engineering laboratory

Performance Benchmarks to Advance the State of Robotic Hands

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NIST
National Institute of Standards and Technology
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Overview

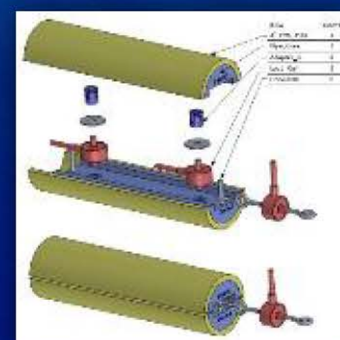
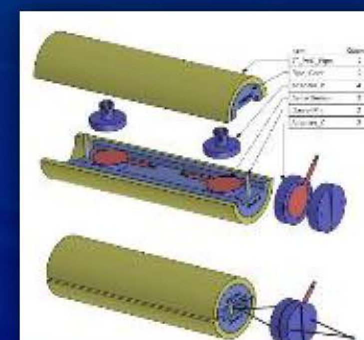
- Why robotic hands?
- Problem
  - What makes a 'good' hand?
  - Informing consumers
- Goal
  - Feedback for R&D, benchmarking
  - Technical specifications
- Mechanism
  - Test methods and metrics
  - Artifacts and datasets
  - Data analysis tools
- Levels
  - Elemental, Functional (task)




NIST Testbed

- Hands
  - SCHUNK Dexterous Hand II
  - ROBOTIQ 3-Finger Gripper
  - Wonik Robotics Allegro Hand
  - Empire Robotics VERSABALL Gripper
  - Soft Robotics Inc.
  - Conventional parallel grippers
- Tactile Sensors
  - Syntouch BioTac, BioTac SP, & Numatac
  - OptoForce 3D Force sensors
  - ATI Industrial Automation Nano17 F/T transducers
  - Weiss Robotics Tactile sensors
- Arms
  - KUKA LWR 4+
  - Universal Robots UR5, UR10
  - ABB YuMi
  - Rethink Robotics Baxter

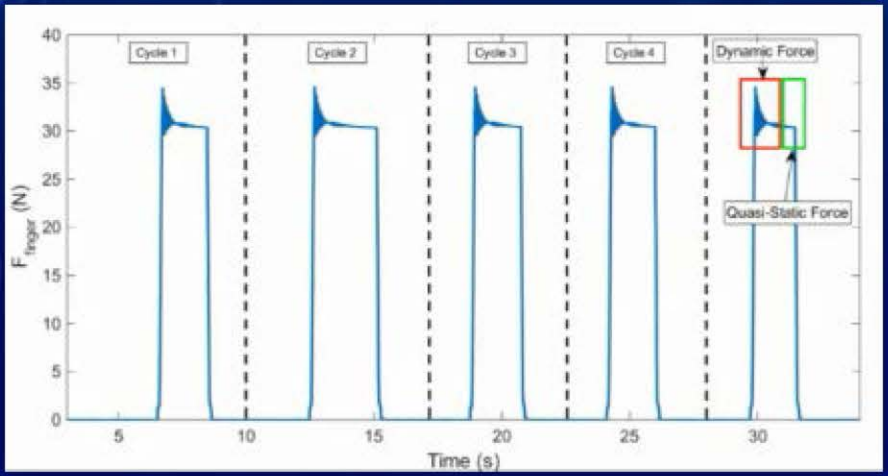
Elemental Test Methods

Test Method	***Measurement Instrument***
Finger Strength Touch Sensitivity Finger Force Tracking Force Calibration	
Grasp Strength Slip Resistance Grasp Efficiency Cycle Time	 
In-Hand Manipulation Object Pose Estimation	

