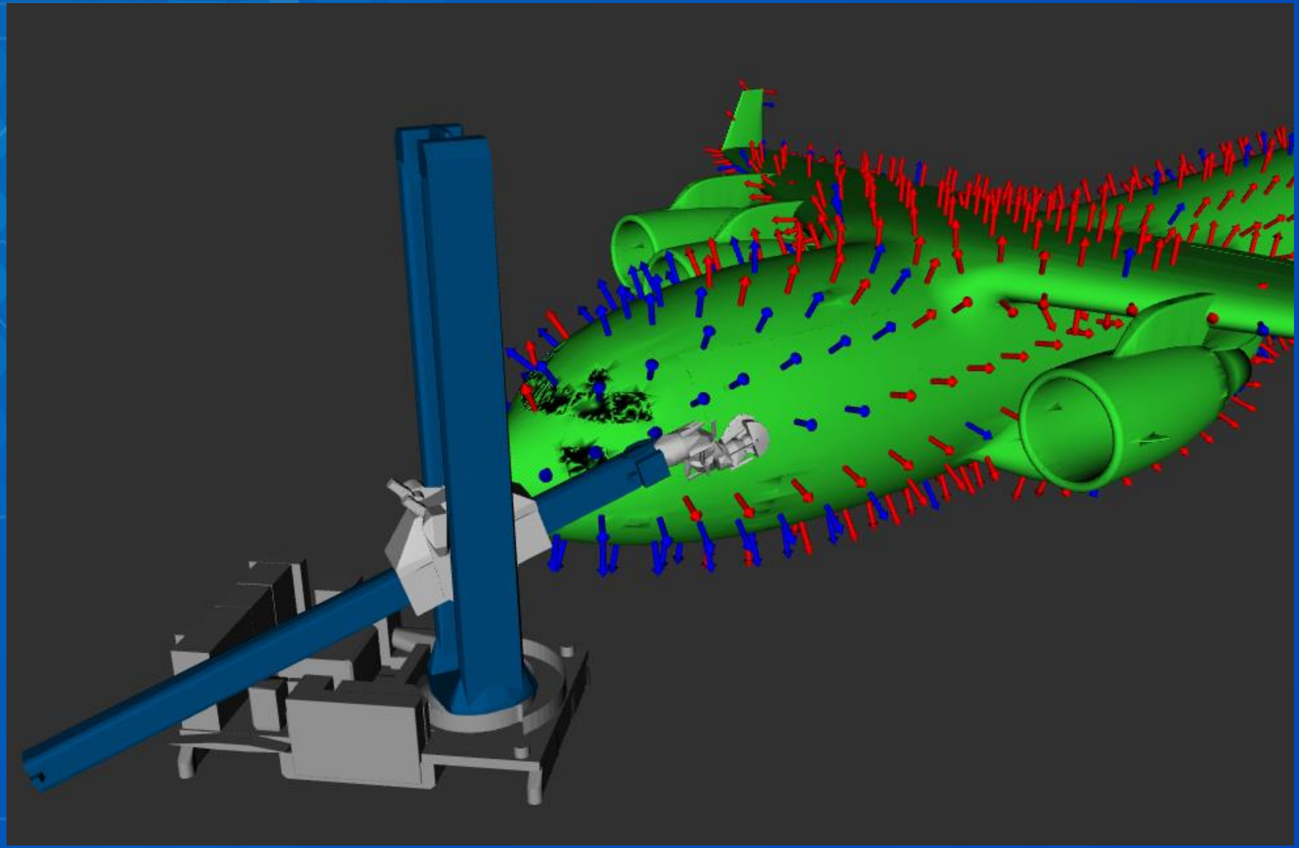
- Brute force
  - CAD environment
  - Offline programming software
  - 3D printed models
  - **Hard , time-consuming, and expensive**
- Smarter Approach
  - Automated robot base placement
    - Siemens Process Simulate
      - **Insufficient for high-DOF systems and mobile robots**
  - Inverse reachability
    - ROS-I Reuleaux package
      - **Lacks focus on the workpiece**



Adapted from [1]

