Benchmarking Protocols for Evaluating Small Parts Robotic Assembly Systems

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About me

Mechanical Engineer from National Institute of Standards and Technology (NIST)

6+ years of experience testing robots

2 years working with assembly robotics and NIST assembly task boards (ATBs)

Introduction

- Automation in robotics has not seen enough adoption due to the inability of robotics to support component variation, tight tolerances, and cost effectiveness.
- Benchmarking performance of assembly based robotics will push design to solve the problems associated with low-volume, high-mixture manufacturing.
- These solutions are needed by small and medium sized manufactures which make up most of the worlds manufacturing base.
- Task boards are designed to address the most prevalent operations in assembly, i.e. insertions, threaded fasteners, and fittings.
- They also address more complex operations such as handling and routing flexible parts.

Assembly Task Boards (ATB)

- NIST ATB 1 (Fig 1): Peg insertions, gear meshing, electrical connectors, and nut threading
- NIST ATB 2 (Fig 2): Alignment and insertions, handling flexible parts, actuating tensioners, and threading bolts
- NIST ATB 3 (Fig 3): Manipulating flexible cables, routing cables through obstacles, and inserting electrical connectors

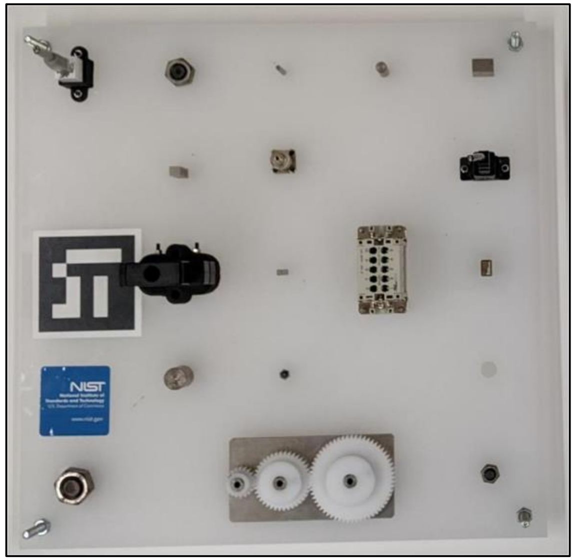


Fig. 1 Insertions and Connectors

Fig. 2 Belt Drives

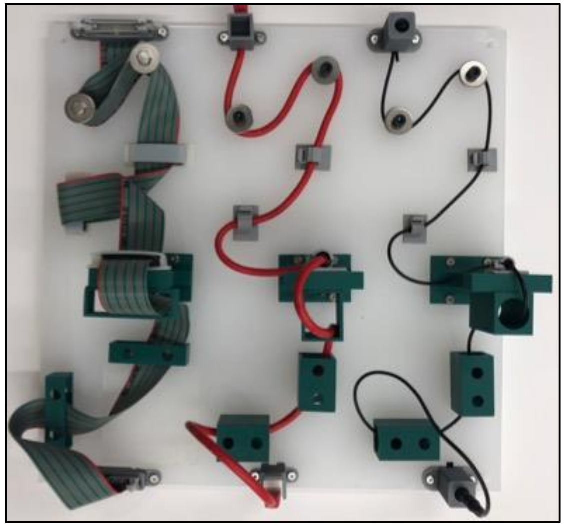
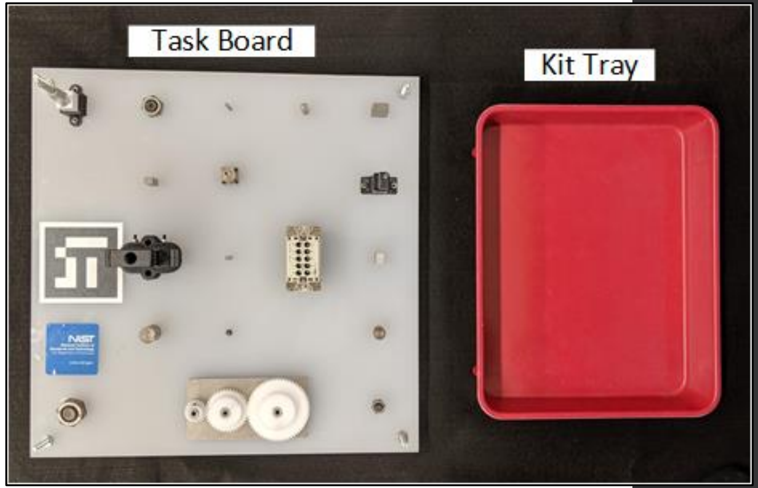