http://www.nist.gov/el/isd/grasp.cfm

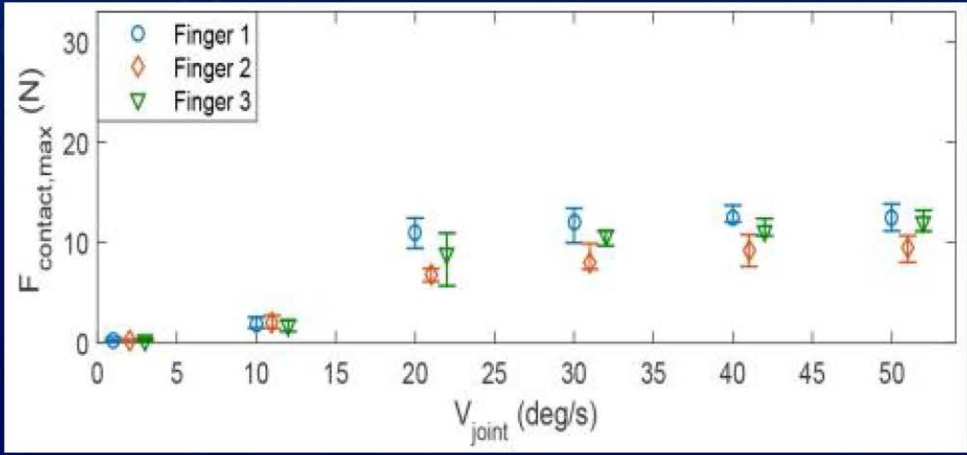
Finger Strength

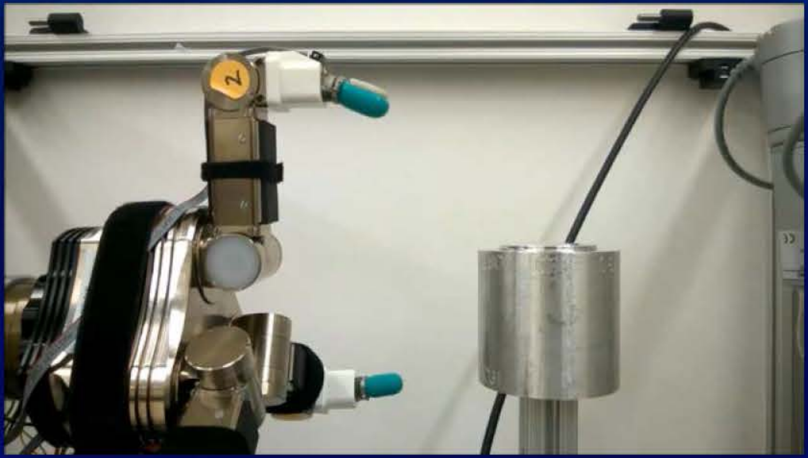
- What: Maximum force a robotic finger can impose on its environment
- How: Measure peak quasi-static forces with load cell at full finger extension
- Why: most independent measure of a hand's strength, inherent variability across mechanically equivalent fingers



Touch Sensitivity

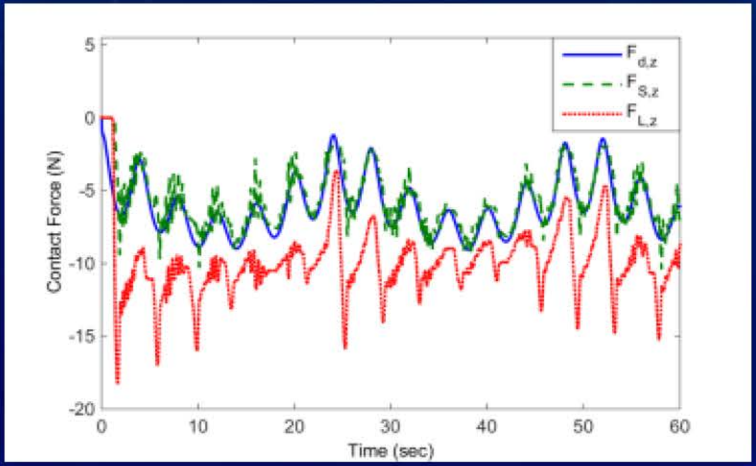
- What: A measure of the smallest, self-registered contact force exerted by a robotic finger on an object
- How: Measure maximum impact force at full finger extension at various joint speeds
- Why: Force dependent on speed, minimize disturbance during object acquisition