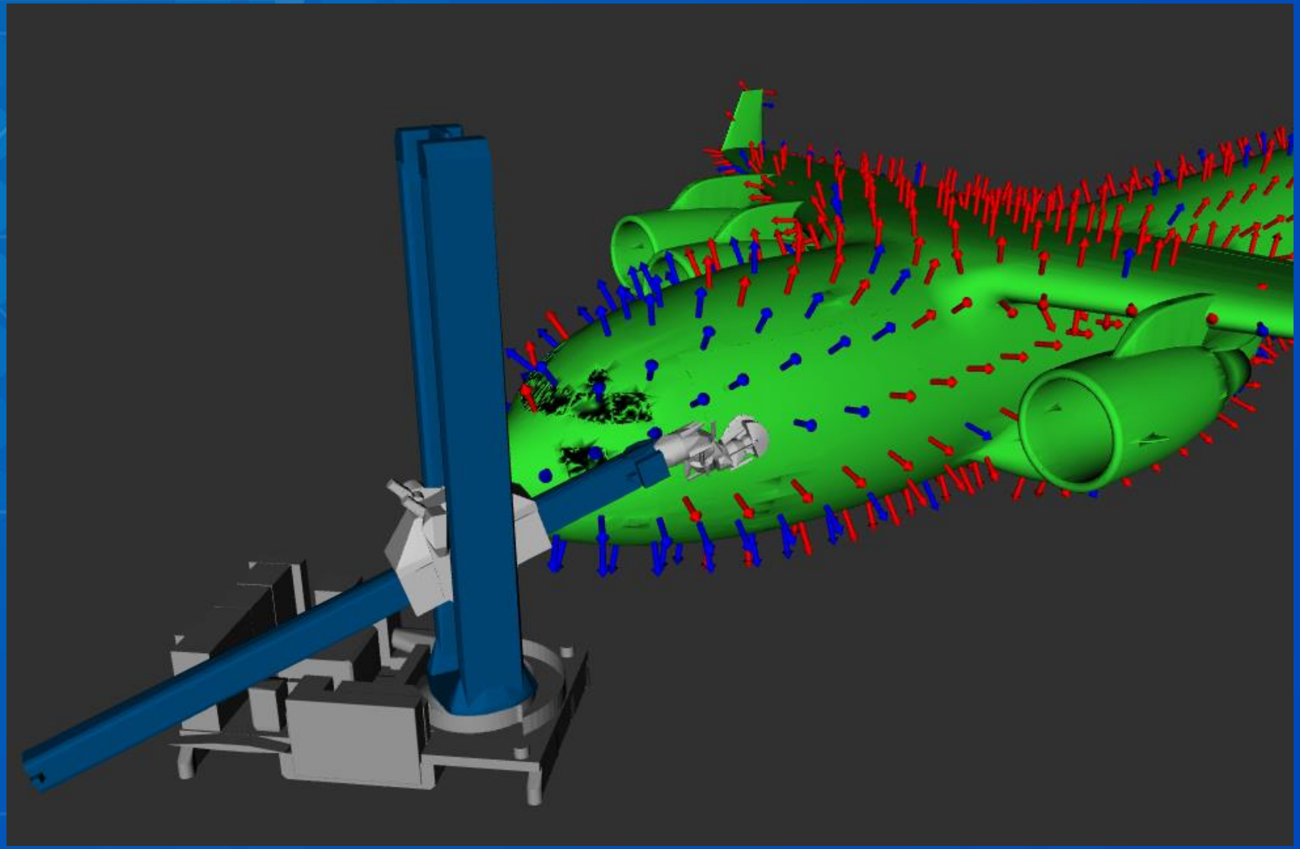
REACH

- REACH
  - https://github.com/ros-industrial/reach
- Core Process
  - Generate desired reach points on a workpiece
  - Solve inverse kinematics at each point
  - Evaluate the reachability at each point
  - **Maximize the reachability values**
  - Report and visualize the results



