# LED Rubik's Cube

## ECE 445: Design Document

Meghan LeMay and Michael Rupp

Team 54

TA: Bryce Smith

February 19, 2018

## 1 Introduction

### 1.1 Objective

The Rubik's Cube is the most popular puzzle in the world with 350 million cubes sold since its inception [1]. Each year, numerous national and international competitions are held where cube enthusiasts compete to see who can solve the 3x3x3 puzzle the fastest [2]. Solving a Rubik's Cube can be a daunting task to those that are not familiar with the puzzle. With over $4.3 \times 10^{19}$ possible permutations of the cube, neither a user nor a computer can determine a solution using a brute force method in a reasonable amount of time. Solving this puzzle take practice, and the LED Rubik's Cube can aid in this task.

One of the main drawbacks of learning how to solve the 3x3x3 puzzle is that there is no reasonable way to reset the puzzle to its initial state if the user cannot solve it. Yes, the user can peel the stickers of the cube and rearrange them to the initial state, but that is a painstaking process a discouraged user may never want to repeat. The purpose of the LED Rubik's Cube is to provide beginning Rubik's cube enthusiasts with an easily resettable puzzle to prevent frustration to the user and any ensuing destruction of the cube. Further, when the user begins to master solving this puzzle, the cube will be able to supply "random" puzzles for the user to solve.

### 1.2 Background

The Futuro Cube and Magic Cube are two examples of LED Rubik's cubes that are on the market. The Futuro Cube is a cube backlit by 54 color changing LEDs that senses rotation, orientation, and tapping. The user taps the side to rotate clockwise, taps the bottom to rotate counterclockwise, and shakes the cube to scramble the puzzle. The cube has other games that use these features as well [3]. The Magic Cube is a cube also backlit by 54 color changing LEDs, but in order to complete a move in a Rubik's cube puzzle, the user pushes a button corresponding to the move they want to make. In addition, the cube has other games that the user can play [4].

What neither of these designs has is the ability for the user to physically rotate each face of the cube like the original Rubik's cube. The LED Rubik's Cube is a teaching tool for individuals new to solving the puzzles and individuals who want to master the game. The cube, therefore, must be able to physically rotate to allow the user to practice moves the same way he normally would implement them on a standard Rubik's cube. The ability to physically rotate along with the ability to implement a reset and a "random" state are the main features that drive the implementation component of the design.

### 1.3 High-Level Requirements

- The cube must be able to physically rotate with the implementation of color changing LEDS.
- The cube must allow the user to reset each face to the solved state of the Rubik's cube.
- The cube must be able to give the user a "random" puzzle at his or her request.

## 2 Design

The Rubik's cube is a large cube comprised of 26 smaller cubes. Each smaller cube is either a center smaller cube in the middle of each face, a corner smaller cube which is a corner of the large cube, or a side smaller cube which lies along the edges of the large cube between the corner cubes. For the purposes of reducing confusion and succinctly expressing ideas, the following nomenclature will be used. The entire "large" Rubik's cube will be referred to as the "cube." The 26 smaller cubes that comprise the cube will be referred to as "blocks." Further, the center smaller cubes will be called the "center blocks," the corner smaller cubes will be called the "corner blocks", and the side smaller cubes will be called the "side blocks."

Several factors needed to be considered due to the mechanical aspects of this design. Since each face of the cube can rotate and each corner and side block can change position due to this rotation, any wires linking blocks will get tangled after several rotations. Therefore, the implementation of the cube will be comprised of self-contained blocks with the necessary circuitry needed to execute all functions each block must perform within the block. Since each block is self-contained, all blocks must be able to update at nearly the same time for a reset or any user specified state, and this update needs happen as quick as possible.

There are three modules within the overall circuit design of the LED Rubik's Cube whose implementation is heavily influenced by the considerations outlined above. The modules are the control unit, the display unit, and the power unit. The control unit is responsible for determining the color each LED should be lit to and implementing resets. The display unit is responsible for lighting up the face of each block to a specific color and communicating color information between the center, side, and corner blocks. The power unit is responsible for maintaining power into the microcontroller of each self-contained block. Together these three modules working symbiotically ensure that the LED Rubik's Cube performs as expected.

The entire cube is comprised of three different types of blocks: center blocks, corner blocks, and side blocks. There are six center blocks, eight corner blocks, and twelve side blocks in total, and the block diagrams for each type of block are shown in Figure 1, Figure. 2, and Figure 3. The relationships between the different types of blocks are extremely important when the LEDs need to be updated which happens right after power-on, a reset, or when the user specifies a "random" orientation.

