ENGR 4590 Testing and Statistical Analysis Worksheet

Team Name: Rubik's Cube Rectifiers

This worksheet describes the quantitative and qualitative testing and analysis for a Rubik's cube solving robot.

Table listing design constraints and test for each: add more rows as needed.

Constraint/Feature	Test/Performance Metric	Result	Explanation
Solve cube in < 5 min	Test solving mixed cubes repeatedly, measure time and accuracy	Close	Results hover around goal time and accuracy; see quantitative testing below
Must not drop cube	Visually observe if cube is dropped during testing	Pass	Cube is never dropped when correctly inserted
Battery life $\geq$ 30 min	See how long battery lasts while cubing	Close	Battery lasts 25 min before recharging
Fit within 0.3 x 0.3 x 0.3 m^3	Measure outer dimensions	Pass	Length, width, and height are all within envelope (0.3 x 0.3 x 0.25 m^3)
Weigh < 5 kg	Weigh system	Pass	Weight is 4.8 kg without controller or cube

Qualitative evaluation:

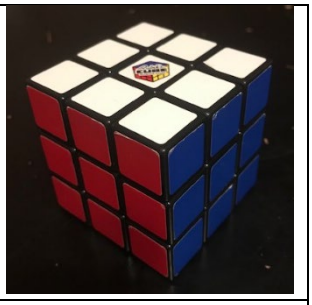
The project meets the goals reasonably well. The system is within the size and weight constraints and is easily transportable because all parts are fixed to a base with handles. The low height is a particular victory accomplished by mounting the camera below the cube (embedded in the base) as opposed to above it as originally planned. Furthermore, the system never drops a cube that is properly inserted. Battery life is unfortunately not quite at goal length, but the battery is located in an accessible area for easy replacement.

The primary constraint of time to solve the cube was in fact the hardest to meet. Considering that only one of the team members was able to solve a cube before the project began, the team considers the fact that we even solved the to be a rousing success. Not only did we solve it, but most of the time, this was done correctly in a time near to the 5 minute goal. Further specifics on the performance of this functional aspect are discussed below.

Quantitative testing:

Quantitative testing consisted of inserting a scrambled Rubik's cube to the rectifier machine and timing how long it took to solve. This test was performed 20 times for repeatability, and the completion times for each phase of the solution were tracked. When the machine completed solving a cube, the number of correct and incorrect squares were visually determined in order to quantify accuracy. Several photos of the solution process are shown in Figure 1 below, and a link to a testing video is here: Test Video Link.

Figure 1: Cube at Various Phases of the Solution Process

			
Step 0 (Scrambled)	Step 2 (Top and Edges)	Step 5 (Bottom Cross & Edges)	Step 7 (Complete)

Numerical results of the testing are shown in Table I below. This table lists completion time for each cube, as well as the number of squares correct and incorrect, and the accuracy.