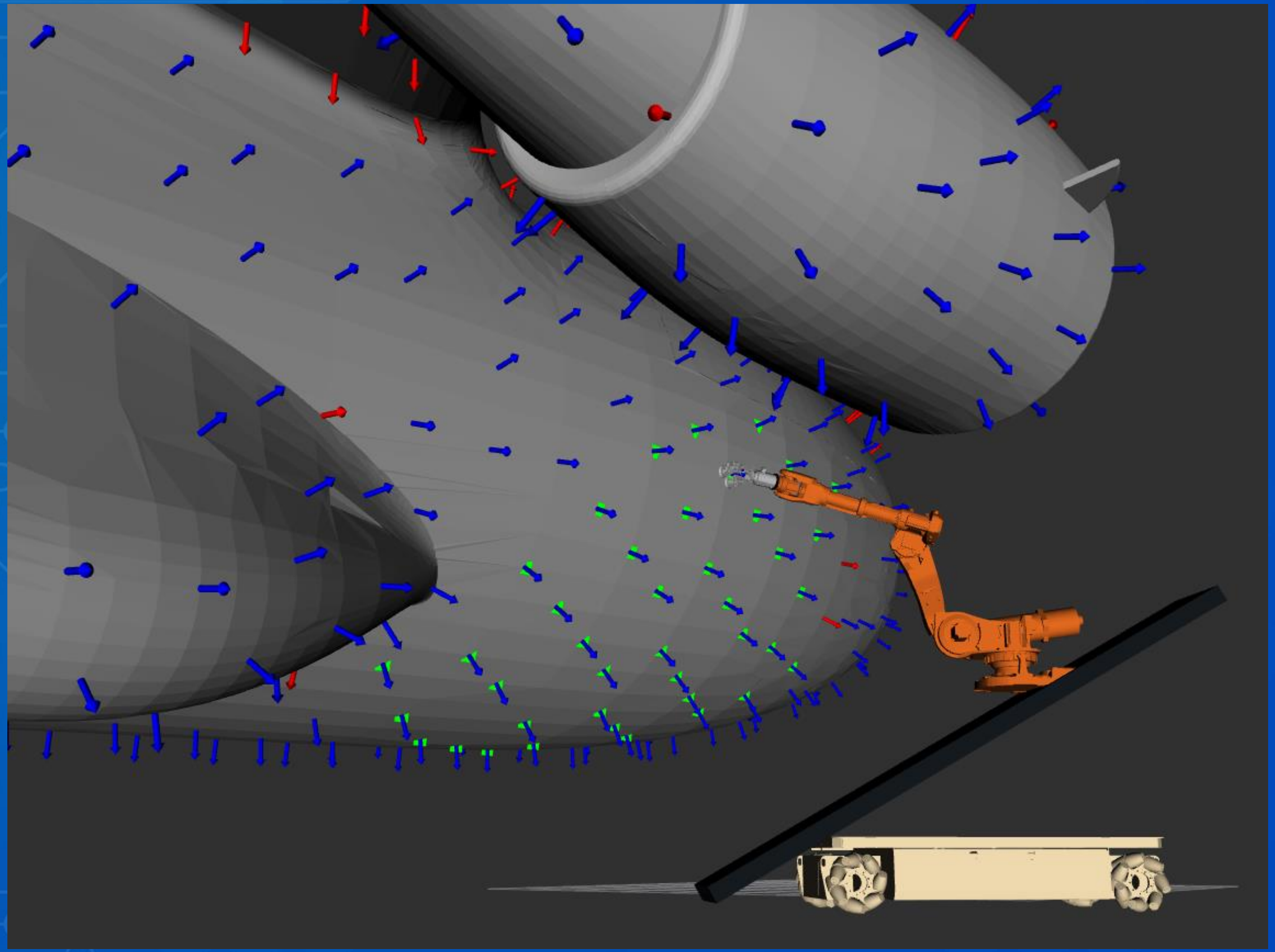
REACH

- Maximize the reachability values
  - Infinite number of IK solutions for high-DOF systems
  - Gradient-based IK solver
  - Initial IK solution generally produces low score (if solution is even found)
  - At each target
    - Use neighbors as IK seed states
    - Re-solve IK at target
    - Re-evaluate reachability at target
  - Iterate until reachability stops improving



