Design Document

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1. Introduction

1.1 Objective

Code is everywhere in the world and coding has become an essential skill for not only the engineers but also everyone who wants to dig in big data. Nowadays, many kids are exposed to coding at a very young age. Their brain is capable of handling different coding problems. According to VentureBeat, many good programmers started programming since 5 or 6 years old [1]. However the steep learning curve of coding can scare off the kids before they really develop interests in it. Young kids sometimes find out that it is hard to start by typing code into the computer. Thus, it is necessary to have a good platform which could serve as a fun and easy coding environment. This platform should consist of both physical and virtual parts, where the virtual part is a coding software which should be simple to learn and the physical part should be responsive to execution instructions. Besides, since this platform serves kids at a very young age, safety precaution needs to be strictly imposed.

In this project, we aim at providing kids with a younger age (from 4 to 8) a platform to learn coding. These kids might not be capable of coding through software and hence our solution will be focusing on the hardware. Our goal is to create a color-coding based robot which converts detected color into different instructions. In order to provide the kids a feasible way of learning codes, the instructions will be executed as simple motions such as moving forward, backwards, turns, etc.

1.2 Background

Many companies target at kids and have different kinds of products which could be used to learn the knowledge of coding. However, color-coding based product is scarce and most of the existing products do not allow kids to write their own color code. So in our project, we aim at developing a kit which will cover these scarceness. The kit itself will be separated as different modules and have the ability to be built completely from scratch by kids. Once they construct the kits, kids will be able to use our intrinsic color-based code or design their own color-based code.

STEM education is a growing trend in the United States. With rising interest creates a demand for STEM education services and products that help people learn principles of engineering and programming at earlier ages. There are already popular products provided by companies like LEGO and Rokenbok education that allow for young students to learn engineering and programming engineering principles for students as young as 6 years old through building robots. What they do is provide a low learning curve platform for students to create different build systems structurally, mechanically and electronically. Learning how to program through programming the robots has also been implemented by many of the same education providers, although there are some companies like Ozobot and Robomation that have made learning programming principles even easier to reach even younger students. They do so by having the students learn how to encode actions through colors. The companies provide a robot that will follow a path naturally and perform different actions as it notices color codes along the path. Students can then create their own paths and encoding to “program” the system, although they are very limited in what they can do to the robots shape and function. What we would like to do is provide a similar color encoding system for young students to learn to code onto an existing building platform. This would allow students to develop basic engineering skills building structural and mechanical systems as well as to explore basic principles of programming. Our responsibilities to the system are to provide sensors for color detection and a electronic control board that would control two DC motors and a Servo motor. The building platform that will be used to create the structure around the electronics can be almost anything; however, for the purposes of this project everything will be done with Robotori pieces [2].

1.3. High-level Requirements

1. The control board can differentiate at least six different colors and is able to execute at least five different instructions accordingly.

2. The kit can be separated as at least three parts and all of them can be fitted into their own cases. The cases should be adequate in size and affordable in cost.

3. The kit will have the ability to be re-programmed by the users with color-based coding and can be reset to default settings.