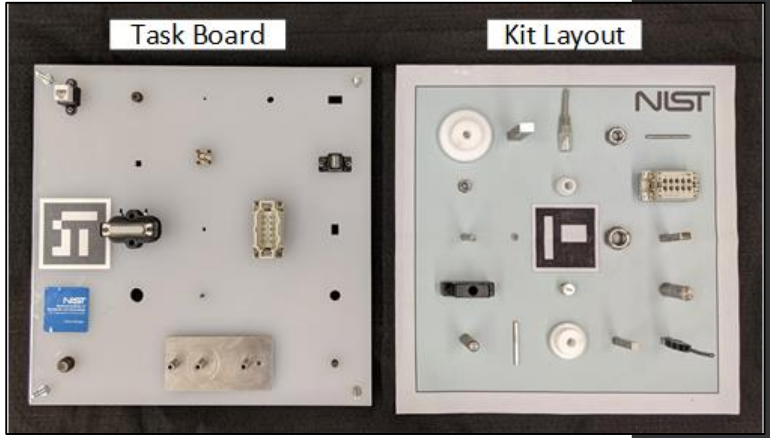
Fig. 3 Cable Routing

Protocol

- Disassembly
  - Boards begin fully assembled with a kit tray.
  - Parts are removed from the board and placed in the tray.
- Assembly
  - Boards begin disassembled with a kit layout locating the parts in predetermined orientations.
  - Parts are taken from the kit tray and assembled on the task board.
- Points are awarded based on the level of completion of individual tasks
  - Time is recorded as a secondary metric for benchmarking performance.

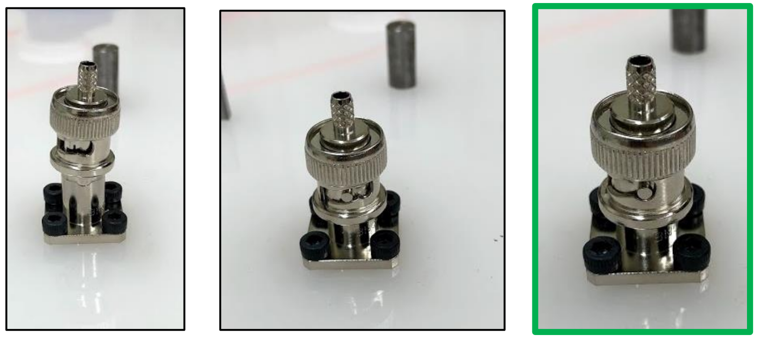


Assembled



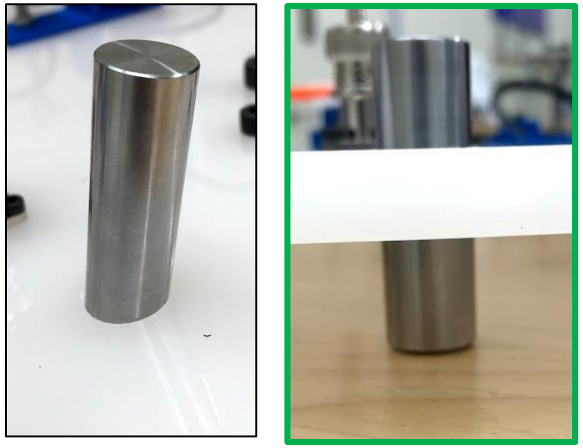
Disassembled

NIST ATB 1
Insertions and Connectors



Insertion of pegs: 4 cylindrical pegs and 4 square pegs (4mm, 8mm, 12mm, 16mm)

- Points for partial insertion and fully seated



Threading nuts: 4 sizes of nuts (4mm, 8mm, 12mm, 16mm)

