PoV Music Visualizer

ECE 445: Design Review

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1. Introduction

1.1 Objective

Circular music visualizers, as shown in Figure (1) below, have recently become popular in the entertainment and music scene for their unique take on music visualization. Creating one is easy on a computer or an HD TV due to the high pixel count and large computation power. However, many light fixtures used by hobbyists / artists / entertainment companies use low resolution square dot pixel displays to visualize their music. This causes jagged edges on the frequency bins of a circular music display. Anti-aliasing filters can fix this issue but the end result looks messy and unprofessional.

We hope to create a Persistence of Vision display that can run a circular music visualizer. The idea for this is that spinning an LED bar at a high enough rate will display the visualizer cleanly and fluidly without the need of a pixelated display.

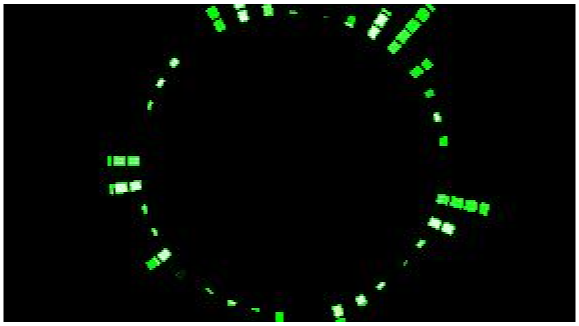

Figure 1: An example of a circular music visualizer

1.2 Background

PoV displays have been done many times before and they cover a wide range of functionalities. They have been used to generate 3D images, clocks or even display messages. Aliasing is a direct artifact of the resolution of a display and creates the commonly referred “jaggies” that appear on an image at a certain resolution. According to NVIDIA the only way to remedy aliasing is “is to create the effect of having more pixels on the screen” [1]. With a static dot matrix you can’t do this unless you create a blending effect between the edges of the image by utilizing more pixels. Utilizing our PoV display allows us to remedy this aliasing effect without the need or utilizing more processing power for our display. Our product is interesting to consumers as it allows the creation of any sort of image to render while captivating audiences with the fact that the image is created with a minimal amount of display elements on a rotating armature.

1.3 High Level Requirements

- Motor must work and spin at a constant speed of 720 RPM with a -/+ 1% delta to ensure stable framerates.

- LEDs must be able to refresh within 1/16th of a half-cycle or roughly 1.2 - 1.3ms in order to keep up with the rotation speed of the system to generate a working display.
- Microcontroller must sample audio, process signals, push data onto a spi bus, and accept interrupts simultaneously without crosstalk.

2. Design

Our block diagram consists of 5 modules: power supply, motor system, control unit, audio interface, and the LED display. The whole design will be powered by a plug-in wall outlet 12V DC power supply that will also be regulated in order to create a 5V and a 3.3V DC railing. The 12V rail will provide power to the motor system exclusively while the 5V rail will supply the LED array and the 3.3V rail will supply the controller unit and the audio interface. The motor system will be controlled to maintain a constant speed and to provide a timing for the microcontroller and LEDs to go off of. We will use a microcontroller to interface with the motor controller, LEDs, and to process the audio signal. The LEDs will be controlled according to the audio and the motor speed while the motor will be controlled purely by the hall sensor.