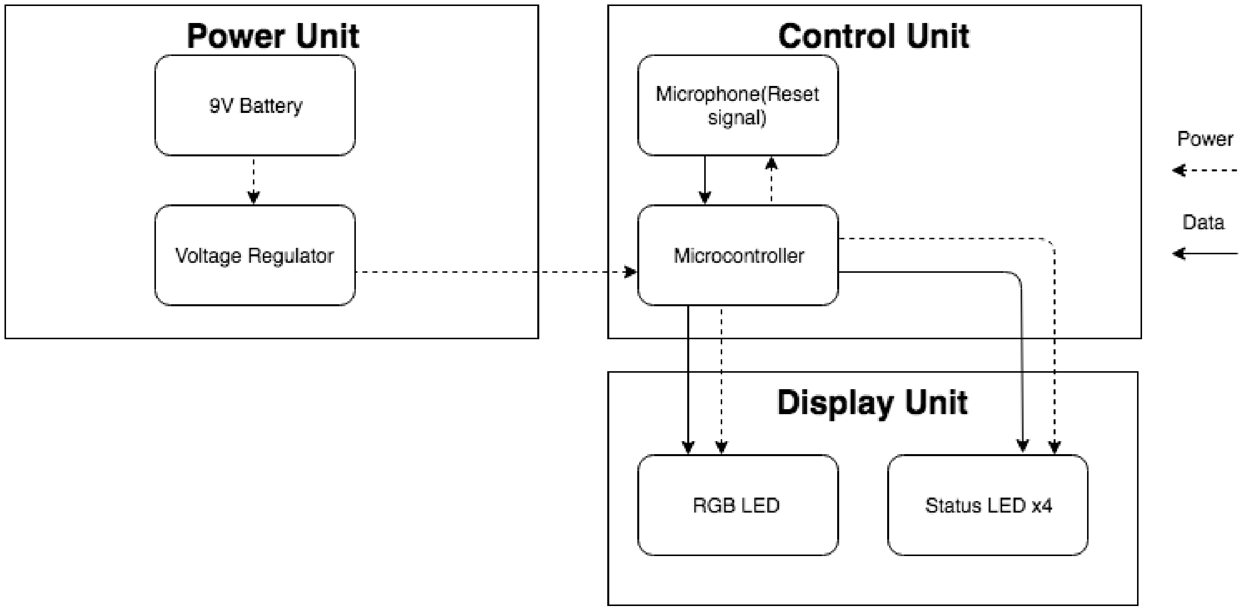

Figure 1: Block Diagram of Center Block

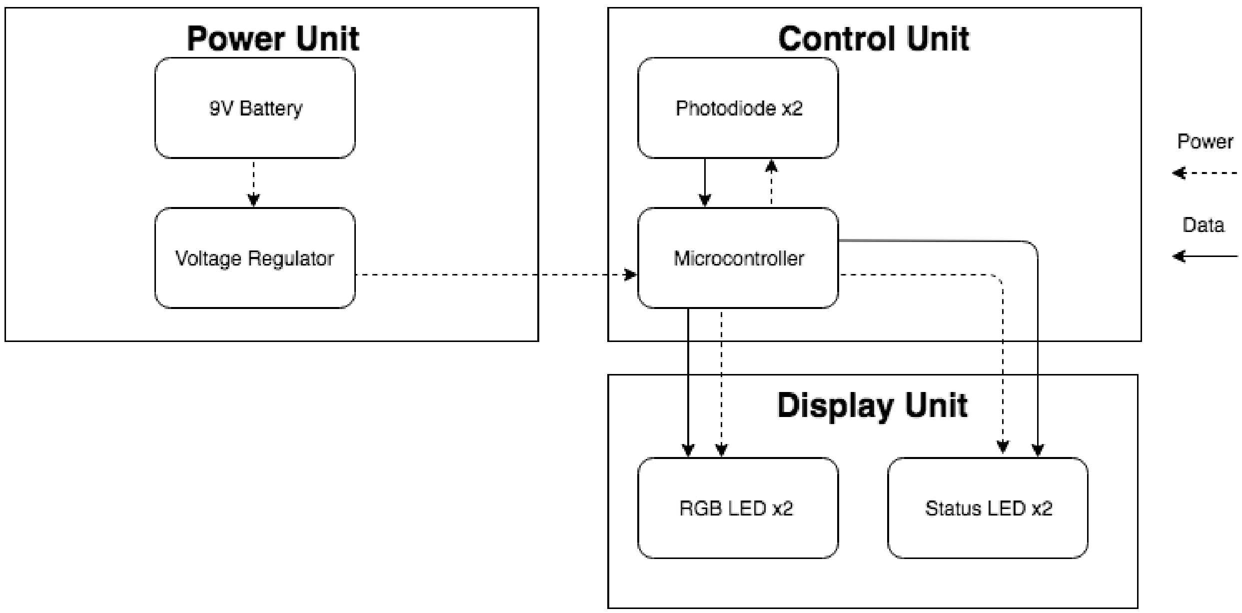

Figure 2: Block Diagram of Side Block

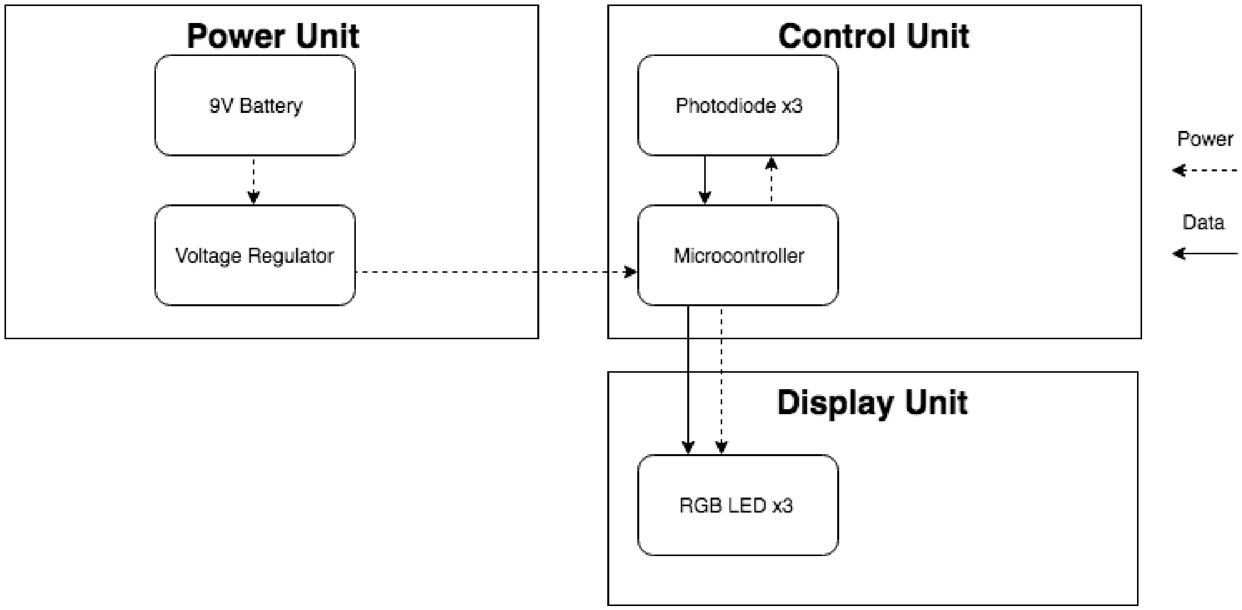

Figure 3: Block Diagram of Corner Block

**2.1 Physical Implementation**

The physical implementation of the cube is the key factor driving circuit design for the individual blocks. A Rubik's cube is a 3 x 3 x 3 puzzle comprised of six colors. The cube purchased to be the base of the prototype with modification is shown in Figure 4 with dimensions of 18 cm x 18 cm x 18cm. A large implementation of the cube was decided upon to make the implementation of each self-contained block easier. The shell of the device is a large size Rubik's cube made of 26 smaller blocks. The color of each visible face of the 26 blocks is the original state of one of the faces of the cube. There are eight corner blocks that have three faces exposed, twelve edge blocks that have two faces exposed, and six center blocks that have one face exposed. The layout of each of the 26 smaller blocks is shown in Figure 5. Each face of the cube can rotate about its center block by the mechanism shown in Figure 6 which allows the design to meet the high-level requirement of being able to physically rotate. The color of each of the visible faces of the blocks will be shown using an RGB LED. Depending on the block type, either one, two, or three RGB LEDs will be housed inside each block to signify what color that each exposed face of the block should be. Holes will be cut into each of the visible faces as shown in Figure 7, and each LED will be housed inside the smaller cubes according to Figure 8 and Figure 9. The necessary circuitry will then be placed in the remaining room of each of the smaller cubes, and additional holes will then be cut to allow communication between the infrared LEDs and the appropriate photodiodes.


Figure 4: LED Rubik’s Cube Base of Physical Implementation

Figure 5: 26 Blocks Comprising Large Rubik’s Cube

Figure 6: Rotation Mechanism

Figure 7: Cutouts Made for Each Block

Figure 8: Top View of LED Housing


Figure 9: Bottom View of LED Housing

### 2.2 Control Unit

The control unit is responsible for ensuring proper operating of the LED Rubik's Cube during power-up, reset, and any user specified mode two help satisfy the high-level requirements of having a reset and "random" user specified mode. The control unit for each of the block types is comprised of a microcontroller and either a microphone or multiple photodiodes. Power is provided to the control unit by the power unit. For the center blocks, the control unit takes inputs from the user with a microphone. For the corner and side blocks, it takes inputs from the status LEDs of adjacent blocks using photodiodes. For all implementations of the control unit, the control unit outputs color data to the display unit. For both the center and the side block implementations, it outputs status data to the status LEDs in the display unit.