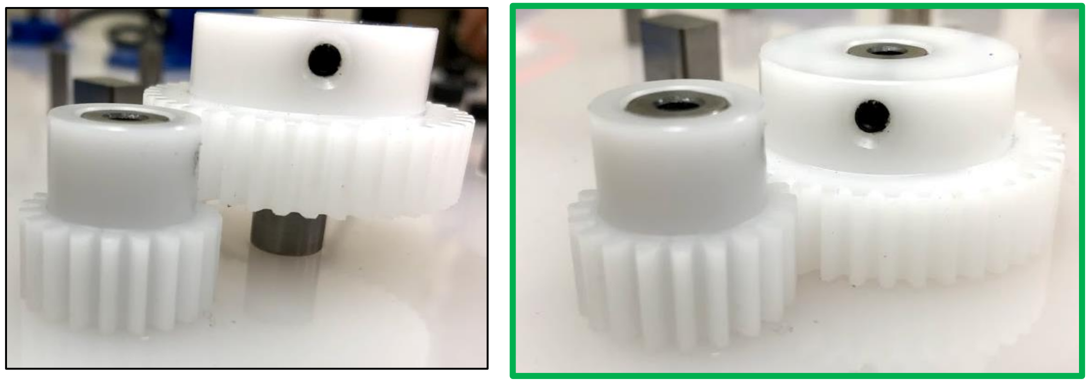
- Points for threading and fully seated

Meshing gears: 3 sizes of gears with interlocking teeth

- Points for insertion and seated with meshed teeth

Attaching connectors: 4 orientationally specific electrical connectors (BNC, USB, RJ45, and DSUB)

- Points for partial insertion and full insertion



NIST ATB 2
Belt Drives

Alignment and insertion: 6 metal collars of various sizes

- Points for insertion

Insertion of Pulleys: 2 round pulleys, 2 sprockets, 2 Timing pulleys

- Points for partial insertion and fully seated

Threading bolts: 6 bolts w/ washers (6mm)

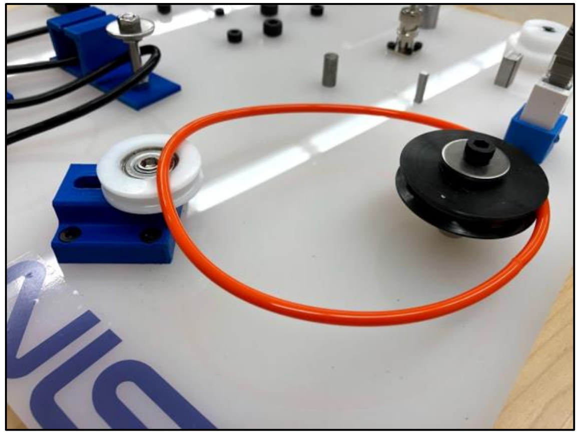
- Points for threading and fully seated

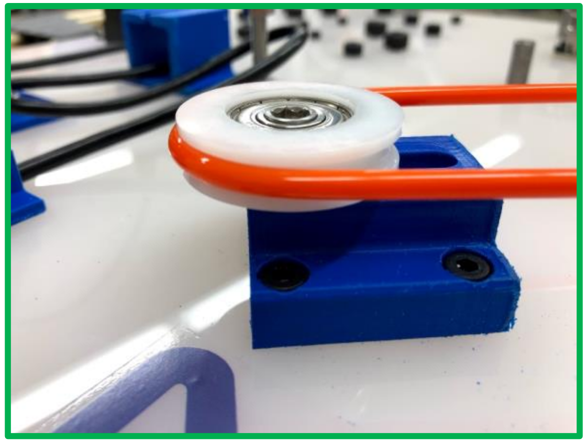
Installation of belts: 1 round belt, 1 timing belt, and 1 chain

- Points for each correctly routed pulley

Actuating tensioners: 1 sliding tensioner, 1 elastic tensioner, and 1 screw tensioner