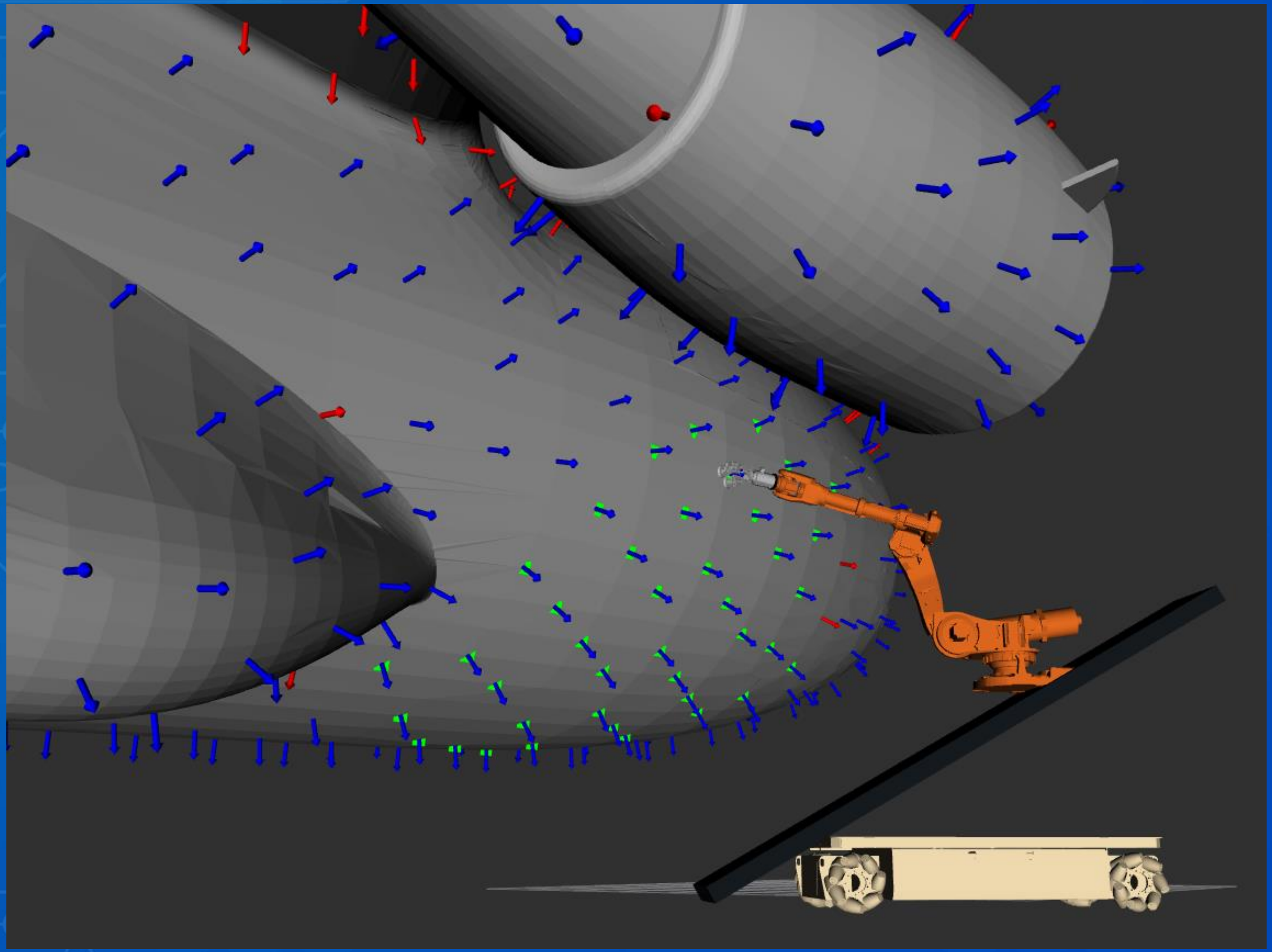
Framework

- Plugin-based architecture
  - Environment/inverse kinematics interface
  - Reachability evaluation criteria
  - Display interface
- Provides flexibility for different back-ends
- User-specifiable via YAML file