#### 2.2.1 Microcontroller

The ATmega328P microcontroller will be used for all implementations of the control unit. This controller was chosen because of its low cost, since 26 are needed, and its small size. since each one needs to fit in a 6 cm x 6 cm x 6cm block. The microcontroller is powered by a 9V alkaline battery whose voltage is regulated to 5V using a voltage regulator that can supply a 6.75 mA current. Supplying 5V to the microcontroller allows the microcontroller to run at speeds of up to 20 MHz [5]. The microcontroller is responsible for powering, grounding, and receiving inputs from the microphone in the center implementation and the photodiodes in the side and corner implementations. It is also responsible for powering and grounding all elements in the display unit (i.e. RGB LEDs and status LEDs). For the center block implementation, inputs from the microphone will be used to determine what mode the cube is in and then output that data to the status LEDs in the display unit. For the side block implementation, inputs from the photodiodes will be used to determine the mode the cube is in and then output color and status data to the display unit. For the corner block implementation, inputs from the photodiodes will be used to determine the mode the cube is in and then output color data to the display unit.

| **Requirement** | **Verification** | **Points** |
|---|---|---|
| 1. The microcontroller should read a reset signal from the microphone and propagate this signal to the IR status LED.<br>2. The microcontroller must output at least 4V to each digital output pin in use to drive each LED color | 1a. Connect microcontroller to computer<br>1b. Send a reset signal to the microcontroller and read output from photodiode showing that the reset signal was propagated through the IR status LED.<br>2. Connect one lead of voltmeter to the supplied ground pin of the microcontroller, then connect the other lead to each digital output pin and measure each potential difference. | 1. 4 pts<br>2. 2 pts |

### 2.2.2 Microphone

The microphone is responsible for initiating the reset sequence. If the microphone in the center block detects a user yelling "reset," it will become active and send a signal to the microcontroller. When the microcontroller receives this signal, it will initiate the reset sequence that will propagate throughout the face of the cube. In total, there will be six microphones each outputting a signal to their respective microcontroller in each center block when the user initiates a reset. Once the microphone is active, the microcontroller can then illuminate an infrared LED used to propagate the reset signal to an adjacent cube. By using the microcontroller to read the output of the microphone, multiple types of sounds can be picked up to display different orientations of the cube.