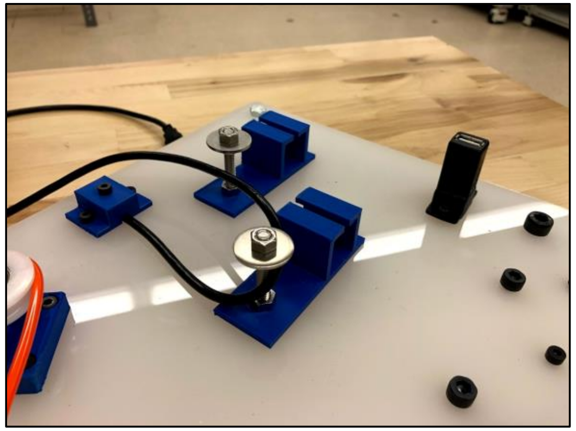
- Points for tension

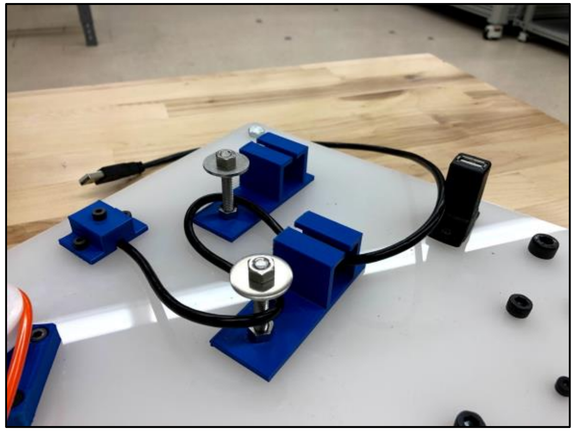


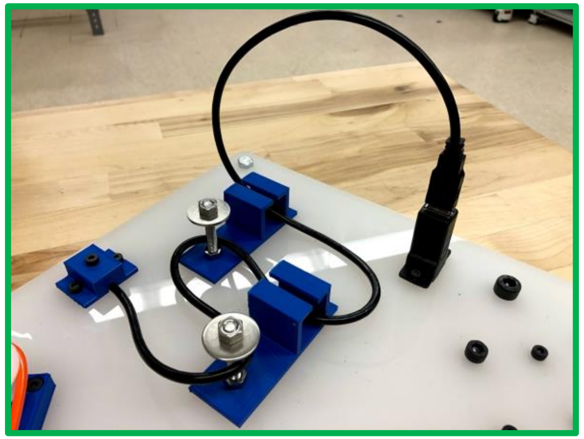


NIST ATB 3
Cable Routing

- Acquiring/Handling loose parts: 1 thin flexible cable, 1 stiff thick cable, 1 flat cable (audio jack, ethernet, and a MIL connector flat cable.)
  - Points for grasping and control
- Routing cables: 2 tall pegs with washer heads for each cable type (sized for each cable thickness)
  - Points for correct routing direction and maintained rout through other tasks
- Weaving/Placing loose parts: 3 printed plastic tubes in different orientations for each cable
  - Points for partial weave and fully weaved through each tube
- Connecting cable: 1 female connector for each cable
  - Points for partial insertion and fully seated

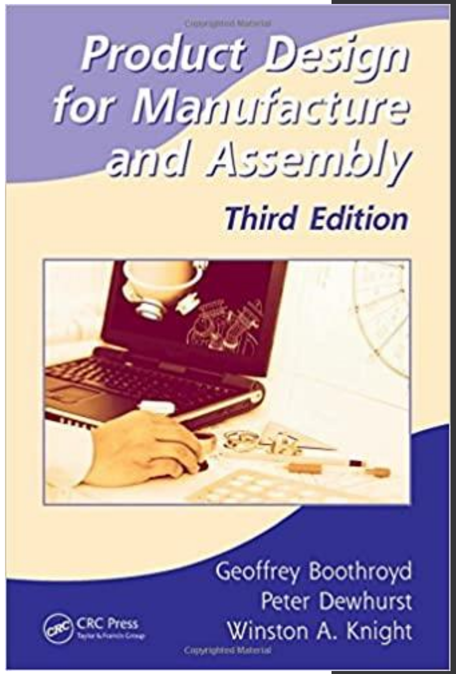






Design Reasoning

- Test common assembly tasks and especially difficult assembly tasks that need solutions
- G. Boothroyd, P. Dewhurst and W. Knight in "Design for Manufacture and Assembly"
  - Manual operation times are recorded for each subtask
  - Compare human performance and robot system performance when handling parts



EXPERIMENTAL TIME FOR HANDLING AND INSERTING PEGS

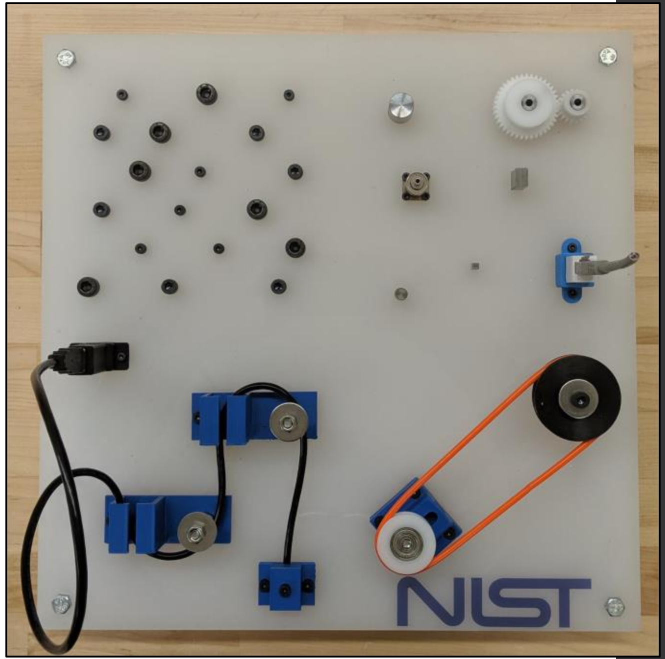
Peg Size	Handling	Insertion	Total
Less than 6mm	1.88	1.5	3.38
Between 6 and 15 mm	1.43	1.5	2.93
Greater than 15mm	1.13	1.5	2.63