2. Design

2.1. Block Diagram

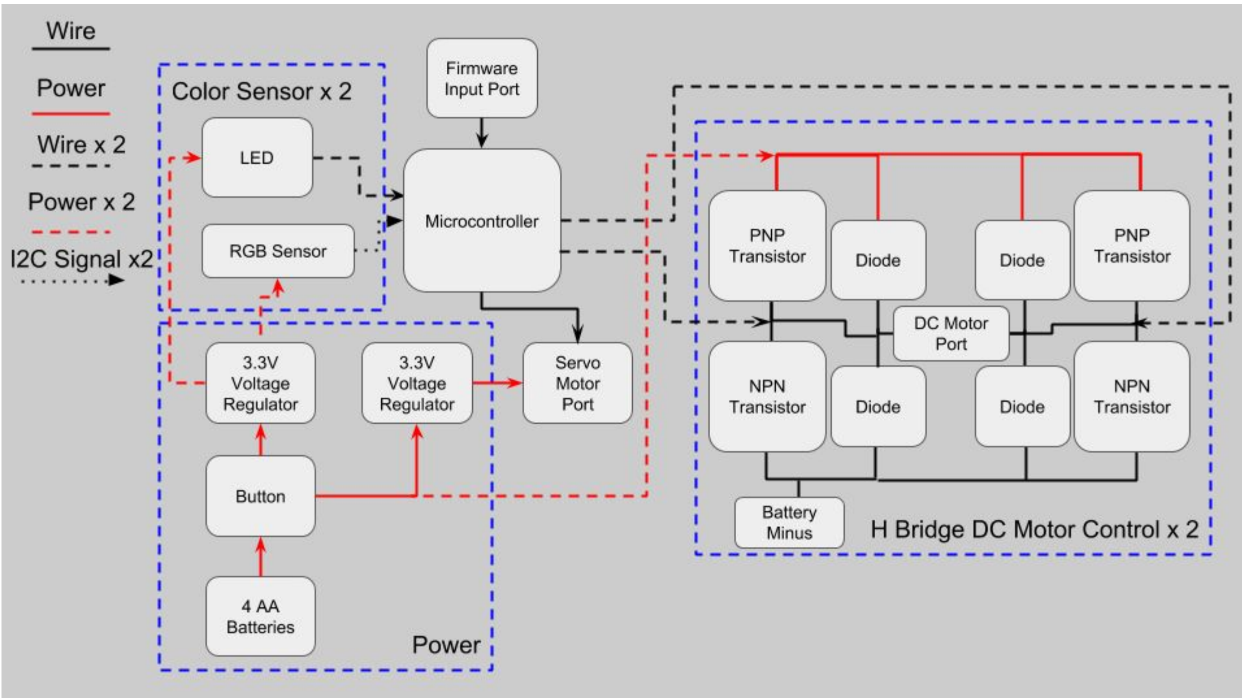

Figure 1. Block diagram

2.2. Circuits

Power

In the circuit below, Battery-1 is the positive lead of the battery source, Battery-2 is the negative lead of the battery, Out-1 is the power lead for the microcontroller and sensors, and Out-2 is the power lead for the servo motor.

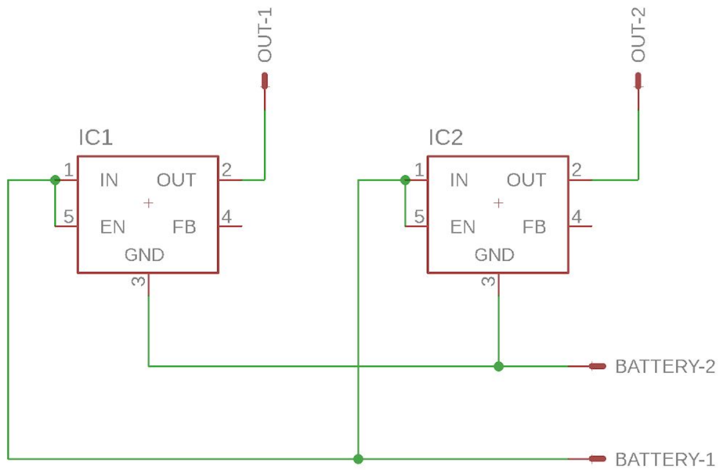

Figure 2. Power supply schematic

H Bridge

In the circuit below, Battery-1 is the positive lead of the battery source, Battery-2 is the negative lead of the battery, IN-1 and IN-2 are signals from the microcontroller.