This microphone outputs a signal with amplitude of a few millivolts. Thus, the output must be amplified to properly identify a signal and distinguish it from noise.

| Requirement | Verification | Points |
|---|---|---|
| 1. Microphone signal must be amplified to at least 30dB gain.<br>2. Microphone must be able to identify the reset signals 9 out of 10 times.<br>3. Must not respond to false positive reset signals 9 out of 10 times. | 1. Provide a small signal sine wave from a function generator with amplitude 1mV. Connect small signal to input of the microphone's amplifier. Read output of amplifier with oscilloscope. Determine if $\frac{V_{out}}{V_{in}} \geq 30dB$<br>2. Trigger reset signal 30 times. Verify that Cube resets at least 27 times.<br>3. Rotate segments of Cube 30 times. Verify that this does not trigger a reset of Cube more than 3 times. | 1. 4 pts<br>2. 2 pts<br>3. 2 pts |

### 2.2.3 Photodiode

The photodiodes are responsible for receiving the reset signal from the infrared status LEDs. Photodiode will send information about receiving infrared pulses to the microcontroller. The number of pulses the status LED sends represents a specific color. The microcontroller will count the number of pulses the photodiode receives and will determine what color the corresponding RGB LED needs to be according to Table 1. If it is a side block, the microcontroller will output data to the corresponding status LED in the display unit so that it repeats the pattern the photodiode received, and the corresponding photodiode in the corner block can receive the pulses.

The Fairchild QSE773 Photodiode was chosen for its capability to convert infrared light pulses into voltage signals and for its peak spectral sensitivity. As shown in Figure 10, the photodiode has a peak spectral sensitivity at approximately 940 nm which is the same wavelength as the infrared LEDs chosen [6].

| Number of pulses | Color |
|---|---|
| 1 | Red |
| 2 | Green |
| 3 | Blue |
| 4 | Yellow (Red + Green) |
| 5 | Purple (Red + Blue) |
| 6 | White (Red + Green + Blue) |

Table 1: Number of Pulses Needed to Indicate a Given RGB LED Color

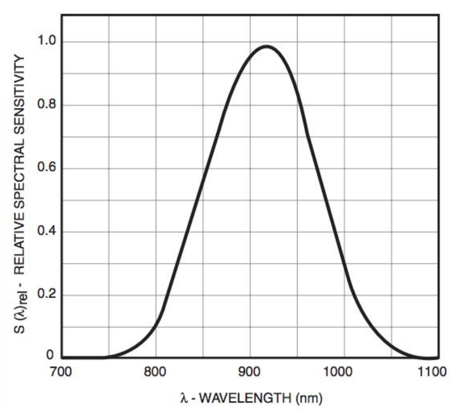


Figure 10: Relative Spectral Sensitivity vs. Wavelength of Photodiode [6]

| Requirement | Verification | Points |
|---|---|---|
| 1. Must be able to sense infrared wavelengths between 900 nm-1000 nm | 1. Connect microcontroller to computer and set up to read photodiode output. Use a spectrometer to verify that the infrared LED emits a wavelength between 900 nm-1000 nm. Shine infrared LED into the photodiode sensor. Determine if output of photodiode is different when shining infrared LED vs. ambient light. | 1. 6 pts |

**2.3 Display Unit**

The display unit is the circuitry necessary to individually light each block with a color changing RGB LED. This module is comprised of RGB LEDs and status LEDs. There are four status LEDs and one RGB LED in the center block implementation, two status LEDs and two RGB LEDs in the side block implementation, and three RGB LEDs in the corner block implementation. The microcontroller in the control unit is responsible for powering, grounding, and sending the appropriate data to the RGB LEDs and status LEDs. The RGB LEDs will update during a reset and a user specified mode. The status LEDs will be initiated to propagate a reset or a user specified mode from the center cube to the corner cubes of on its face. This is necessary to complete both the reset and user specified “random” functions in the high-level requirements.

| Requirement | Verification | Points |
|---|---|---|
| 1. Must consume less than 225mA of current for 2 hours of play time on a 450mAh battery.<br>2. Must be self-contained | 1. Turn on all components in display unit connected to microcontroller. Measure the total current output running through each component. Verify that sum of total current does not exceed 225mA of current. This will ensure that the battery can last for at least 2 hours of play time.<br>2. No wires leaving any of the small cubes | 1. 3 pts<br>2. 2 pts |

### 2.3.1 RGB LEDs

54 RGB LEDs will display the proper color of the of each face of each block based on the voltage across them. There are four terminals on each RGB LED, one connected to ground and three controlling the amount of light emitted from their respective color LED, red, green, or blue. The red, green, and blue terminals are connected to resistors as shown by the schematic in Figure 11 obtained from wiring.org [7]. The voltages across the terminals and the ground for the RGB LED is provided by the microcontroller in the control unit. There are six colors representing the initial state of each of the six faces of the cube. The colors chosen are red, green, blue, yellow, purple, and white. These colors were chosen because they are formed by turning on combinations of the red, green, and blue LEDs inside the RGB LED with the same intensity making it easy to switch between colors simply by turning on or off different LEDs within the RGB LED. To emit red, green, or blue light, only one of the three LEDs need to be turned on either the red, green, or blue LED, respectively Additionally, each red, green, and blue LED consumes 20 mA of current. To emit yellow light, the red and the green LEDs are turned on giving a total current consumption of 40 mA. To emit purple light, the red and the blue LEDs are turned on giving a total current consumption of 40 mA. To emit white light, the red, green, and blue LEDs are turned on giving total current consumption of 60 mA. The current specifications for each color are additionally referenced in Table 2.