EXPERIMENTAL TIME FOR HANDLING WIRE IN SECONDS

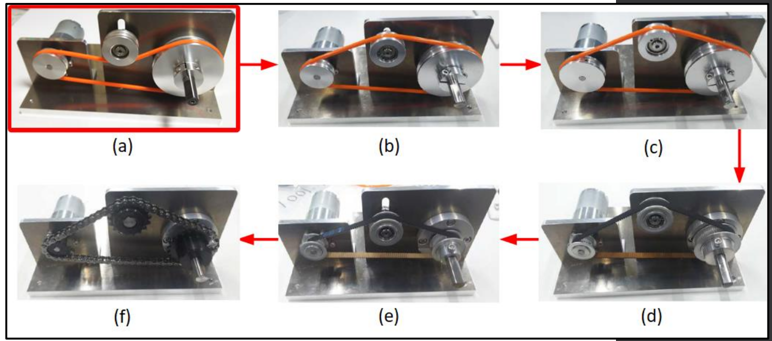
Wire Type	Length (ft)	Handling	Routing	Dressing	Insertion	Total
Flexible wire	3.6	5.58	7.08	7.72	1.9	22.28
Stiff wire	3.4	8.78	10.28	7.48	2.2	28.74
Flat cable	3.3	9.98	12.14	11.38	2.5	36

Competitions

- IROS 2020 virtual
  - Repeat of 2019 competition with some Taskboard design changes. (Teams were given minimal time to program a task board that combined the competencies of NIST ATB 1-3.)
- IROS 2019
  - Teams were given minimal time to program a task board that combined the competencies of NIST ATB 1-3.
- WRS 2018
  - Teams competed to complete as much of a belt drive unit as possible. Belt drives of increasing difficulty were available. This utilized the elements presented in the belt drive task board.
- IROS 2017
  - Teams constructed a gear assembly used at future competitions. Teams also competed in the assembly and disassembly of NIST ATB 1.



IROS competition board



WRS Belt Drive assembly

Solutions

- Previous competitions were heavily weighted with manual programming solutions. This is not what these competitions are trying to promote.
- Use of expedient lead-through programming and application based user interfaces is a step in the right direction, but fully autonomous assembly is the future.
- Teams are starting to incorporate the use of force control, CAD data, AI and perception systems into their solutions. These systems with easy to use interfaces (no robot expertise necessary) is the future of adopting robotics into small and medium sized manufacturers.
- Teams have started to prove competency on competition taskboards with time to spare.

Feedback for Improvements

Limitations of the benchmark

- Threaded holes in the task boards are subject to wear over time that affects performance; when used in competitions or other testing, are new boards used?
- Cable routing board design may get augmented with channels to accommodate robotics,
- Looking to improve tolerances in the boards; possibly through using an aluminum board instead of plexiglass

Ideas for future benchmarks

- Develop assemblies that utilize a subset of the components of each task board and can be powered once it is finished being built, so if it is built correctly then it will operate
- Not just vertical insertions; insertions that require more complicated movements and/or orientations to be inserted
- Objects that can be deformed during insertion (e.g., blister); tasks that are more sensitive to force application
- Tying knots, manipulating flexible materials
- Two-hand manipulation where an object gets stabilized by one and assembled by the other

Closing

- By developing these benchmarks for robot system performance on assembly task boards NIST hopes to encourage progress in the field as well as to provide tools that assess a robot system's assembly capabilities for choosing the best system for an intended application.
- Feedback on board designs, future task boards and/or better applications are welcome.
- Up and coming task board designs…

Wire harness

Assembly that is removed
when finished
Built from cable routing

Vision challenge: Object identification

Transparent objects
Negative spaces (not just holes)
Reflective surfaces
Similar shapes and sizes

Resources

Benchmarking Protocols for Evaluating Small Parts Robotic Assembly Systems Paper:

- https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8957300

NIST assembly performance metrics and test methods website:

- https://www.nist.gov/el/intelligent-systems-division-73500/robotic-grasping-and-manipulation-assembly/assembly

NERVE center website for ordering boards:

- https://www.uml.edu/research/nerve/

To apply for NIST ATB #1 click the link at the bottom of the page

- https://www.uml.edu/Research/NERVE/NIST-Assembly-Task-Board-Form.aspx

Thank you