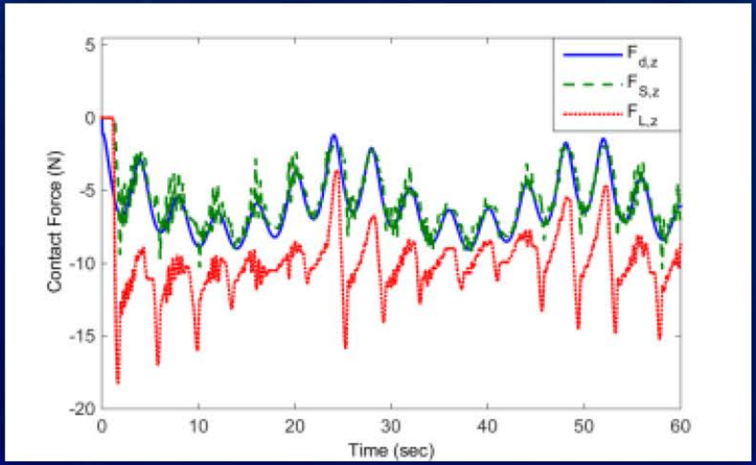
Finger Force Tracking

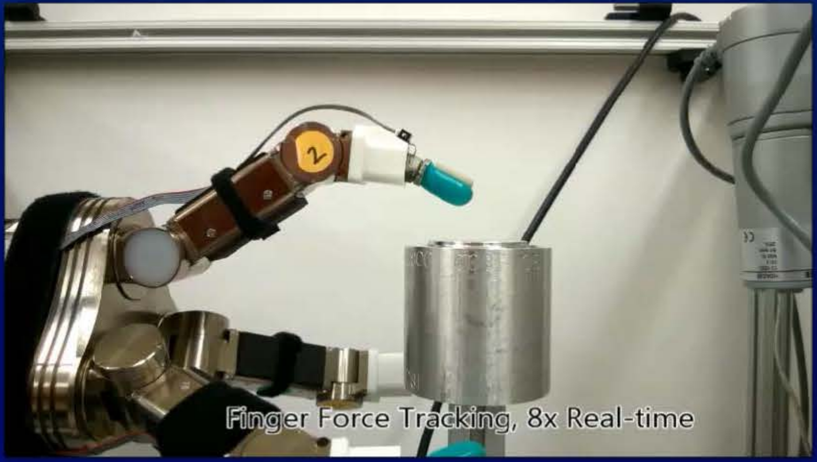
- What: Finger ability to impose desired contact forces on its environment
- How: Measure disparity between hand-reported forces and reference force-torque transducer
- Why: Prerequisite for force-modulated grasping and manipulation



Force Calibration

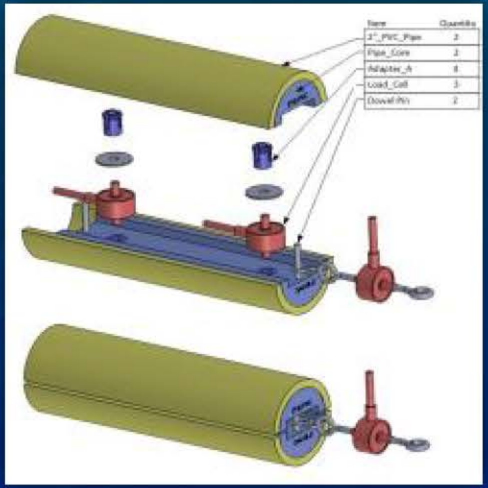
- <u>What:</u> Quantifying force calibration accuracy of onboard tactile sensing
- <u>How:</u> Coupled with finger force tracking test
- <u>Why:</u> Non-removable force sensors, force accuracy often not reported/available, impacts force control strategies