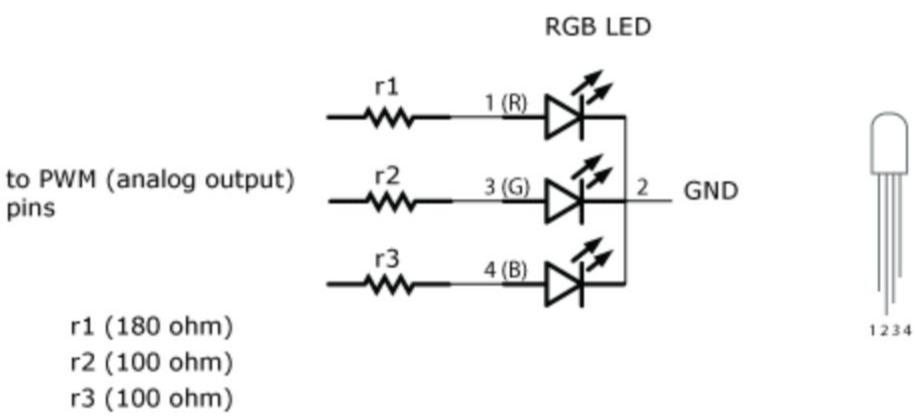


Figure 11: Schematic for RGB LED [7]

| **LED Color** | **Current Usage** |
|---|---|
| Red | 20mA |
| Green | 20mA |
| Blue | 20mA |
| Yellow | 40mA |

| | |
|---|---|
| Purple | 40mA |
| White | 60mA |

Table 2: Current Usage of RGB LEDs per Color

| Requirement | Verification | Points |
|---|---|---|
| 1. Must be easily visible to user from a distance of 2 feet away.<br>2. Must be oriented in each block such that multiple LEDs in a single cube do not interfere with each other. | 1. Measure 2 feet with a ruler. Inspect LED to see if its color can be easily determined.<br>2. Check colors of all LEDs to make sure that the only colors displayed are red, green, blue, yellow, purple and white. | 1. 3 pts<br>2. 4 pts |

### 2.3.2 Status LEDs - Infrared LEDs

The infrared LEDs are responsible for sending signals in between each block. The machine shop is in the process of drilling holes in between the blocks so that the infrared beam can be picked up by a photodiode located in the receiving block. The main purpose of the infrared LEDs is to propagate a reset signal initiated by the microphone in the center block. Infrared LEDs were chosen to transmit data because wires entering and exiting the cubes would tangle when the user rotates each face of the puzzle.

The infrared LEDs chosen are GaAlAs semiconductors that emit light at a wavelength of 940 nm. As seen in Figure 12, the diode emits the highest intensity of light at wavelengths near 940 nm [8]. The infrared LEDs are responsible for sending sequences of pulses to the photodiodes. Each sequence of pulses represents one of the six colors of the RGB LEDs. For example if one of the photodiodes receives two pulses of light from an infrared LED, the microcontroller will specify the color of the RGB LED to be green as determined by Table 3.

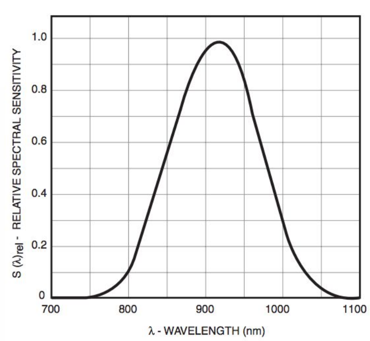


Figure 12: Spectral Distribution of Radiant Intensity [8]

| Number of pulses | Color |
|---|---|
| 1 | Red |
| 2 | Green |
| 3 | Blue |
| 4 | Yellow (Red + Green) |
| 5 | Purple (Red + Blue) |
| 6 | White (Red + Green + Blue) |

Table 3: Number of Pulses Needed to Indicate a Given RGB LED Color

| Requirement | Verification | Points |
|---|---|---|
| 1. Must be able to send six unique signals to the photodiode<br>2. Must emit a wavelength of light between 900nm-1000nm | 1. Write a test Arduino program that creates six different pulse sequences to excite the infrared LED. Verify that this program can produce six different RGB color outputs.<br>2. Move a spectrometer near the IR LED. Direct LED beam into spectrometer and measure the frequency reading. Use following formula to calculate wavelength.<br>$\lambda = \frac{1}{f}$ | 1. 9 pts (1.5 pts for each color)<br>2. 4 pts |

### 2.4 Power Unit

The power unit is responsible for maintaining a constant 5 V to the microcontroller. Without power to the microcontroller, the high-level requirements of implementing a reset and additional user-specified modes of operation could not be possible.