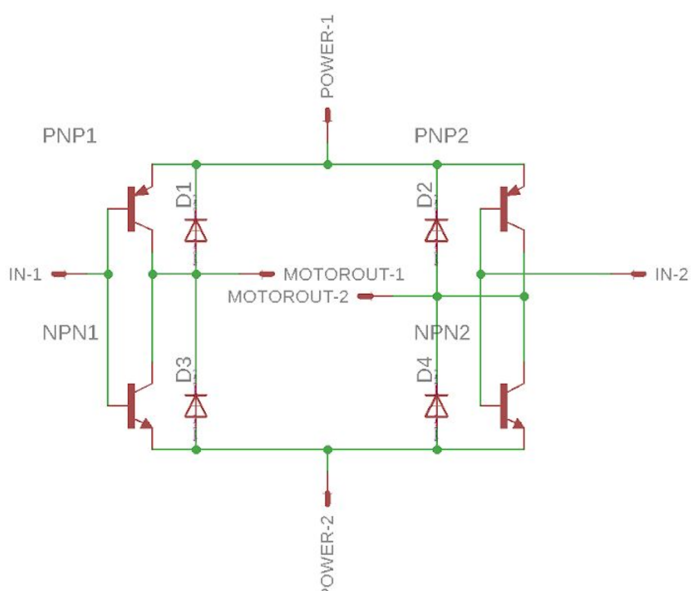

Figure 3. H-bridge schematic

RGB Sensor

VDD will use the same voltage as the microcontroller. The SCL port is connected to the microcontroller's I^{2}C clock. The SDA port will be connected to the I^{2}C I/O port. The interrupt port is open drain and can be used to wire-OR with other device. For our interest, it will be left open and kept for possible future usage.

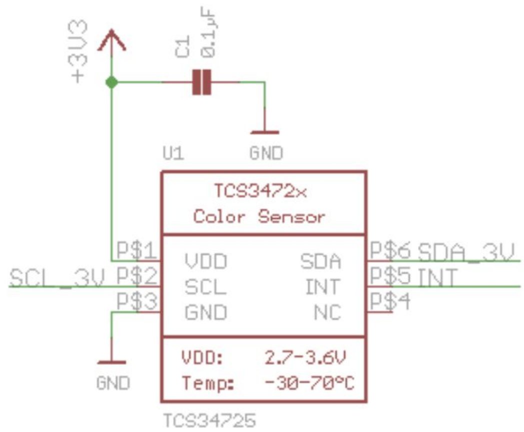

Figure 4. Color light-to-digital converter schematic

2.3. Plots

Voltage Regulator

This voltage dropout characteristic plot shows the output voltage response according to any input voltage. Clearly, in order for the voltage regulator to work properly, we need to keep the input voltage above 3 volts.

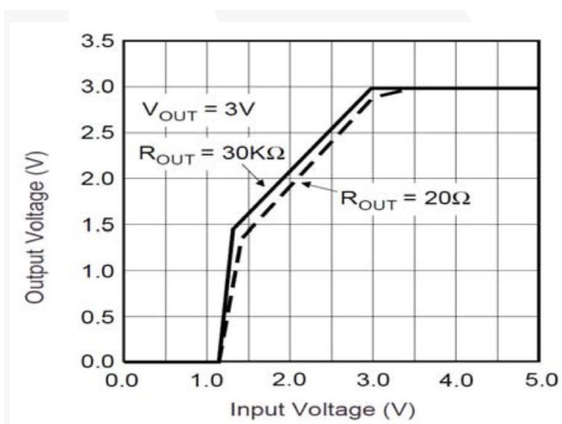

Figure 5. Dropout characteristic [3]

Diode

The diode current vs. voltage plot shows the working condition in different temperature. It is crucial for us to keep track of the current since we want to prevent the current overflow from happening.

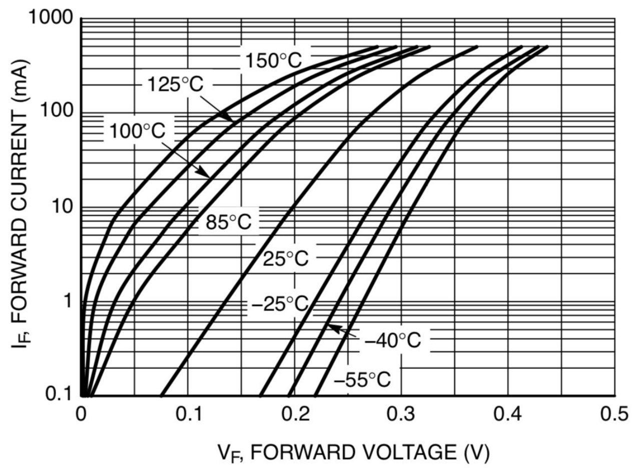

Figure 6. Forward current vs. forward voltage under different working temperature [4]

NPN and PNP Transistor

Similar to the diode, the transistor current needs to be monitored in order for us to control the current overflow.

