Self Solving/Scrambling Rubik's Cube for Learning and Training

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1 | Introduction

1.1 Background

Designed and created by Hungarian teacher, Erno Rubik, the Rubik's Cube has been a smash hit for puzzle solvers across the globe. Since its release to stores in 1980, over 450 million Rubik's cubes have been sold making it the most popular and best-selling toy in history. Along with these incredible numbers, Rubik's Cube has also found itself a dedicated group of avid solvers, commonly known as 'cubers'. From the beginning, these people have been learning, working, and competing for faster times in solving the cube. With the current world record for a single 3x3 Rubik's cube solve sitting at 3.47 seconds, it is clear that modern cubers have become incredibly quick at solving the once impossible puzzle.[1]

The standard Rubik's Cube consists of six faces each with a 3x3 grid of colored squares. In its solved state, all 9 of the squares per side will show the same color. In a scrambled state, the colors are scattered and each face will show an array of colors. The standard color set is red, blue, white, orange, green, and yellow. Each of the sides revolve around the center square within the 3x3 grid and can be rotated in either direction.

1.2 Problem

Naturally, the puzzle can be difficult to solve when attempting it for the first time. Beginners are often daunted by the algorithms used to solve the cube and struggle with memorizing them as well. It can almost even feel like learning a new language with all of the new terms and the strings of letters, numbers, and apostrophes that instructionalize the solving algorithms.There are many tools and resources online that can be used to aid the learning process, but these are not always perfectly clear in depicting the necessary steps required to solving the cube. Especially for a beginner, starting out on the cubing journey can be complicated.

On the other end of the spectrum, skilled cubers often find scrambling the cube to be a cumbersome task. You have to randomize which sides to turn and which way to rotate them by. There must be at least around 20 steps worth of randomization in order to achieve a high quality scramble[2]. However, years of practicing cubing leads to random biases during the scrambling process. Turns become less random and cubers often end up giving themselves suboptimal scrambles. These make for worse practice and slow down improvements to skill.

1.3 Solution

We will work towards solving the listed problems by creating a Rubik's Cube that is capable of scrambling and solving itself. Our device contains six integrated motors with controllers to turn each of the sides of the cube. It will be controlled by a microcontroller and powered by batteries run in series. Limit switches will also be used on each face of the cube to aid with precision turning control. Users will be able to interface with the cube and change from solving/scrambling settings by turning sides in a specific pattern.

The cube will be programmed to use the hardware inside to solve the cube regardless of what kind of scramble it is given. This will allow beginner cubers to visually see the necessary steps to solve the cube and gain better hands-on experience with the correct algorithms. No longer will beginners have to sift through dense tutorials for suboptimal solving algorithms.

Experienced cubers will also be able to extend their skills through better scrambles. The cube will be programmed to scramble itself to the correct extent with (pseudo) random processes. This will prevent experienced users from gravitating towards biased scrambles from their years of continued cubing.