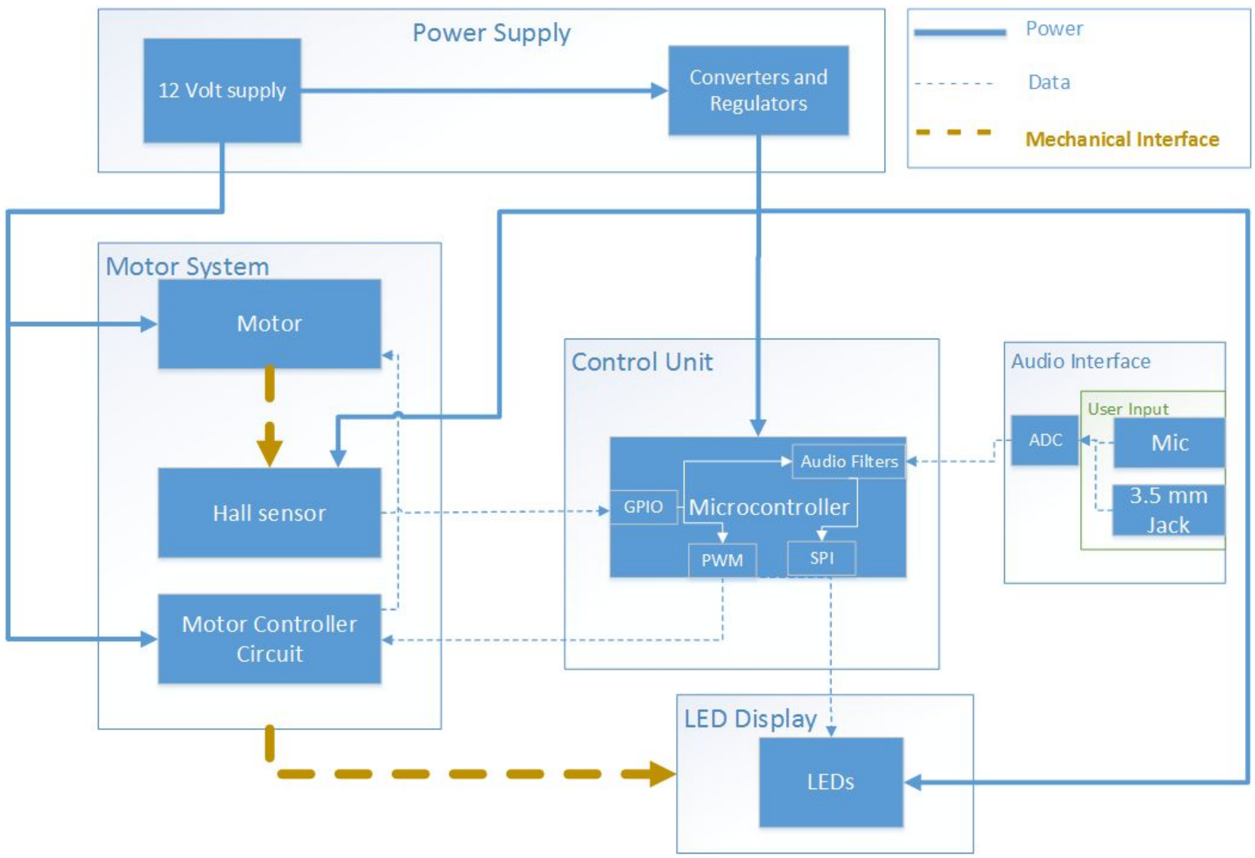

Figure 2: Block diagram of the system

Figure 3 shows a rough sketch of our proposed physical design. Four components are marked within the enclosure. This enclosure will act the same way as a mount does by stabilizing the motor system and other components but it will also act as a barrier from the spinning armature and the power supply. Details on the enclosure can be found in the safety and ethics section. Component 1 is the power supply and component 2 is the motor controller. The placement of these components may not directly reflect the final design. Components 3 and 4 are the motor and the LED armature respectively. These will be placed in the center to avoid contact with the sides of the enclosure. Components that are not presented in the sketch are the magnet/hall sensor, PCB with the microcontroller, and the slip ring coupled to the armature and motor. All of these components will be mounted with support from the machine shop.