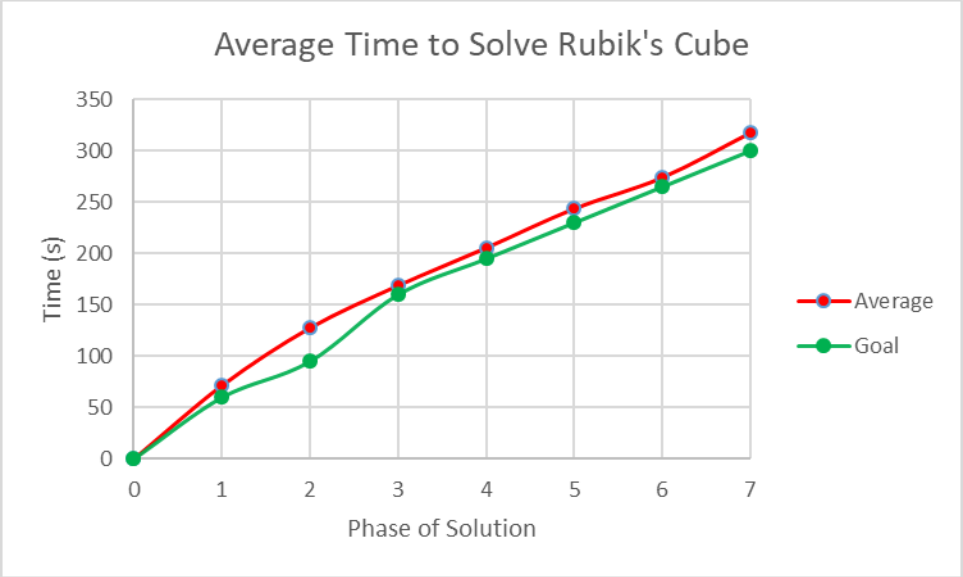
Table I: Solution Time and Accuracy

test	Solve time (s)	squares incorrect	squares correct	% correct
1	346.8	1	53	98.1
2	276.8	1	53	98.1
3	271.6	2	52	96.3
4	344.9	0	54	100.0
5	275.4	1	53	98.1
6	347.4	0	54	100.0
7	294.7	3	51	94.4
8	315.2	2	52	96.3
9	300.0	1	53	98.1
10	305.0	0	54	100.0
11	311.2	0	54	100.0
12	273.2	1	53	98.1
13	341.4	1	53	98.1
14	348.1	0	54	100.0

15	355.1	3	51	94.4
16	349.1	1	53	98.1
17	320.5	0	54	100.0
18	279.3	2	52	96.3
19	348.5	3	51	94.4
20	338.0	4	50	92.6
average	317.1	1.3	52.7	97.6
st. dev.	30.6	1.2	1.2	2.3

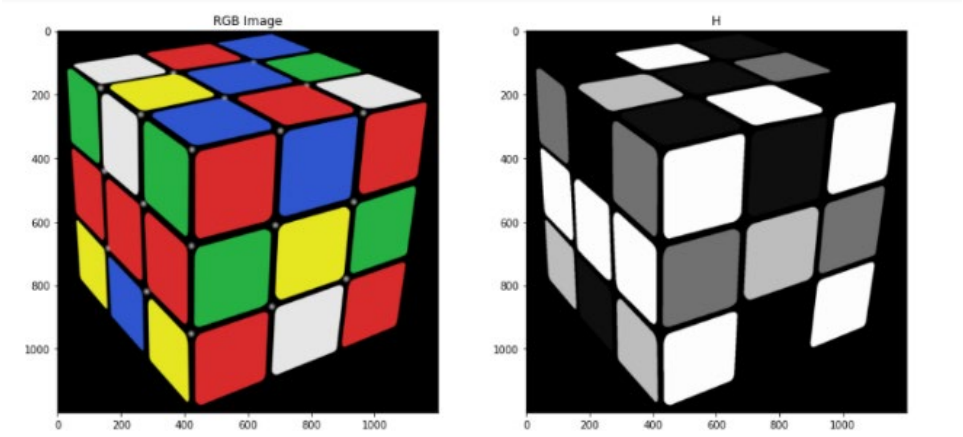
The machine took an average of 317.1 ± 30.6 s (5:17 ± 0:30 min) to solve each cube, which is close to the goal time of 5 min. In six instances (highlighted in yellow), the solution was actually completed faster than goal. The variability in time is likely due to the fact that some squares happen to be already in the right place and/or require more or fewer moves to relocate to the proper location.

Average time to solve each phase of the cube (red) is plotted in Figure 2 below along with goal time (green). Actual time only slightly exceeds goal time for each phase with the exception of phase 2 taking approximately 30 s longer than expected.



The machine solved cubes with an average accuracy of 97.6 %, meaning that 97.6 percent of squares are in the correct location at the end. In six instances (highlighted in green in Table I), the machine solved the cube with 100% accuracy. Any inaccuracies are due to the fact that the camera vision occasionally misclassifies yellow and white squares as each other. Better lighting, a better camera, and/or eliminating hysteresis in the color thresholding algorithm could improve this. A sample photo of color thresholding is shown in Figure 3 below. In this photo, one can see that certain colors are not always translated to the same grayscale value consistently.

Figure 3: Color Thresholding


RGB Image
H
0
200
400
600
800
1000