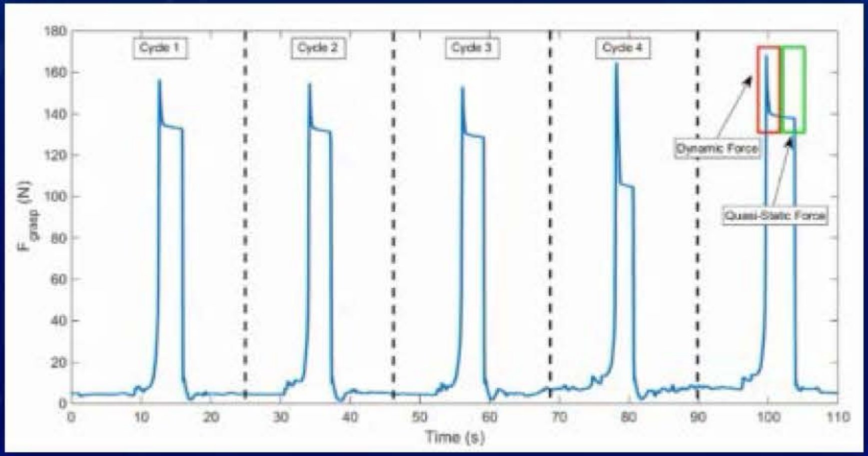




Grasp Strength

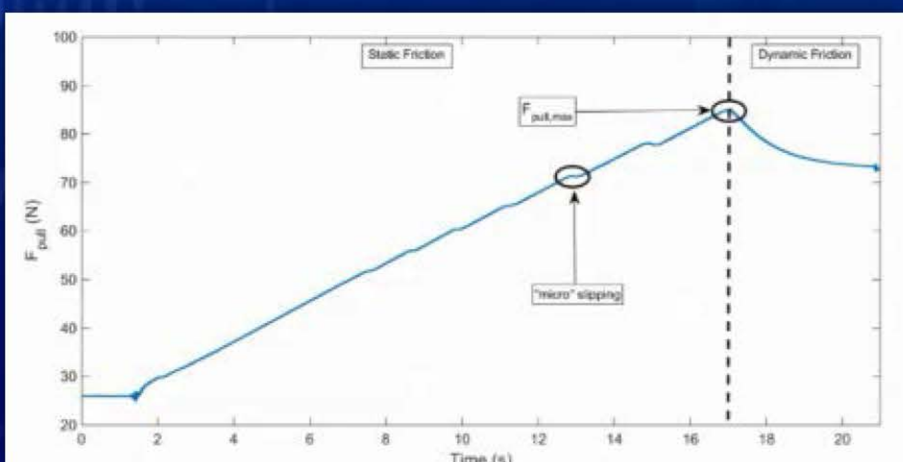
- <u>What:</u> The maximum force a robotic hand can impose on an object
- <u>How:</u> Artifact with intrinsic force sensing
- <u>Why:</u> Estimate payload





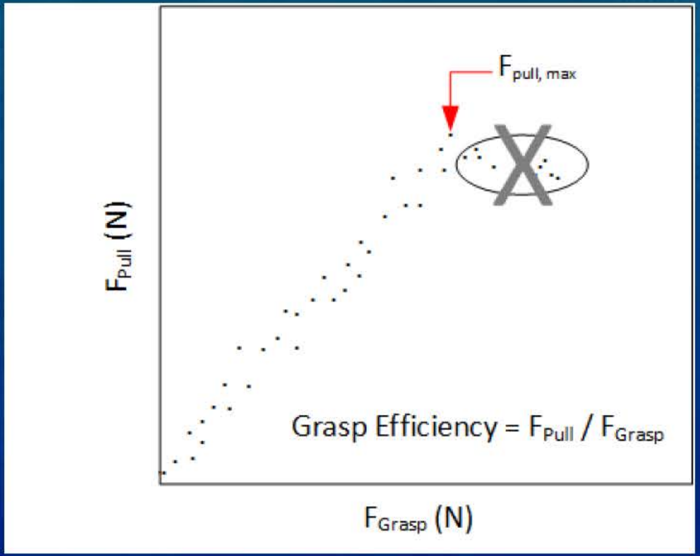
Slip Resistance

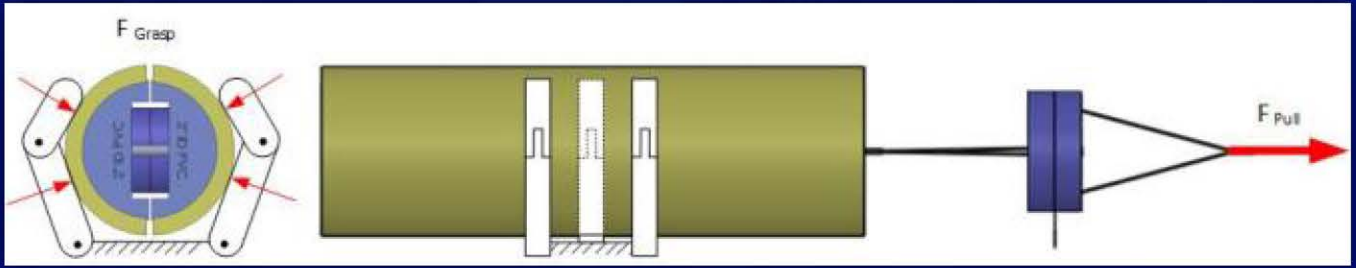
- What: Maximum force hand can sustain in shear
- How: Measure peak force at the onset of gross slipping
- Why: Indicator of minimum payload, indicator of whole-hand friction coefficient, safer to test