#### 2.4.1 Voltage Regulator

The voltage regulator is used to maintain a 5 V input to the microcontroller from the 9 V battery. The regulator must bring this voltage down to 5 V and be able to supply a current of 6.75 mA to power the microcontroller. The maximum allowed input voltage to the ATmega328P microcontroller is 5.5 V, so the input voltage to the microcontroller must be well below 5.5 V to make ensure that no ripple or noise voltages damage the device. In addition, the voltage regulator prevents large amounts of current from flowing into the microcontroller. The voltage regulator requires an input voltage at least 2 V higher than the output voltage to be supplied which is 5 V in this case.  Therefore, a 9 V battery was chosen because it is well above the 7 V minimum.

| **Requirement** | **Verification** | **Points** |
|---|---|---|
| 1. Provides 5 V from a 9 V source within a 5% error<br>2. Supplies current at 6.75 mA | 1. Connect voltmeter to output of voltage regulator and check if voltage is between 4.75-5.25V.<br>2. Connect a test load to the output of the regulator with a resistance of 740Ω or less. Connect an ammeter in series with the resistor. Measure the current reading of ammeter. | 1. 3 pts<br>2. 2 pts |

### 2.4.2 9 Volt Battery

A standard 9 V battery is used to power the microcontroller in the display.  This was chosen because it would have a longer lifetime than a smaller battery, and it was the largest battery that could fit inside each small cube.  Since there are a total of 26 9 V batteries between all of the color display modules, it makes sense to not have to charge 26 different batteries for this implementation.

## 2.5 Schematics

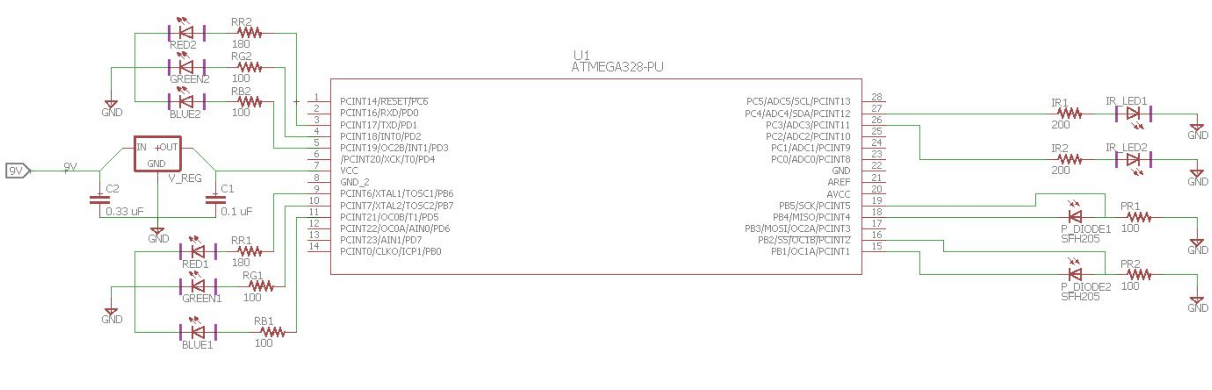


Figure 13: Schematic of Block Diagram for Side Block

**2.6 Tolerance Analysis**

The tolerance analysis was done on the L7805CV Voltage Regulator. It is important that this component functions within a certain tolerance because this project contains sensitive electrical equipment that could be damaged if this part does not deliver an output voltage within a certain range of voltages. The ATMega328P microcontroller can operate between 1.8 V to 5.5 V. However, it can operate at speeds up to 20MHz if the voltage is between 4.5 V to 5.5 V. The L7805CV Voltage Regulator can be used to achieve this voltage range. According to the Texas Instruments datasheet, this regulator outputs an average voltage of 5 V, but can vary from 4.8 V-5.2 V [9].

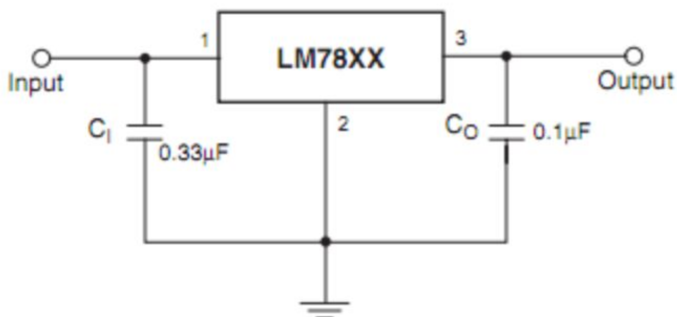


Figure 14: Voltage Regulator circuit [9]

The voltage regulator circuit in Figure 14 was built and tested for a range of input voltages. The coupling capacitors $C_1$ and $C_0$ are used to help reduce noise and perturbations. The voltage regulator requires a minimum voltage of 7 V to properly supply a 5 V output. Since a 9 V battery is the input to the regulator, tests were run on the L7805CV at input voltages of 7.5 V, 8 V, 8.5 V and 9 V as shown in Table 4. After the battery has discharged past the point where it can provide a 7 V potential, it should no longer be used to power the microcontroller.

| **Input Voltage (V)** | **Output Voltage Mean (V)** |
|---|---|
| 7.5 | 4.9973 |
| 8 | 4.9981 |
| 8.5 | 4.9988 |
| 9 | 4.9996 |

Table 4: L7805CV outputs for inputs of 7.5 V, 8 V, 8.5 V and 9 V

Tests were also run to determine the noise of the voltage seen at the output of the regulator when a 9 V power supply was connected to its input. According to the datasheet, the voltage regulator has a max output regulation of 100 mV which is a rather large perturbation. The output voltage of the regulator for a 9V input is shown in Figure 15. With the help of coupling capacitors specified by the schematic in Figure 14, the peak-peak small signal noise voltage is only 16.9mV.