1.4 Visual Aid

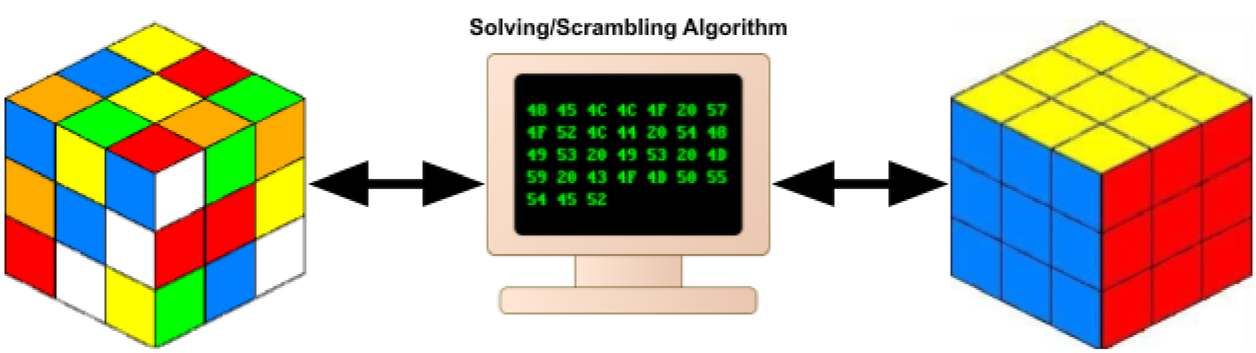

Figure 1: Project Functionality Visual Aid

1.5 High-Level Requirements List

1. The cube must be able to function as a normal cube would, independent of the electronics inside of it.
2. The cube must be able to use the motors and switches to rotate each side with perfect precision.
3. The cube must be able to use the microcontroller to understand the location of each of the colored squares around itself.

2 | Design

2.1 Block Diagram

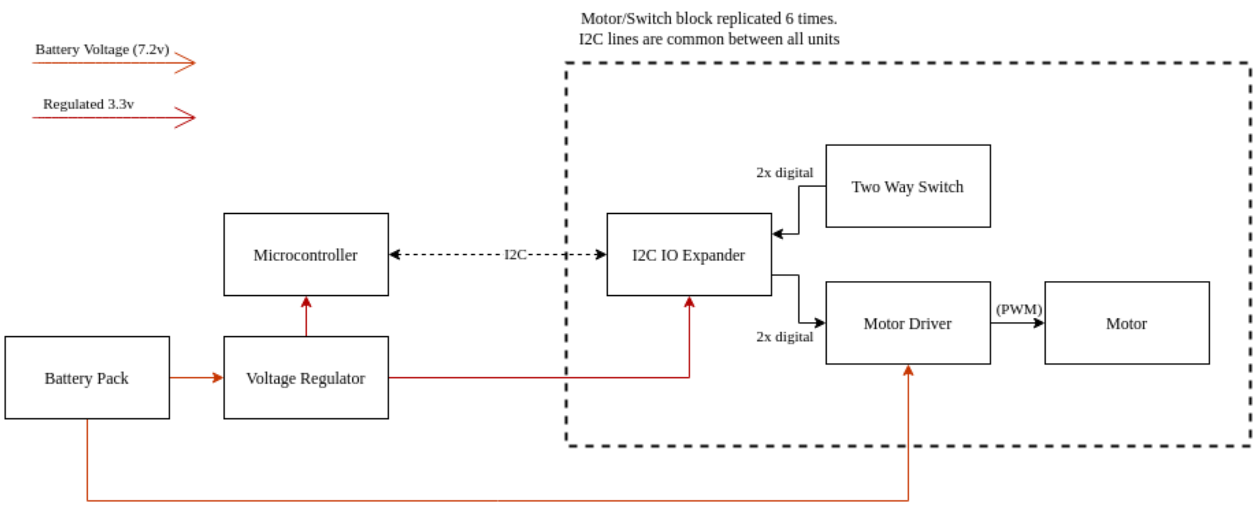

Figure 2: Block Diagram of Project Systems

2.2 Subsystem Overview

2.2.1 Control System

The control system consists of an STM32 Microcontroller which is capable of communicating over the I2C bus. The microcontroller can read the positions of each of the six switches and set the motor directions over the I2C bus.

Requirement: Microcontroller must be able to communicate over I2C and have enough memory and compute capability to track the cube position and solve the cube.

