

RUBIK'S CUBE MANIPULATION PROTOCOL

Reference No / Version	RAL-SI-2020-P19-0840-v1.0 (for the latest versions of the protocol, please refer to https://homes.cs.washington.edu/~boling/ or https://www.ycb-benchmarks.com/protocols-and-benchmarks/)
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Purpose	Evaluating a robotic system's overall manipulation accuracy, speed, and robustness by measuring the minimal time it takes to successfully execute a manipulation sequence on a Rubik's cube.
Task Description	<p>In this evaluation, we propose twelve tiers for the experimenter to attempt. Each tier is denoted as Rubiks-M-N. Rubiks-M-N consists of M consecutive trials, where in each trial the robot must pick the Rubik's cube up off of the table and complete N rotations. Each of the M trials prescribes a distinct manipulation sequence of length N. The solution sequence is specified with standard Rubik's cube notation. The following software is provided to ensure benchmark consistency across research groups, and to aid in validation of the achieved score: https://gitlab.cs.washington.edu/bolingy/rubiks-cube-benchmark</p> <p>The proposed tiers are: Rubiks-1-5, Rubiks-1-10, Rubiks-1-20, Rubiks-1-50, Rubiks-1-100, Rubiks-1-200, Rubiks-5-5, Rubiks-5-10, Rubiks-5-20, Rubiks-5-50, Rubiks-5-100, and Rubiks-5-200.</p>
Setup Description	<p><u>List of objects and their descriptions:</u> A standard 3 by 3 Hasbro Gaming Rubik's cube (item number A9312) of dimension 5.7 cm. Researchers can choose to use a table placed against a wall to decrease uncertainty or extend manipulability.</p> <p><u>Initial and target poses of the objects:</u> The Rubik's cube should initially be positioned to rest on top of the table's surface such that its center is located at the middle of the robot's workspace in the x and y directions (with respect to the robot's base frame). It should be oriented such that its top face is parallel to the ground, and its back face perpendicular to the sagittal plane of the robot. The robot's manipulator(s) should not initially make contact with the cube.</p> <p><u>Description of the manipulation environment:</u> Place the Rubik's cube on top of the table's surface such that its center is located at the middle of the robot's workspace in the x and y directions.</p>
Robot/Hardware/Software/Subject Description	<p><u>Targeted robots/hardware/software:</u> This protocol is designed to evaluate general purpose robots – any dedicated Rubik's cube solving machine is not applicable.</p> <p><u>Initial state of the robot/hardware/subject with respect to the setup:</u> As long as the robot's manipulators are not making contact with the Rubik's cube, the robot can be initialized in any configuration.</p> <p><u>Prior information provided to the robot:</u> The initial pose of the Rubik's cube can be provided to the robot.</p>

Procedure	<ol style="list-style-type: none"> 1. Experimenter specifies a tier to attempt and obtains the corresponding manipulation sequence from the provided program. 2. Experimenter places cube on table. 3. Robot picks up cube and begins to execute the generated set of turns. 4. Experimenter records time elapsed. 5. Robot terminates manipulation after executing the manipulation sequence. 6. Experimenter validates that the final cube state is correct. 7. If the final cube state is correct, the system's score is the time elapsed between the robot first making contact with the Rubik's cube and the termination of manipulation. 8. Return to step two if there are remaining trials to be completed 9. For each completed tier, the experimenter should report the corresponding average speed score, standard deviation and a clear video recording of this score being attained.
Execution Constraints	The experimenter should report any completed tiers. Any form of human intervention is not allowed once the robot has started the manipulation process.