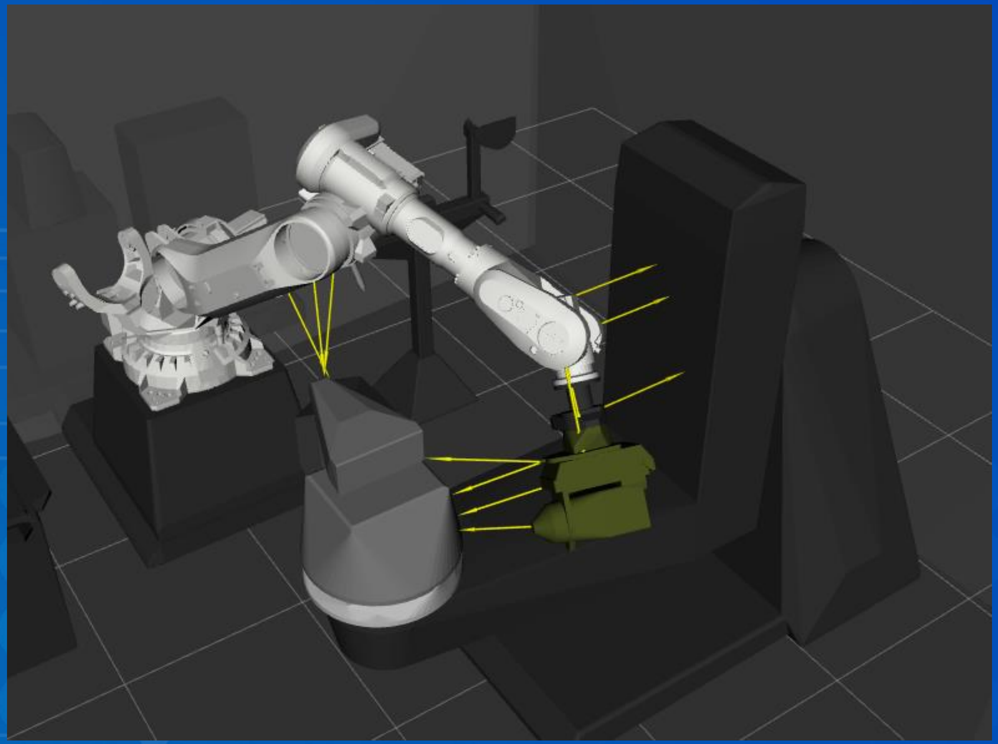
Results Metrics

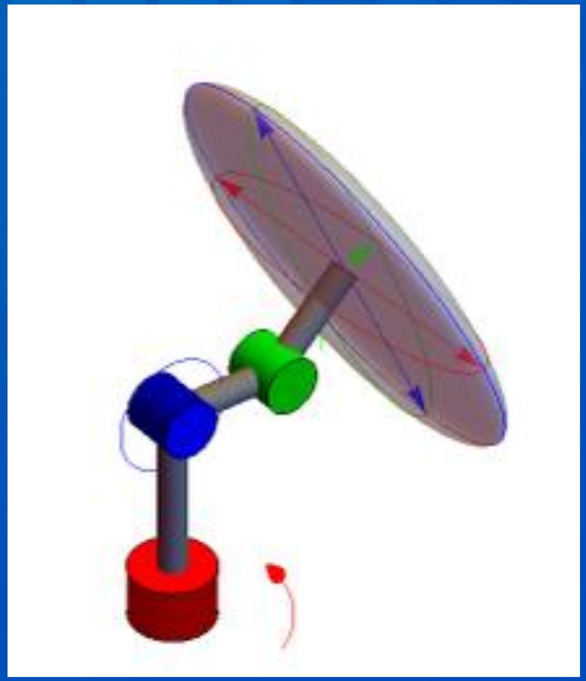
- Results Metrics
  - Percentage of targets reached
  - Total reachability score of all points
  - "Potential" total reachability score
    - What would the score be if the robot reached every target?
    - Total score / percentage reached
  - Average number of reachable neighbors



Plugins

- Inverse Kinematics
  - 6-DOF constraint
  - Discretize about Z-axis
- Evaluation criteria
  - Manipulability
    - How easily the robot can move in any direction from a given pose
  - Nearest distance from collision
  - Distance from joint configuration
  - **Combination of metrics (sum, product, etc.)**