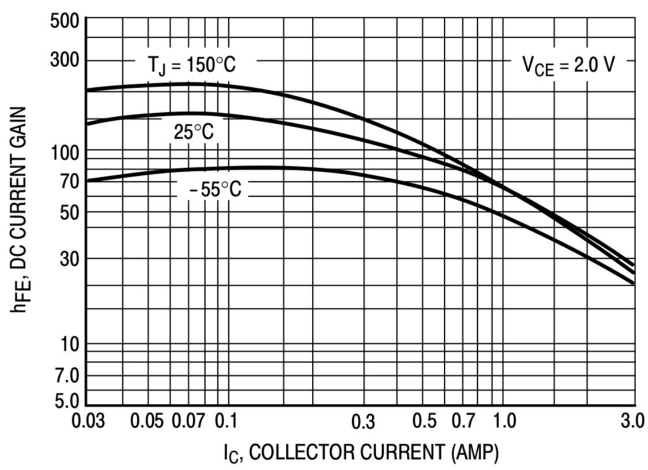

Figure 7. DC current gain [5]

Photodiode on RGB Sensor

The responsivity of photodiode on RGB sensor is responsible to differentiate different color and crucial for us to achieve the desired sensing distance.

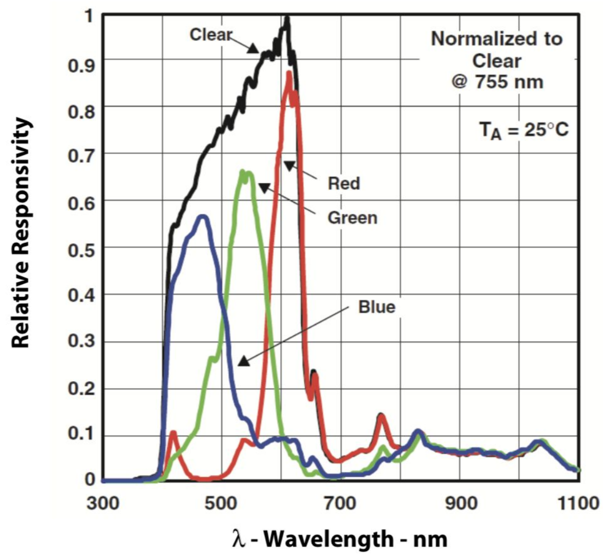

Figure 8. Photodiode spectral responsivity RGBC [6]

2.4. Functional Overview, Requirements and Verification

Microcontroller

The microcontroller should be able to understand the signals coming from color sensors and be able to differentiate between different colors based on that signal. It should then be able to send appropriate control signals to DC and Servo motor control modules based on sensor input. Lastly, it should be able to accept flashed firmware onto it in the event that software changes need to be made.

Requirements	Verification
1. Must must be able to measure voltage signals between 0 to 3.3 volts within an accuracy of 0.1 volts.	1. Install a program onto the microcontroller that would output the voltage it reads from an input.
2. Must be able to send signals between 0 to 3.3 volts to the H-Bridge with an accuracy of 0.1 volts.	2. Send voltages from 0 to 3.3 in 0.1 volt increments from the microcontroller and measure the output with a voltmeter.
3. Must be able to operate on a power source of 3-3.6 volts.	3. Power the microcontroller from a power supply at 3 volts and 3.6 volts and test a program on it.
4. Must not draw more than 20 mA.	4. While testing the microcontroller, read the current being drawn with an Amp meter to ensure it doesn't exceed 20 mA.
5. Must be able to understand I2C signals from the RGB sensor.	5. Connect the microcontroller to a working RGB sensor that communicates via I2C and load a program that will display the different colors the microcontroller reads, and compare the output with the input color that the RGB sensors are detecting.
6. Must have a PWM resolution of at most 50ns	6. Connect the output of the PWM I/O pin to an oscilloscope and configure the microcontroller to send pulses of less than 50ns through and measure the the width of the pulses on the oscilloscope.

Power Button

The purpose of the button is to turn the board on and off by controlling current flow from the battery power supply to the rest of the system.

Requirements	Verification
1. Must be able to withstand current up to 500mA.	1. Send a steady flow of 500mA current through the button over 30 minutes and ensure that afterwards the button hasn't broken the connection or overheated.

Batteries

The purpose of the batteries is to provide a mobile power source. There should be a total of 4 of these batteries as the main power source connected in series to provide a total voltage between 4.6 to 5 volts. The cutoff voltage for operation will be 1.15 volts per battery.