Grasp Efficiency

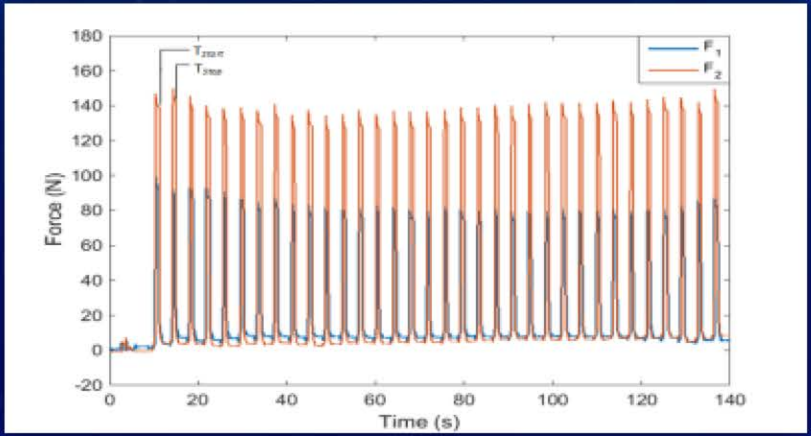
- What: Ability to force-modulate grasp with increasing object disturbance
- How: Computed at each data point collected from initial grasp force until maximum pull force (gross slipping)
- Why: Automated grasping efficiency, minimize power consumption, minimize wear-and-tear





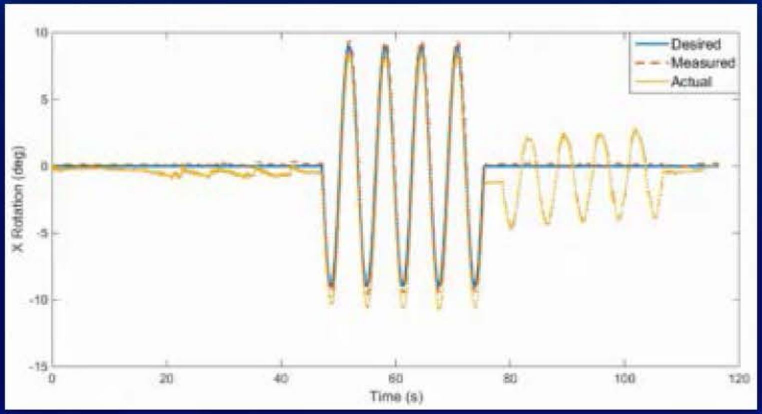
Cycle Time

- <u>What:</u> A measure of the minimum time required for a robotic hand to cycle from pre-grasp, to grasp, to pre-grasp
- <u>How:</u> Requires two consecutive cycles with a force sensing object artifact
- <u>Why:</u> estimating ppm, guide controllers and planners



