HERBERT

AUTONOMOUS RUBIK'S CUBE SOLVER

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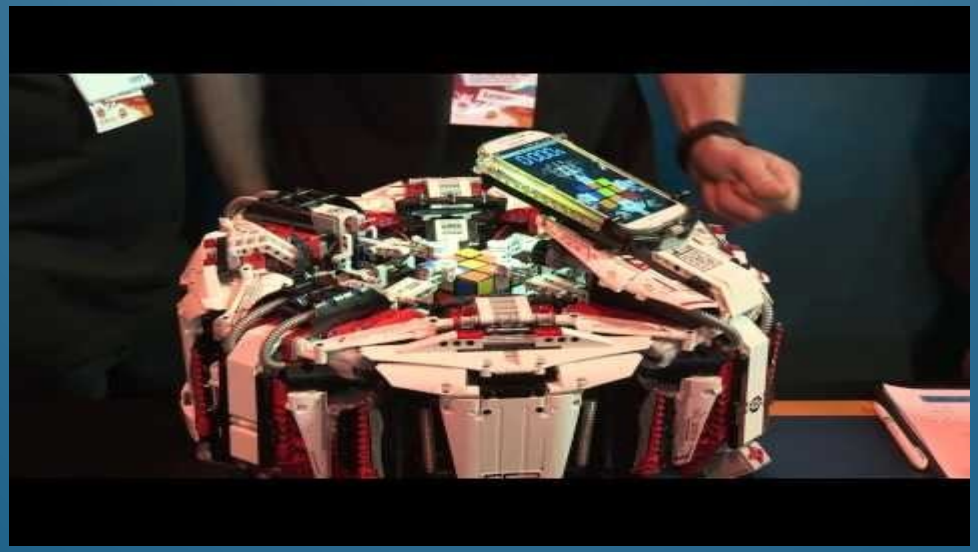
BACKGROUND

- CubeStormer 3 – Fastest robot to solve a Rubik's Cube (3.253s) [1].

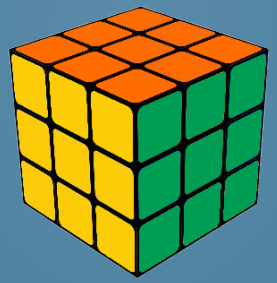


INTRODUCTION

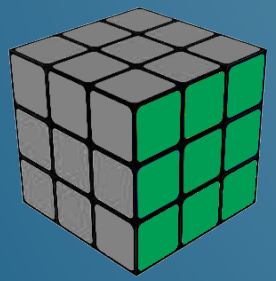
GOAL: Create an autonomous robotic Rubik's Cube solver.

- Integrates various technologies
  - Video cameras, stepper motors, mechanical actuators, single-board computer, FPGA
- Take Guinness World Record (3.253s)
- Optimize mechanical operations while maintaining the precision needed to rotate the cube.

Cube Representation

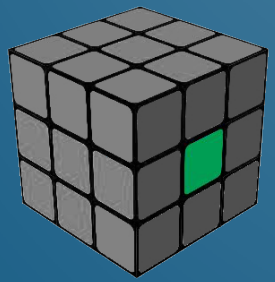


Face

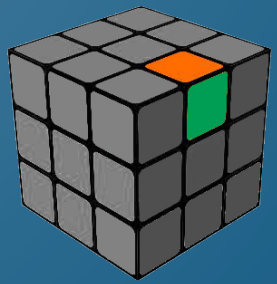


Corner

Cubies



Cubelet

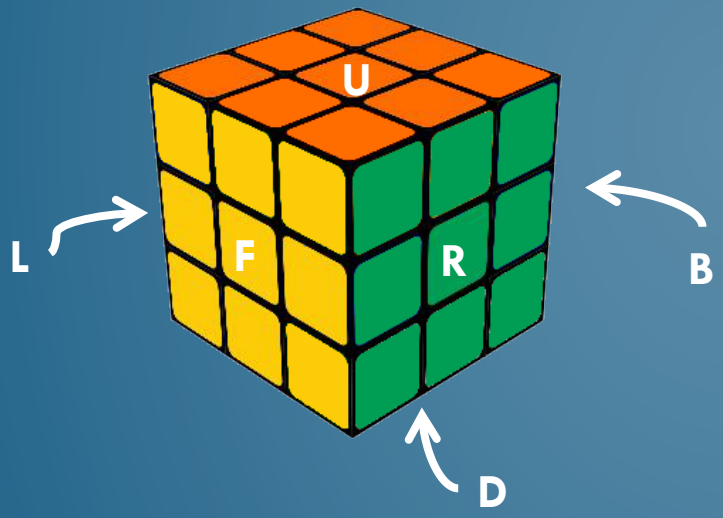


Edge

Middle Facelets Determine Face Color
(U = Orange, R = Green, F = Yellow, etc.)