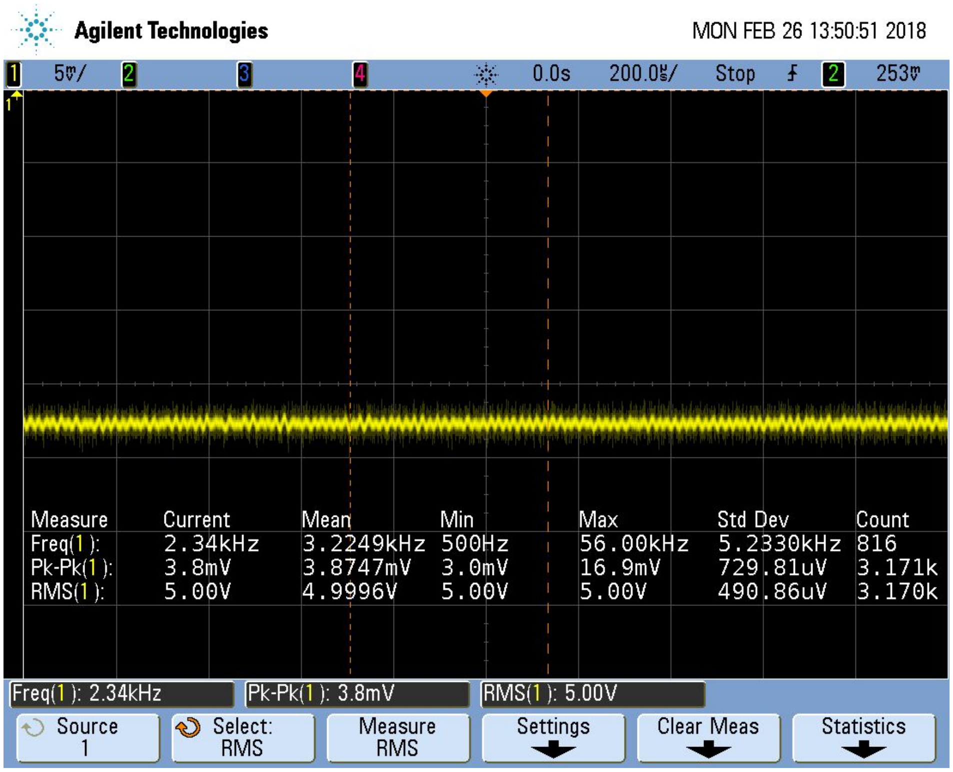


Figure 15: Oscilloscope Measurement of Voltage Regulator Characteristics

## 3.1 Costs

### 3.1.1 Labor

**Partner Labor**

We estimate that each partner will spend between 8-10 hours per week on this project. Each of the three partners works 9 hours on average per week, and according to the ECE Illinois website, an average Electrical Engineering Graduate made $67,000 starting salary. Assuming a 2000-hour work year, this boils down to $33.50 per hour [10].

$$2 * \frac{\$33.50}{hr} * \frac{9hr}{week} * 16weeks * 2.5 = \$24120$$

**Machine Shop Labor**

The manufacturing shop estimated that they will put 70 hours of work into the project. The hourly rate of machine shop labor as quoted by the machine shop is $55 per hour.

$$70hrs * \frac{\$55}{hr} = \$3850$$

### 3.1.2 Parts

| **Part** | **Cost** | **Quantity** | **Total** |
|---|---|---|---|
| **Microcontroller (ATmega328P)** | **$2.54** | **26** | **$66.04** |
| **RGB LEDs (100 pack)** | **$8.96** | **1** | **$8.96** |
| **Photodiode (QSE773)** | **$0.76** | **48** | **$36.48** |
| **IR LEDs** | **$0.75** | **48** | **$36.00** |
| **9V Alkaline Battery** | **$1.99** | **26** | **$51.74** |
| **Voltage Regulator (L7805CV)** | **$0.22** | **26** | **$5.72** |
| **Microphone (Electret)** | **$0.95** | **6** | **$5.70** |
| **Resistors (100 pack)** | **$1.59** | **1** | **$1.59** |
| **PCBs (PCBway)** | **$3.00** | **26** | **$78.00** |
| **Total cost:** | | | **$290.23** |