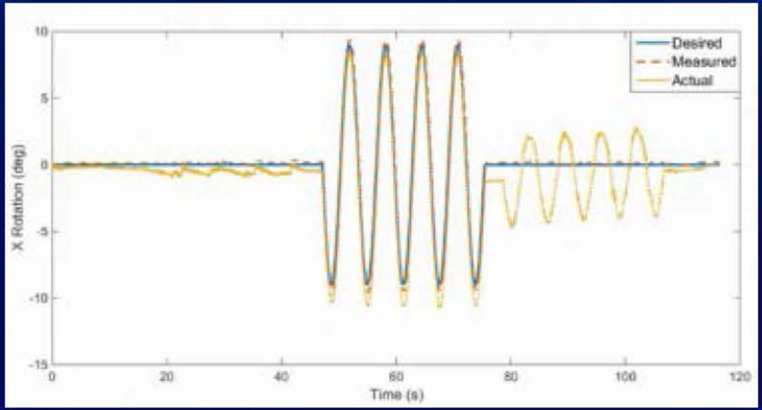
In-Hand Manipulation

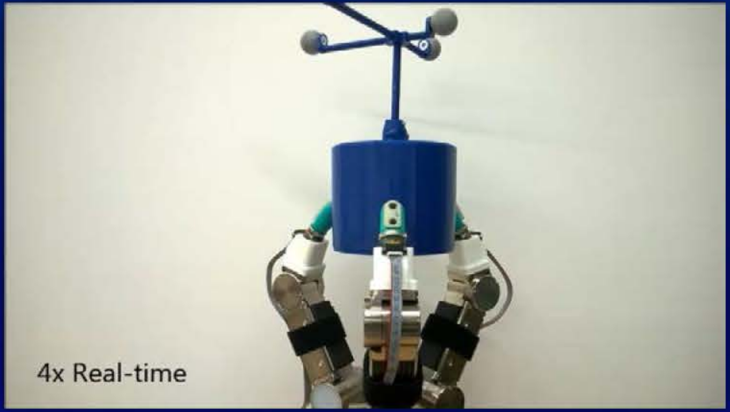
- <u>What:</u> Measure of a robotic hand's ability to control the pose of an object
- <u>How:</u> MoCap system and objects with optical targets
- <u>Why:</u> Quantifies range-of-motion, frequency response, controller accuracy and repeatability, useful for functional-level tasks



Object Pose Estimation

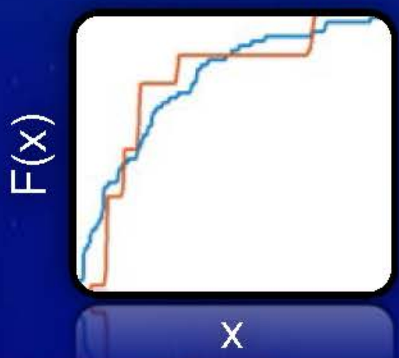
- What: Measure a robotic hand's ability to estimate the pose of an object (contact or non-contact)
- How: MoCap system and objects with optical targets
- Why: Object pose information can inform task-level operations, objects can move within grasps, visual occlusion





Functional Performance Testing

- Quantify performance of a robotic system completing a task
- Tests target assembly operations: pick-place, insertion, fastening
- Whole system-system testing
- Component testing
- Data analytics



Data Analytics

- Ordinal or Attribute Data
  - Detecting statistical difference in datasets – Kolmogorov-Conover
  - Check for differences as a whole or on a per rank basis
  - Primary performance measure: probability of success (PS)
- Continuous Data
  - Detecting statistical difference in datasets – Kolmogorov-Smirnov
  - Check for differences between sample means and variances
  - If no detectable differences, difference exists somewhere else (skewness, kurtosis)

http://www.nist.gov/el/isd/software.cfm

Pick-and-Place

- Functional test methods to measure the performance of robot systems in pick-and-place operations
- Primary measures
  - initialization time
  - execution time
  - placement accuracy

high volume, low mixture

low volume, high mixture

Pick-and-Place Gripper Effect

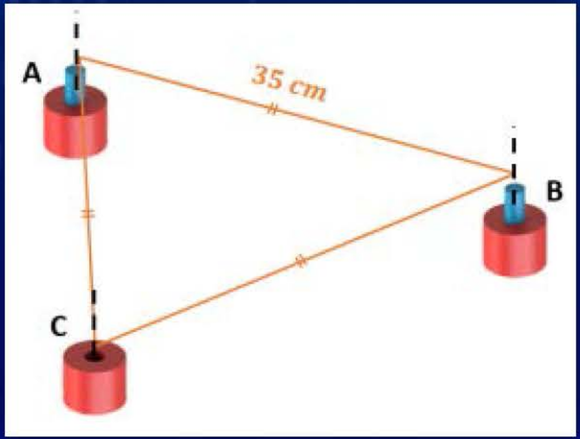
Rank	Accuracy (mm)
1	< 2
2	< 4
3	< 6
4	< 8
5	< 10

