**ROBOTIC DISASSEMBLY/ASSEMBLY PROTOCOL**

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| Reference No / Version  URL | RAL-SI-2020-P [Benchmarking Protocols for Evaluating Small Parts Robotic Assembly Systems]-V1.0 |
| <https://www.nist.gov/el/intelligent-systems-division-73500/robotic-grasping-and-manipulation-assembly/assembly> |
| Authors | Kenneth Kimble1, Karl Van Wyk2, Joe Falco1, Elena Messina1, Yu Sun3, Mizuho Shibata4, Wataru Uemura5, Yasuyoshi Yokokohji6 |
| Institution | 1National Institute of Standards and Technology (NIST), 2NVIDIA, 3University of South Florida, 4Kindai University, 5Ryukoku University, 6Kobe University |
| Contact information | [falco@nist.gov](mailto:falco@nist.gov) |
| Purpose | Metrics and benchmark protocols to support the evaluation of small parts robotic assembly and disassembly operations. |
| Task Description | Small part insertions and fastening operations such as threading, snap fitting, and meshing with standard screws, nuts, washers, gears, electrical connectors, belt drives, and wiring. |
| Setup Description | List of objects and their descriptions:  *Task Board 1:*  Competencies: peg insertions, gear meshing, electrical connector insertions, nut threading  <https://www.nist.gov/document/assemblyinstructionsv4docx>  *Task Board 2:*  Competencies: alignment and insertion of collars and pulleys, handling flexible parts, meshing/threading belts, actuating tensioners, and threading bolts.  <https://www.nist.gov/document/beltdriveassemblyinstructionsdocx>  *Task Board 3:*  Competencies: tracking, placement, weaving and manipulation of loose cables, handling flexible parts, and inserting ends into various connectors.  <https://www.nist.gov/document/wireharnessassemblyinstructionsdocx> |
| Initial and target poses of the objects:  Disassembly: Objects located in task board in the fully assembled state.  Assembly: Objects placed on a templated kit layout. Locations on the template should be unknown to the system at the start of the benchmarking procedure. |
| Description of the manipulation environment:    Task boards, containers and kit setups are placed within the robot work volume in random positions. These items can be fastened to the work volume surface (e.g. Velcro, tape) to prevent movement due to external assembly and other manipulation forces. |
| Robot/Hardware/Software/Subject Description | Targeted robots/hardware/software:  No specific hardware or software required. A description of all robots, end-effectors/tooling hardware, sensor systems and software implementation should be described. |
| Initial state of the robot/hardware/subject with respect to the setup:  Not specified. |
| Prior information provided to the robot:  Optional: CAD data, semi-autonomous with expedient programming methods. AI based systems can be trained with the predefined parts typically well-defined in a manufacturing operation. |
| Procedure | **Disassembly:** A fully assembled manufacturing task board is placed on the table alongside an empty container. The goal for the robot system is to remove all components from the board and randomly place them in a predefined container. The protocol steps are as follows:   1. Randomly place the task board within the robot system work volume 2. Randomly place the container to receive disassembled parts within the robot system work volume. 3. Initialize timing, recording the start time Tstart 4. If used, perform lead through (teach) programming 5. Start autonomous operation of the robot system 6. The robot system disassembles a part from the task board 7. The robot system places the removed part into the associated container 8. Repeat steps 6 and 7 for all parts in task board. 9. Record the finish time Tfinish 10. Repeat this protocol for the desired number of trials of the task board under test.   **Assembly:** A fully disassembled manufacturing task board is placed on the table alongside a kit setup. The kit area and the task board location are randomly set on a surface. The goal for the robot system is to grasp all components from the kit and insert them into their respective destinations on the task board. The protocol steps are as follows:   1. Randomly place the task board within the robot system volume 2. Randomly place the kit of parts to be assembled within the robot system volume. 3. Initialize timing, recording the start time Tstart 4. If used, perform lead through (teach) programming 5. Start autonomous operation of the robot system 6. The robot system grasps a part from the kit layout 7. The robot system assembles the part onto the task board 8. Repeat steps 6 and 7 for all parts in the kit. 9. Record the finish time Tfinish 10. Repeat this protocol for the desired number of trials of the task board under test   Performance Measures:  The performance metrics chosen to evaluate robotic assembly systems include speed and reliability. Speed is measured as the completion time of a task or sub-task as Ttaskboard = Tfinish − Tstart. For each set of trials, compute the mean, standard deviation, and 95% confidence interval of the completion times.  Score each operation per each disassembly and assembly operation over all trials as specified in the benchmark instructions for each task board.  Reliability is captured as the probability of successfully completing a task or sub-task. The theoretical upper bound probability for successfully inserting a component (PS) is calculated given a confidence level (CL), the number of successes (m), and the number of independent trials (n). Given the binomial cumulative distribution function:    The PS is its minimum value to some precision while still satisfying the above inequality. |
| Execution Constraints | All component locations whether on the task board or kit layout should be considered random and unknown by the system under test at the start of this protocol.  During task board operations, the use of multiple end-effectors and tools is permitted, although manual changing of these system components is not. In the case of threaded fasteners, commercially available automated fastener dispensing systems can be used.  Multiple robots can be used as part of the assembly operation.  Once autonomous system operation begins, there can be no manual or teleoperated intervention by a human throughout the task board disassembly or assembly process.  The default task board orientation is flat on a table surface. Additional configurations can be tested as vertical (task board surface is perpendicular/90 degree to table surface or at a specified angle relative to the table surface. |