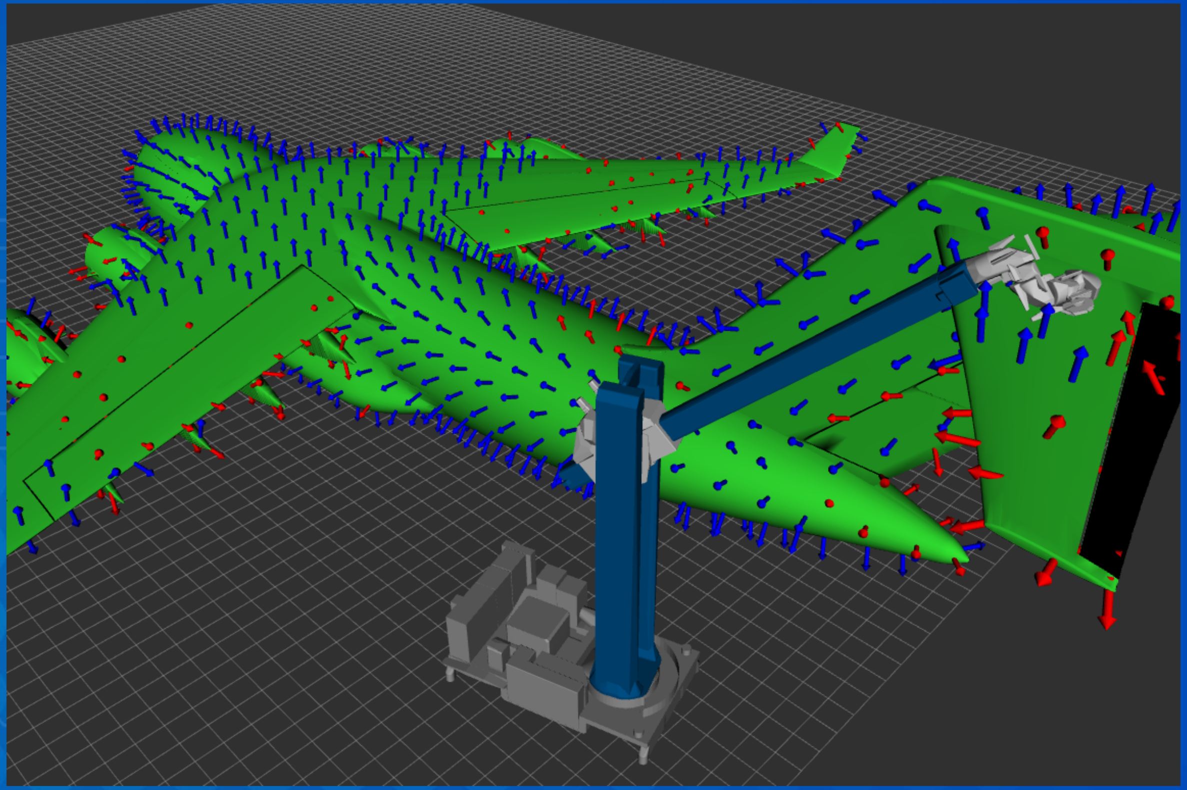


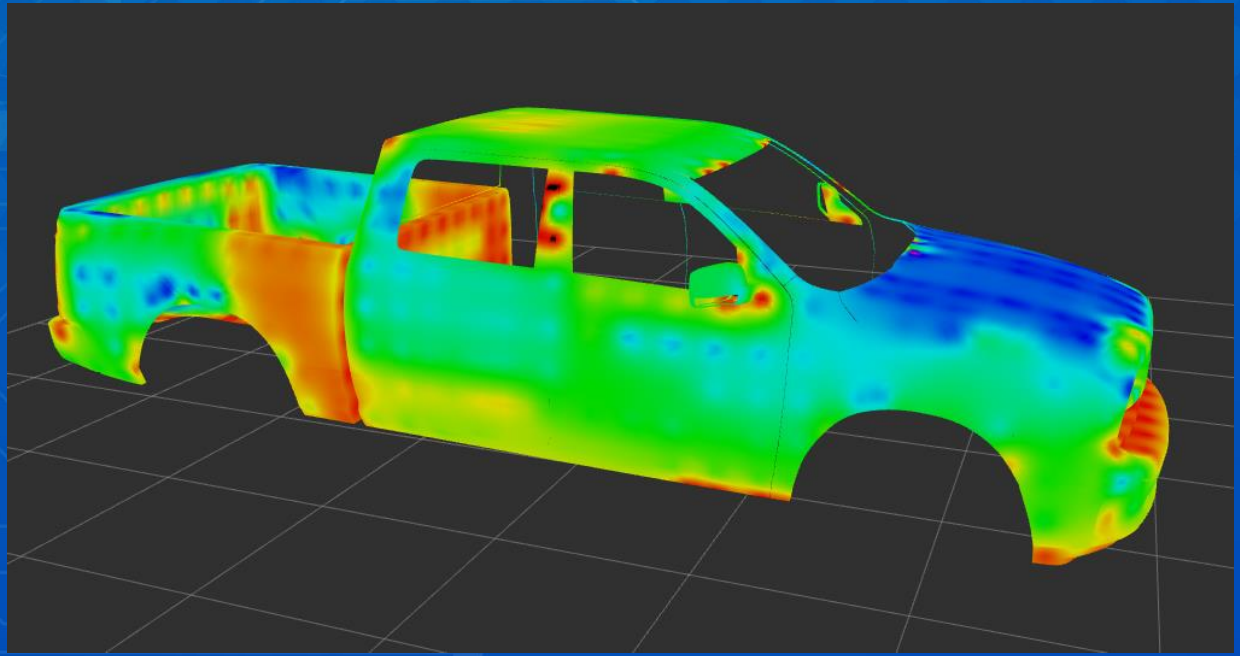


Adapted from [2]