Requirements	Verification
1. Batteries must be rechargeable batteries that supply between 1.15 to 1.25 volts each.	1. Measure the voltage across a single battery and unsure it is within 1.15 to 1.25 volts. Then deplete the battery and repeat the test after attempting to recharge.
2. Each battery must have a capacity of 1500mAh, and able to supply 500mA to a load before dropping to 1.15V.	2. Setup up the battery to an Ammeter and a variable resistor in series. Vary the resistance on the resistor till the Ammeter reads 500mA and measure the voltage across the batteries with a voltmeter over 3 hours of use to see if it drops below 1.15 volts.
3. Must be manually rechargeable	3. Deplete a battery and test recharging it on an eneloop battery charger.

3.3 Voltage Regulators

The purpose of the voltage regulator before the sensors and the microcontroller is to provide a steady source of power. This helps the color sensors reduce the chance it misinterprets a color and ensures the microcontroller has reliable power. One regulator will be allocated to the sensors and the microcontroller and the other will be allocated to the servo motors. This is to guarantee that draw from the activation of the servo motor is completely separated from the sensors and microcontroller so that it will not cause a voltage drop in the RGB sensors. Dropout voltage for these regulators should not exceed 1 volt and they must maintain a temperature below 50 degrees Celsius. They should also be able to handle currents up to 500mA.

Requirements	Verification
1. Must be able to withstand current up to 500mA.	1. Setup the voltage regulator to an Ammeter and a variable resistor in series such that the draw is 500mA and measure that it is still outputting a steady 3.3 volts
2. Must be able to take in between 4.6 to 5 volts as an input from the battery power supply and output 3.3 volts with a tolerance of 5%	2. Input the battery power supply and measure the output voltage with an oscilloscope to ensure it is outputting a steady 3.3 volts within the tolerance.

Transistors

The purpose of the transistors is to act as switches in an H bridge for DC motor control. The H bridge needs only control the direction of the motors. There must be 2 PNP and 2 NPN transistors.

Requirements	Verification
1. Must be able to handle current from 100mA to 300mA to power the motors.	1. Setup the transistors in the H bridge configuration connect the outputs, MOTOROUT1 and MOTOROUT2, to an Ammeter and a variable resistor in series. Vary the potential across the resistor such that the Ammeter reads a draw of 300mA.
2. Must maintain a temperature below 50 degrees Celsius.	2. Setup the transistors in the H bridge configuration and measure their temperatures while powering a motor.
3. Must also be able to act as switches when provided a voltage to the base of 0 to 1.5 volts and 2 to 3.3 volts	3. Setup the transistors in the H bridge configuration and ensure the motors spin can be controlled by the values of the bases to the input transistors, IN-1 and IN-2, as shown in the truth table below. High values are voltages between 2 and 3.3 volts and low voltages are between 0 and 1.5 volts.

Below is a truth table provided for the H-bridge that the transistors will create. Please refer to figure 3 to see the positions of the transistors in the H-bridge.

IN-1	IN-2	MOTOROUT-1	MOTOROUT-2	Motor Spin
High	High	Low	Low	None
High	Low	Low	High	Anticlockwise
Low	High	High	Low	Clockwise
Low	Low	High	High	None

Diodes

The purpose of the diodes are to act as catch diodes in the H bridge for DC motor control. The motors in our system are an inductive load which will create a sudden voltage spike across itself when the motors either stop spinning or change it's spin direction. The purpose of the catch diodes are to eliminate the flyback voltage spike from the motors. The diodes must be standard diodes with a reverse voltage of 200 volts with a current rating of 500mA.

Requirements	Verification
1. Must be able to catch back current flow when a motor changes direction.	1. Setup the diodes in a working H bridge configuration and measure the current across them for any spikes, as the motors are controlled to change directions.

RGB Sensor

The purpose of the RGB Sensor is to read the color of a surface near it and send I2C signals to the microcontroller.