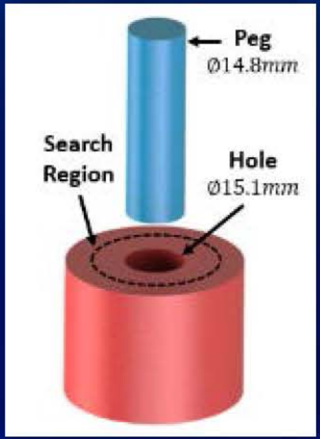
System	Execution Time (s)	PS per Rank (%)				
		1	2	3	4	5
1	168.91	6.1	43.7	78.1	96.8	98.8
2	193.55	17.3	53.4	76.7	95.6	98.8

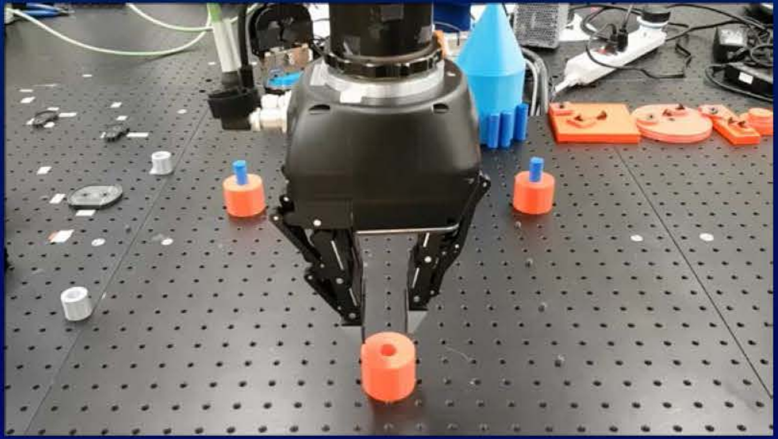
significant
not significant

Peg-in-Hole

- Functional test method to measure the performance of robot systems at basic insertions
- Triangular design facilitates cyclical testing
- Peg-hole parameters, spacing based on human data







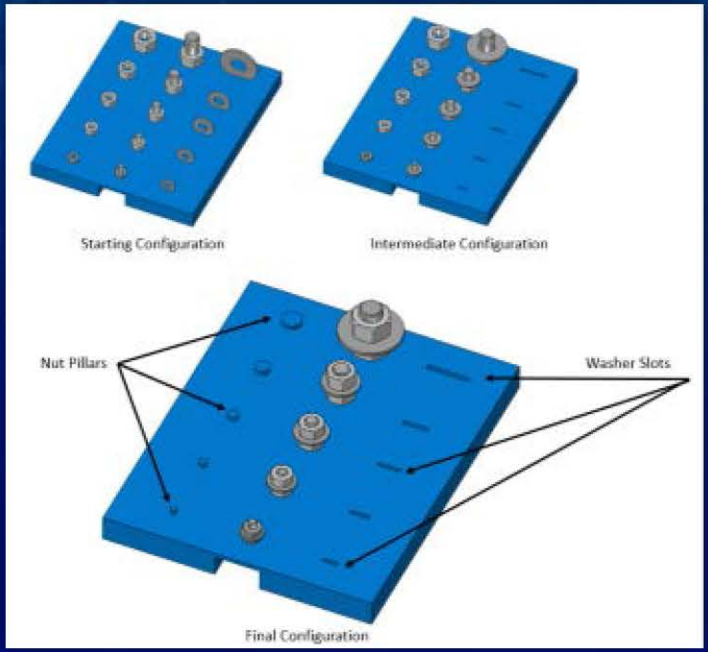
Peg-in-Hole Search Effect

Search Routine	Insertion Time (s)
Sobol	11.06
Spiral	26.23
Random	11.12

Comparison	Min. Mean Difference (s)
Sobol vs. Spiral	12.42
Sobol vs. Random	0
Random vs. Spiral	12.25

Future Test Concepts

- Pick-place object set expansion
- Fastening test
- Full assemblies
- Use of hand tools



Links

Elemental Hand Tests and Datasets - http://www.nist.gov/el/isd/grasp.cfm

Functional Tests and Datasets - TBD

Data Analytics Software - http://www.nist.gov/el/isd/software.cfm

IROS Grasping/Manipulation Competition
http://www.rhgm.org/activities/competition_iros2016/

Team

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