Plugins

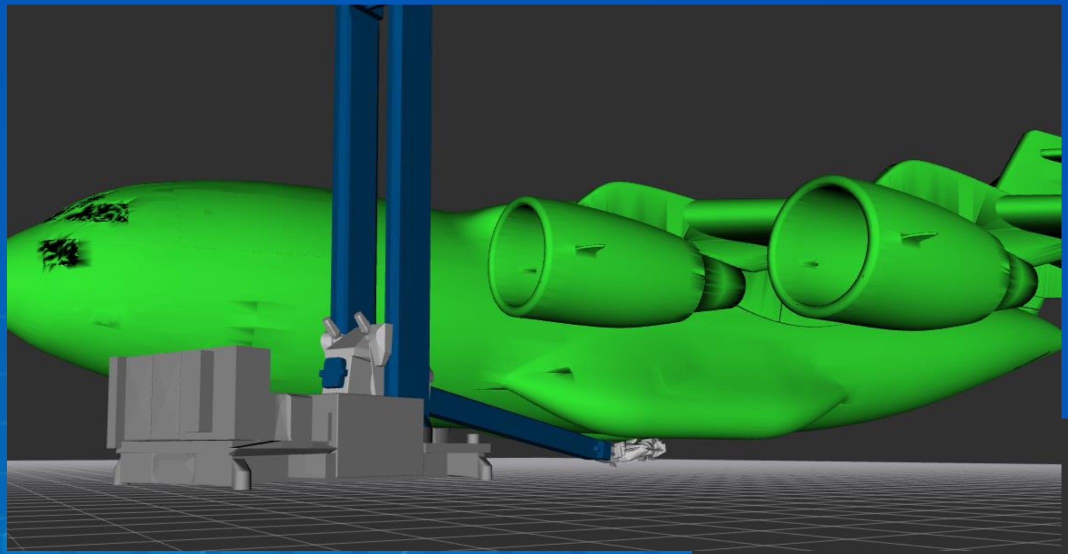
- Display plugin
  - Interactive markers at targets
    - Display robot state
    - Re-solve IK
    - Show seed state
  - Comparison between configurations
  - Results heat map