12 Edge Cubies

8 Corner Cubies

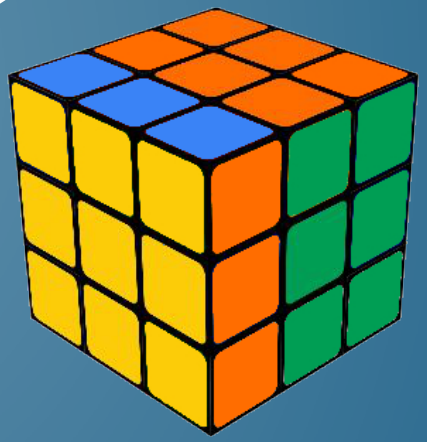


R’

R Face Twisted Counterclockwise

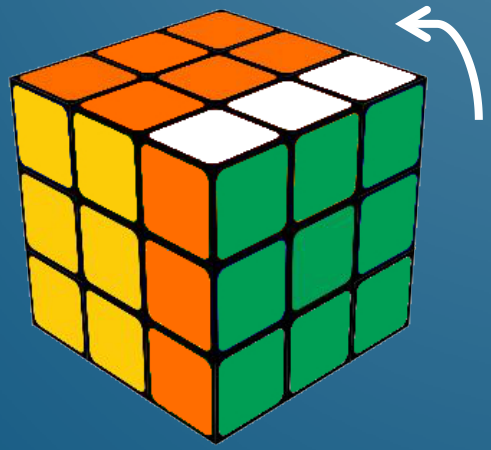
F

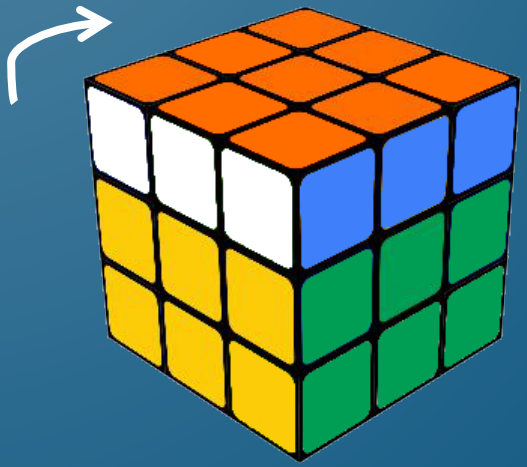
F Face Twisted Clockwise



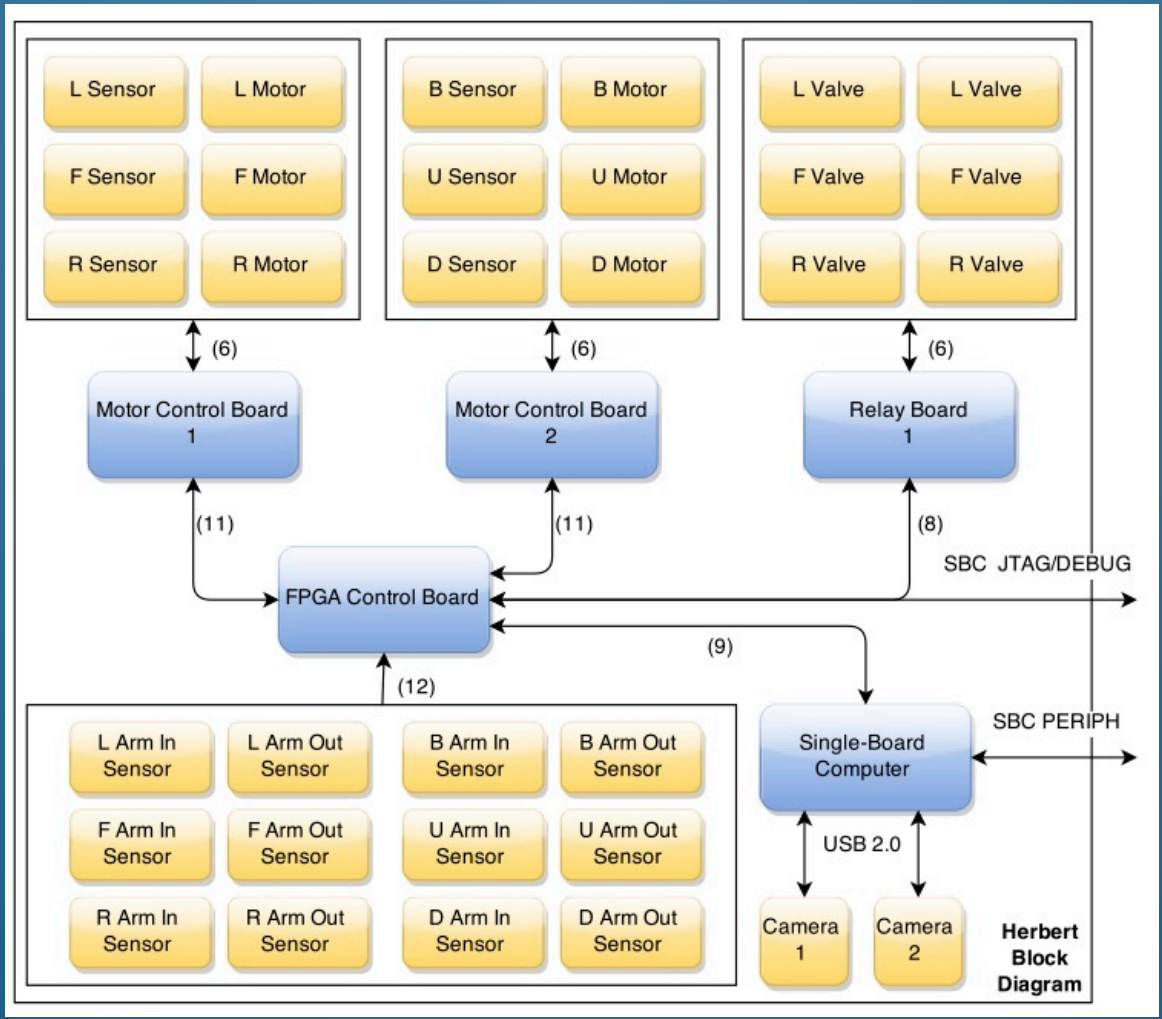
U2

U Face Twisted 180 Degrees





HIGH LEVEL SYSTEM DIAGRAM



OPENCV & IMAGE PROCESSING

- Two cameras, one for three of the six faces of the cube.
- Grayscale conversion – Convert RGB to pixel intensity for feature filtration [2].
- Canny edge detection - Identify the edges of the cube and the faces [3].
- Contour filtering - Identify cubelets on each face [4].

KCUBE & SOLUTION SEQUENCE

- Cubelets represented with an ASCII character
  - ‘W’, ‘R’, ‘B’, ‘G’, ‘O’, ‘Y’
- Kcube application used to generate the solution sequence [5].
  - Created by Greg Schmidt
  - Utilizes Kociemba’s algorithm

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Microsoft Windows [ Version X.X. XXX ]

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c:> kcube L: GGWWOWBRB F: GWGBGYWBO U: YOOOWYROY D: ORGWYYYRB R: OGBBRYWRR B:
YBROBGWGR
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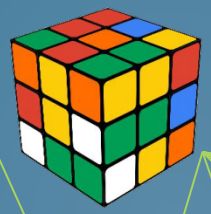


F R U B L D F' R' U' B' L' D' F2 R2 U2 B2 L2 D2

U

F F2

F L2

F U2

B2

L'

U → R2 → F → B'

D2

Kociemba Two-Phase Algorithm

Phase 1

- 43,252,003,274,489,856,000 possible starting orientations
- All 18 possible moves are used
- Uses pruning and symmetries
- 2,217,093,120 possible phase 1 solutions

Phase 1 Solution: **F, U, F2, L2, U2, B2, L', U, R2, F, B'** (11 moves)