2.2.2 Switch Module

The switch modules contain a bidirectional switch, a simple motor driver, and an I2C IO expander. The switch is a Panasonic ESE24, which features separate outputs for if it is switched to the left or to the right. The IO Expander is a

PI4IOE5V9554, which has 3 address pins allowing up to 8 to be used in the same system. It contains 8 IO pins, of which only 4 are needed. The ZXBM5210 Motor Driver allows the motor to be driven in forward, reverse, coast, or brake. This motor driver has a maximum output current of 1.5A, well above the 0.67 A stall current of the motors. Additionally, the driver contains an internal pwm oscillator which can be tuned to lower the motor output power if needed. The maximum supply voltage is 18 volts, well above the nominal motor voltage of 6V. Each motor driver will drive one mini gear motor. The motors have a 1:1000 gear ratio, rotating at approximately 10RPM at 6 V. We plan to power the motors with 2 batteries, which would result in a voltage of 7.4V. As the motors will only be one for ~1 second at a time, this will not overload them. If the motors do get overloaded, the output power of the motor drivers can be reduced as mentioned above. The motors are similar to Pololu Micro Metal Gearmotors.

*Requirement: Switch must be activated when each face is aligned 90 degrees. The motors must have enough torque to turn the cube (est. 0.5N*M). The motor driver must supply enough power to each motor without overloading. (1 A Max)*

2.2.3 Power System

Power is supplied by two LiPo batteries, resulting in a nominal battery voltage of 7.4V which is used to drive the motors. A 3.3v regulator is used to regulate power for the microcontroller and IO Expanders

Requirement: Batteries must supply enough current to power the motors (1 A Max)
Requirement: Voltage Regulators must supply enough current to ICs (250 mA Max)

2.3 Tolerance Analysis

The block with the greatest risk to implement is the motor and feedback system. Each switch is bidirectional, with contacts for left and right. The cube will have

some ability to center itself, but it is important for the switches to activate only when the face is aligned, and for the controller to stop the movement as soon as the switch is hit. Any distance the face spins after the switch is activated will not be detected, and the motor will have to realign itself if this happens.
There is no official torque specification for a rubix cube, although 0.05 N-M for speed cubes and worst case 0.5 N-M for original cubes are good estimations. We plan to 3D Print our own cube which will allow for optimizations

3 | Ethics and Safety

3.1 Ethics

As engineers working towards a brighter future and a better planet, we adhere to the IEEE Code of Ethics throughout all engineering practices. For the duration of the project and going forward during work in the real world, we will ensure integrity, responsibility, and ethical practices in our work environment. All members of our team are mutually respected and treated as such. We will work to ensure the ethical nature of our project is not tainted and it will likewise refrain from producing unethical outcomes for others. We do not foresee many points of ethical contention with our project, but that will not prevent us from remaining weary of any possible conflicts.[3]

3.2 Safety

We are aware of a few safety concerns with our project. Namely with all electronics there is danger of electrical shock. As such we will work to create a non conductive housing for the electrical components to prevent injuries or accidents of this nature. Additionally, with small consumer electronics often comes batteries.

Our project is no exception and, of course, batteries will come with their own set of potential hazards. We must be cautious when working with such components as they are prone to cause major accidents when not kept a watchful eye over. We will work to make sure batteries are in good, working condition when in use and stored away properly when not. This will all ensure a safe workplace for our team and others around us. As a final safety concern, we recognize that there is a potential issue for people with long hair. Our project contains strong turning motors with crevesaces that allow for hair to get caught. Users with longer hair are at a higher risk for an accident of this nature. To prevent this as much as possible, we will work to minimize gaps in the hardware and warn users of this hazard when applicable.

4 | References

[1] "The Inventor of the Rubik's Cube Took This Long to First Solve It." *CBCnews*, CBC/Radio Canada, 13 Mar. 2021, https://www.cbc.ca/radio/undertheinfluence/the-inventor-of-the-rubik-s-cube-took-this-long-to-first-solve-it-1.5945283#:~:text=Soon%2C%20Rubik's%20Cube%20become%20part,the%20pandemic%20has%20boosted%20sales.

[2] "God's Number Is 20." *God's Number Is 20*, http://www.cube20.org/.

[3] "IEEE Code of Ethics." *IEEE*, https://www.ieee.org/about/corporate/governance/p7-8.html.