### 3.1.3 Grand Total

$$\$36,180 + \$3,850 + \$290.23 = \$40,320.23$$

### 3.2 Schedule

| | |
|---|---|
| **Week of 2/18** | Make final decision on which parts to use and determine total power usage of our project (Michael). Determine implementation of photodiodes and IR LEDs between blocks and decide on the physical design of the implementation (Meghan). |
| **Week of 2/25** | Characterize LED circuit and determine necessary control logic of microcontroller to choose the colors of the RGB LEDs (Michael). Design circuit combining all components of each block implementation for all three block implementations (Meghan). |
| **Week of 3/4** | Build LED circuit portion of PCB (Michael). Build microcontroller and voltage regulator portion of PCB (Meghan). |
| **Week of 3/11** | Attempt to read color data from IR LEDs with photodiodes and microcontroller (Michael). Output color data to the RGB LEDs and status data to the IR LEDs from the microcontroller (Meghan). |
| **Week of 3/18** | **Spring Break** |
| **Week of 3/25** | Read and characterize microphone data such that it can be used to implement a reset (Michael). Integrate the functionalities of Week 3/11 to have a propagating reset signal (Meghan). |
| **Week of 4/1** | Assemble cube. Attempt to implement signals that can bring the cube into a predetermined state (Michael and Meghan). |
| **Week of 4/8** | Expedite reset process so that the propagation of the reset signal between blocks goes unnoticed by the user and finetune any color display issues (Michael and Meghan). |
| **Week of 4/15** | Add features to allow the user to implement “random” puzzles (Michael and Meghan). |
| **Week of 4/22** | Sync center cube microphones so that reset propagates at same time for all faces (Michael and Meghan). |

### 4.1 Ethics

We have done research on similar products, and we believe that our product is different from other LED Rubik's Cube because ours will feature physical rotation and rotation sensors. One example of a similar product is the Rubik's Futuro Cube [3]. This product features an LED Cube that is interfaced with a touch screen. There are different games that can be played on this 54 LED 3 x 3 x 3 puzzle. The touch screen can sense if you've made a swiping or a tapping motion, and will adjust the LEDs according to your move. However, there is no physical rotation of the Futuro Cube. All moves are done using the touch screen. Our project features a physical Cube that can rotate. We will act in accordance with the IEEE Code of Ethics #9 and make every effort to avoid infringing on the intellectual property of the Futuro Cube and other similar products [2].

Every project utilizes assistance from outside it's core group at some point. Our project will be getting assistance from the ECE Machine Shop. When first ordering our novelty Rubik's Cube, we had no way to get inside of the Cube to place LEDs and other components easily. We have asked David Switzer and Scott McDonald from the ECE machine shop to create latches on each of the outer cubes that can be easily opened and closed so components can be placed. To properly follow the IEEE Code of Ethics #7 and to credit the contributions of others to our project [2], we will take the time necessary to make sure that we do not claim any work that is not our own, and to give credit where credit is due.

### 4.2 Safety

We do not have any outstanding safety concerns related to our project. However, one should always exert proper precaution and respect for all electrical devices no matter how harmless they may seem. The most dangerous part of our project lies in its power supply, 9 volt batteries. Batteries may seem like harmless tiny objects that we encounter and interact with on a daily basis, but proper precautions must be taken whenever dealing with batteries to prevent human harm. Provided in references [12] is a battery safety manual. One important battery safety precaution relevant to our project is that the battery leads should never with loose metal. This may cause the battery to discharge and heat up the metal which has the potential to cause a fire. This has a decent potential to happen to our project while the Cube is being rotated and our batteries are not secured properly. We will use proper leads that will connect and snap on to the battery to prevent this from happening.

Another potentially dangerous component is the infrared LEDs used to communicate between cubes. In most normal use cases, the infrared LED will be completely covered and the light will not be able to escape the cube. However, in the process of developing the cube, the infrared light may be exposed. It is known that infrared light has the potential to cause damage to the corneas of one's eye. One should never intentionally bring infrared light close to their eye or direct the light into their eye. Some safety precautions regarding infrared LEDs can be found in reference [12]. In our design, we will include casings around the LEDs to direct the beam into the photodiode. This will also serve as an extra layer of protection so that the beam does not accidentally harm anyone.

## 5 References


[1] “Cube Facts.” Rubiks, www.rubiks.com/about/cube-facts. [Accessed: February 2, 2018].

[2] “Competitions.” World Cube Association, World Cube Association, www.worldcubeassociation.org/competitions [Accessed: February 18, 2018].

[3] Ing. Jan Krejsa, Ing. Jaroslav Altmann, Ing. Vladimir Vejvoda, “Rubik’s Futuro Cube” PCT CZ2013/000013 November 2nd, 2013 [Accessed: February 4, 2018].

[4] Kit Eaton, “LED Rubiks Cube is Unnecessary Digitization of a Classic”, *Gizmodo*, October 21, 2008. [Online] Available: https://gizmodo.com/5066330/led-rubiks-cube-is-unnecessary-digitization-of-a-classic [Accessed: February 16, 2018].

[5] Everlight, “Technical Datasheet 5mm Infrared LED”, IR333-A, July 2005 [Accessed: February 20, 2018].

[6] Fairchild, “Sidelooker Pin Photodiode”, QSE773, August 2013.

[7] Hernando Barragán, “RGB LED”, *wiring.org*. [Online] Available: http://wiring.org.co/learning/basics/rgbled.html [Accessed February 2, 2018].

[8] Everlight, “Technical Datasheet 5mm Infrared LED”, IR333-A, July 2005 [Accessed: February 20, 2018].

[9] Texas Instruments, “A7800Series Positive-Voltage Regulators”, May 1976 [Accessed: February 22]

[10] “Salary Averages, ” ECE Illinois, University of Illinois at Urbana-Champaign, [Online] Available: ece.illinois.edu/admissions/why-ece/salary-averages.asp [Accessed: February 20, 2018]

[11] Ieee.org, "IEEE IEEE Code of Ethics", 2016. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: February 18, 2018].

[12] Energizer, “Alkaline Battery Product Safety Data Sheet”, 2017 [Online] Available: data.energizer.com/pdfs/alkalinecylindrical_psds.pdf [Accessed: February 12, 2018].