Requirements	Verification
1. The RGB sensor must be able to detect the color of a 1cm by 1cm area being illuminated by a white LED that is between 0.5 cm to 4cm from the sensor. 2. Must be able to send I^2C signals to the microcontroller to accurately detect colors that to the naked eye look red, blue, green, black, gray, and brown.	1. Read the values from the RGB sensor while it is placed at 0.5 and 4cm away from the surface of a 1cm by 1 cm square of various colors. 2. Draw squares that are 1cm by 1cm of the colors red, blue, green, black, gray, and brown and ensure that sensor can differentiate between them.

LED

The purpose of the LED is to illuminate the area in front of the photodetector to increase the intensity of the reflected color.

Requirements	Verification
1. The LED should provide a broadband white light across 400nm to 700nm. 2. The LED should be able to illuminate an area of 1cm by 1 cm between 0.5cm to 4cm.	1. This can be tested by focusing the light into an optical spectrum analyzer and reading the spectral response. 2. Draw a 1cm by 1cm square on a piece of paper and see that it is illuminated by the LED when places at 0.5cm away and 4cm away.

2.5. Allocation of Points

Module Name	High Level Requirement	Points
Microcontroller	● The microcontroller must be able to appropriately differentiate between red, blue, green, black, gray, and brown from an I2C signal sent by the Color Sensors. ● The microcontroller must be able to interpret color codes of up to four colors long and make decisions on how to control the motors as a result. ● The microcontroller should be able to control a servo motor with a PWM signal. ● The microcontroller must be able to control DC motors by sending signals to the DC motor control module	20
Color Sensor	● The Color sensor module will be composed of color sensors that must be able to differentiate between red, blue, green, black, gray, and brown colors and send an appropriate I2C signal to the microcontroller.	15
DC Motor Control	● The DC motor control module must be able to direct sufficient current to two DC motors individually and be able to control their rotation direction.	10
Power Module	● The power module must provide sufficient power to the microcontroller, sensors, servo motor, and DC motor control.	5
	Total	50

2.6. Tolerance Analysis

An important tolerance for this project is the microcontrollers ability to control the servo motor. Most common servo motors use pulses between 1ms and 2ms at a duty cycle of 20ms to control the angle, with 1.5ms pulses being the neutral position, 90 degrees in our case[7].

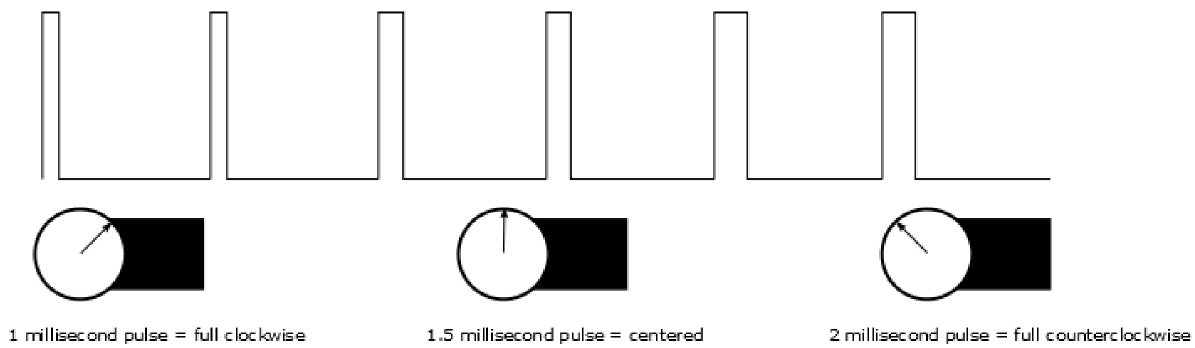

Figure 9. PWM Pulses [7]

The pulses will be sent directly from the microcontroller although the power will be provided from a voltage regulator in the power block that was specifically allocated to the servo motor.

The servo motor will be expected to be controlled in 45 degree increments according to the pulse widths shown below.

Angle	0 degrees	45 degrees	90 degrees	135 degrees	180 degrees
Pulse Width	1ms	1.25ms	1.5ms	1.75ms	2ms

Even though, in our case, the servo motor will only be sent signals to move in 45 degree increments from 0 to 180 degrees, the servo motor would still be capable of moving to any angle. To ensure that the servo motor keeps it angle steady the pulses would need to be accurate enough so that the servo does not misinterpret the requested angle. We can test the accuracy of the PWM signal from the microcontroller by attaching the appropriate I/O port to the oscilloscope and measuring the pulse size in nano second. The PWM resolution must be under 50 ns and the smaller the resolution the more accurately we can make a pulse. Lastly we would test the servo motor by seeing if there are any jerks of movement noticeable to the human eye. Since the application is more geared towards educating young kids generally how servo motors work, ensuring that the servo doesn't move an amount that a human eye can notice is sufficient.