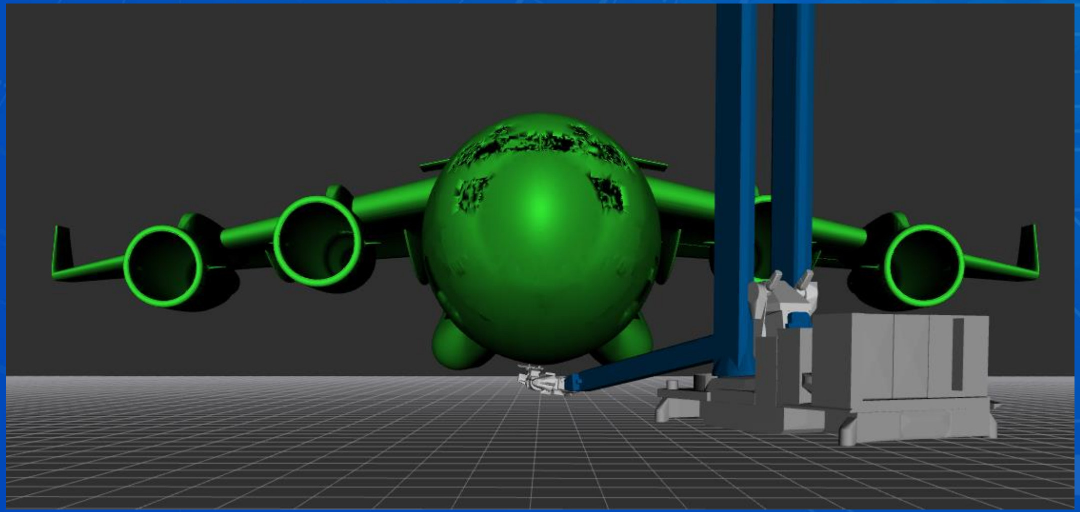


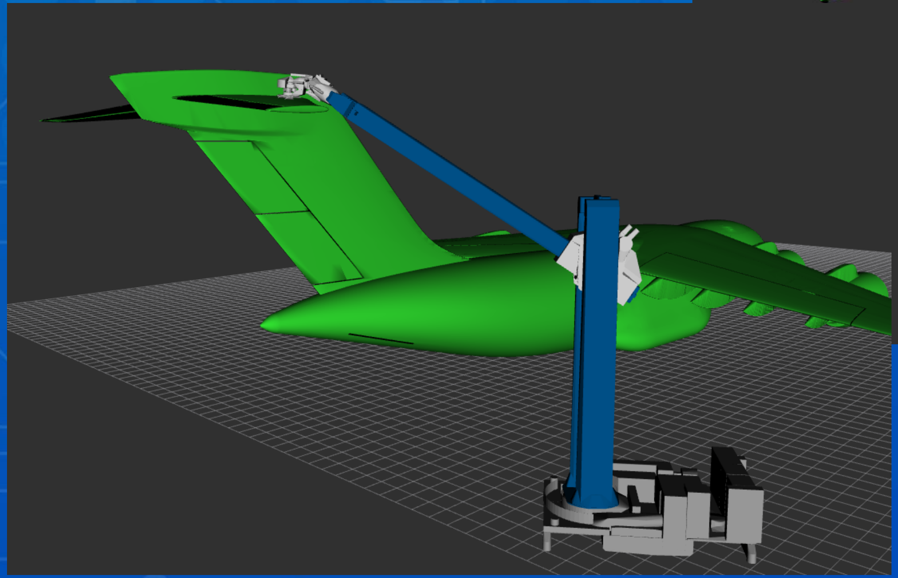


Example

- Laser De-paint Robot
  - C-17 aircraft
  - Results
    - Reach percentage: 93.6%
    - Score: 328,378
    - Normalized score: 350,832

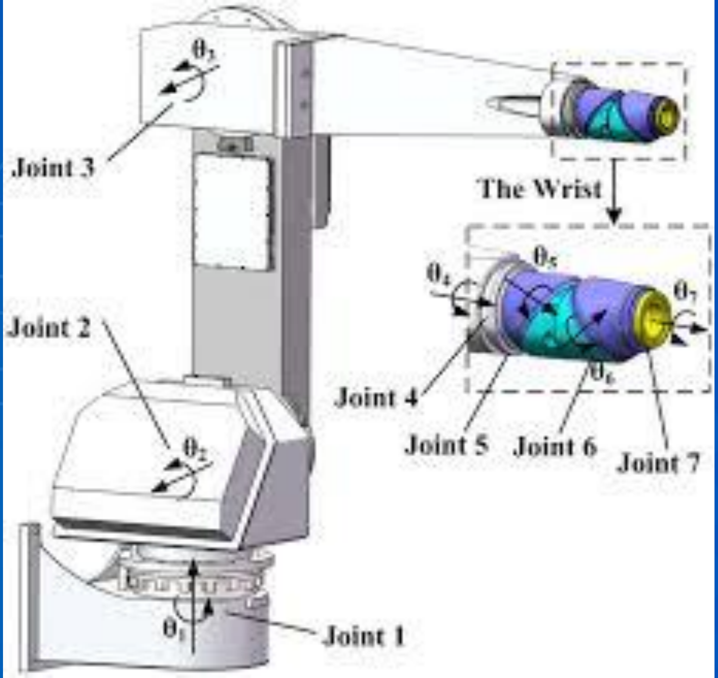






Example

- Decide between several design concepts
  - Robot mounted on gantry
  - Multiple workpieces
  - Spherical wrist vs. offset wrist robot
- Use reach study data to narrow down concepts
  - % reachable: R1 ≈ R2
  - Raw score: R2 > R1
  - Potential score: R2 >> R1
  - Use Design1, Robot 2



Adapted from [2]

Design	Work-piece	Robot 1			Robot 2		
		% Reached	Raw Score	Potential Score	% Reached	Raw Score	Potential Score
D1	Object 1	91.90%	338.5	368.3	91.20%	351.9	385.9
	Object 2	73.60%	290.5	394.7	70.20%	345.2	491.79
D2	Object 1	92.70%	357.5	385.7			
	Object 2	73.20%	287.2	392.4			
D3	Object 1	74.80%	301.8	403.5	73.50%	317.0	431.3
	Object 2	57.40%	271.1	472.3	54.10%	317.5	586.85

Future Work

- Reduce setup complexity
  - GUI
  - Improve mesh sampling to produce target points
  - Tighter integration of mesh sampling into application
- Visualization
  - Interpolate results to create heat map
  - Results by individual evaluation metric
- Non-linear optimization to maximize pose reachability

Relevance

- Makes analysis of robotic systems more feasible (especially high-DOF systems)
- Better analysis for single robot
  - Task/process oriented
  - Reach percentage
  - Visualize robot state at various target points
- Better analysis for multiple robot concepts
  - Compare reachability scores directly
  - Visualize reachable target “diffs” between various concepts
- Informs design decision more effectively than “gut feel”

Questions?

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2. http://demonstrations.wolfram.com/ManipulabilityEllipsoidOfARobotArm
3. Wang, Xuhao & Zhang, Dawei & Zhao, Chen. (2017). The inverse kinematics of a 7R 6-degree-of-freedom robot with non-spherical wrist. Advances in Mechanical Engineering. 9. 168781401771498. 10.1177/1687814017714985.