U D U' D' F2 R2 U2 B2 L2 D2

U

U

U

R2

D'

R2

U'

F2

U

D → B2

Phase 2

- 2,217,093,120 possible starting orientations
- A subset of 10 moves are used
- Uses pruning and symmetries
- 1 possible phase 2 solution

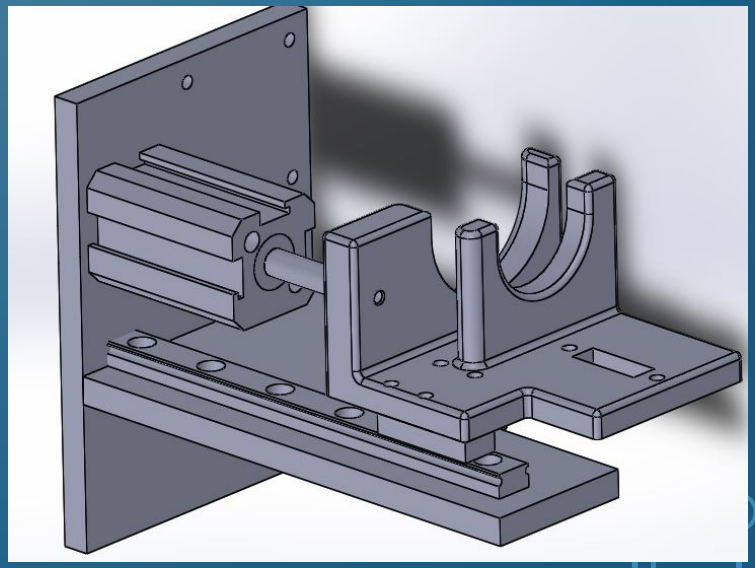
D2

Phase 2 Solution: **U, R2, D', R2, U', F2, U, D, B2** (9 moves)

Final Solution: **F, U, F2, L2, U2, B2, L', U, R2, F, B', U, R2, D', R2, U', F2, U, D, B2** (20 moves)

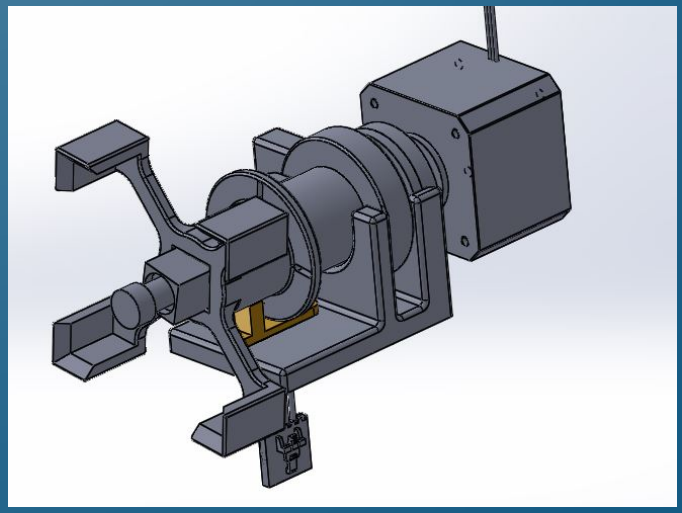
MECHANICAL ACTUATORS

- One arm for each face
- Each arm must actuate, avoiding contact with the other arms
- Initial design ideas:
  - Rotary motion to linear motion
  - Linear actuator motor
- Solution: Double action pneumatic air cylinder
  - High Speed
  - Affordable
  - Small footprint
- Controlled by solenoid valve and a relay board
- Simultaneous coaxial pair motion
- Approximately 80-100psi



ELECTRO-MECHANICAL STEPPER MOTORS

- Each actuating arm will have a stepper motor to rotate each face
- 90/180 degree rotations clockwise or counter-clockwise
- Controlled by an FPGA and proprietary motor control board
- Full steps, no micro-stepping
- Break sensor for 90 degree alignment.



SUMMARY

- Integrates various technologies and domains of engineering.
  - Computer and Electrical engineering combined with mechatronics and robotics
- Great application of system integration and teamwork.
- Mechanical components pose the greatest limitations.

ACKNOWLEDGMENTS

- Point Grey Research

- BioFire Defense

- Futura Industries

REFERENCES

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