3. Project Cost and Schedule

3.1. Cost

Labor

Name	**Weekly Hours (hrs)**	**Hourly Rate ($)**	**Weeks**	**Cost ($)**
Anthony	25	30	8	6000
Danson	25	30	8	6000
Totals	**50**	**30**	**8**	**12000**

Parts

Items	**Quantity**	**Unit Cost ($)**	**Total Cost ($)**
Voltage Regulator	2	0.69	1.38
Diode	4	0.97	3.88
Transistor	4	0.57	2.28
Microcontroller	1	5.89	5.89
Servo Motor	1	15	15
Motor	2	8	16
Color Converter	1	1.71	1.71
LED	1	0.36	0.36
Button	1	0.5	0.5
PCB	3	N/A	~20
Total			**67**

Grand Total

Total Cost = Labor Cost + Part Cost = **$12067**

3.2. Schedule

Week	**Anthony**	**Danson**
2/26	Order parts and prepare for design review	PCB design
3/5	Test all components that came in	Color sensor unit design
3/5	Learn to work with microcontroller IDE	Learn to work with microcontroller IDE
3/12	Motor control circuit design and testing	Voltage regulating circuit design, PCB design
3/19	Calibrate microcontroller to receive incoming data	Code writing, PCB design
3/26	Order PCB	Color sensor precision test and improvement
4/2	Test PCB	Solder parts
4/9	Test motor, test voltage regulator and current overflow	Test color sensor, test programmability, test sensitivity
4/16	Prepare Mock Demo powerpoint	Prepare Mock Demo presentation
4/23	Finish final paper	Finish final paper
4/30	Prepare for final presentation and demo	Prepare for final presentation powerpoint and demo

4. Ethics and Safety

4.1. Safety

This project is meant to be used by children around the ages of 4-8 years old so we do have an obligation to make sure that everything is safe to use. This includes making sure there are no dangerous amounts of current or voltage present that might cause harm to the child as well as making sure that temperatures of all devices stay at a comfortably safe level. Current around

20-100mA can be lethal to the human body although our devices must not only prevent death but also ensure no children are even slightly hurt by using them [8]. We will ensure that there is never a situation where even 5mA has a chance to flow through the user. We will have cases to prevent users from getting touch with the circuit and also short circuit protection. The two areas where current flows the most would be directly from the batteries and from the DC motor ports. To safely protect users from these areas the ports must be encased such that the leads cannot be touched while the casing is on.

Since the children using these devices may be as young as 3 or 4 years old, we must also account for choking hazards. Objects smaller than a cylinder with diameter of 1.25 inches by 2.25 inches deep are considered a choking hazard [9]. The smallest component in our project would be the color sensors so we must ensure that they are larger than the above specifications. Our sensor will be approximately 1cm x 3.5cm x 0.5cm without the case and 3cm x 6cm x 2cm with the case.

4.2. Ethics

IEEE code of ethics states that, “to improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies, including intelligent systems.” [10] Our project aims at help kids to explore their capability of coding when they did not start to realize and understand their ability in this field. We strive to develop a straightforward and obstacle-free platform for these kids. In the foreseen future, skill of coding would be essential for new technologies in science. We hope our project can serve as a good introductory product for kids. IEEE code of ethics also states that, “to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment.” [10] Our project will strictly enforce the safety precaution. By following the safety check during the design of our project, we will make sure that no parts would ever harm any child.

References:

[1] Farr. 'What's the right age for kids to learn to code?'. 2013. [Online]. Available: https://venturebeat.com/2013/06/25/whats-the-right-age-for-kids-to-learn-to-code-debate/

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[4] 'Datasheet for NSR05T30XV2 500 mA, 30 V Schottky Barrier Diode'. 2017. [Online]. Available: http://www.onsemi.com/pub/Collateral/NSR05T30XV2-D.PDF

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