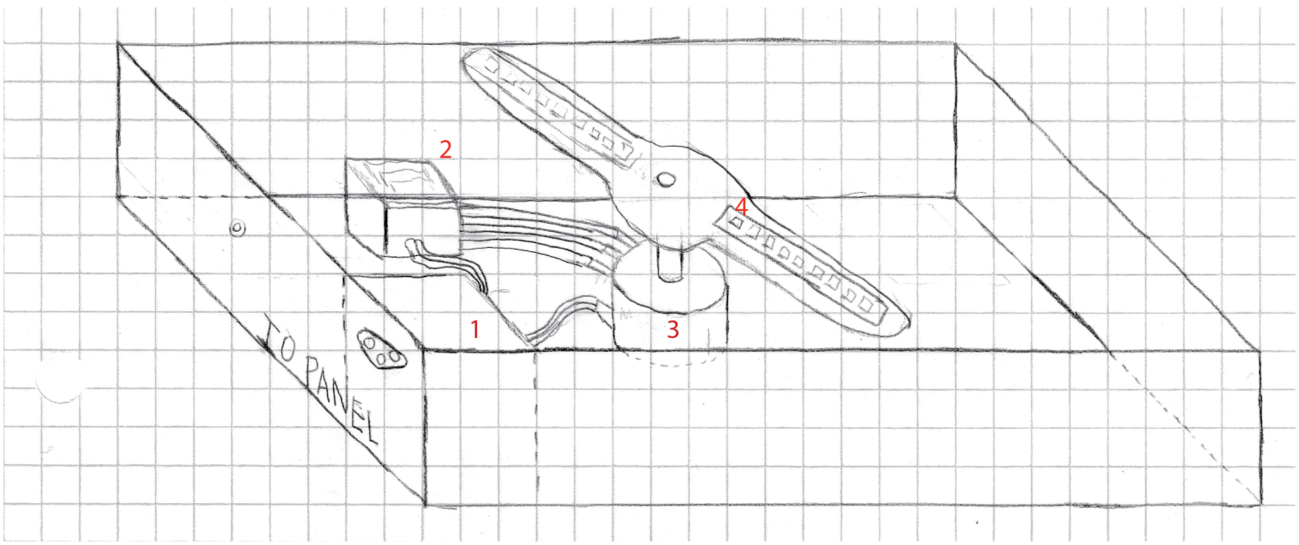

Figure 3: Rough Mockup Sketch

2.1 Power Supply

Power Supply: The power supply is a necessary and important component in most projects. Our project will need a 12V DC supply in order to properly power the entire system. We choose a 12V DC supply because our motor is going to consume a majority of the power in our project and the motor that we choose is a 12V DC motor. The power supply will be connected to all of the subsystems in our project. The power supply is the most crucial component in our system as without it, we can’t satisfy any of our requirements as they would not be able to operate.

Requirement	Verification
1. Power rating of 75 - 85W and capable of outputting 4.5 - 5.5A. 2. Must provide 12V DC value and have less than +/- 1% ripple such that components are not damaged and can receive sufficient power.	1. a. Use power resistors to create max load situation and hook up supply to load. b. Measure resulting voltage and amperage with power meter and record values measured and load situation used. 2. a. Create load situation that is low amperage and measure load voltage with oscilloscope and measure voltage ripple. b. Save image of resulting voltage ripple waveform and record load situation used.

Converter Chips: The converters are important as they are needed to convert the 12V DC value into a 5V and 3.3V DC value in order to power the other portions of the system. The LEDs will need the 5V railing and the audio interface and the controller will need the 3.3V railing. We choose to regulate our 12V supply as opposed to getting individual power supplies in order to cut back on cost and form factor while also being capable of supplying large amounts of power to the motor and LED array. The converter circuit will be hooked up to the output of the power supply and produce the 2 separate voltage rails. The converter circuit is crucial to the system as without it, we would not be able to give power to our controller, audio interface, or controller and thus, would not be able to meet any of our requirements. The equation used for calculating the output voltage and the resistor ratio in Figures 5 and 6 is as such [2]:

$$[1] \quad V_{out} = 0.768(1+\frac{R1}{R2})$$

Where Vout is 5V in Figure 5 and 3.3V in Figure 6. It is important to note that when choosing the resistors that too high of a value will add more noise to the output and too low of a value will result in a lower efficiency.

Requirement	Verification
1. Must be able to handle 2.7 - 3A. 2. Can convert 12V to 5V and 3.3V effectively while keeping resulting voltage ripple below +/- 1%.	1. a. Use power resistors to create a 3A load situation and see if chip operates correctly / doesn't break. b. Measure resulting voltage and amperage with power meter and record values observed and load situation used. 2. a. Create 2 converter circuits that are low amperage and measure load voltages with oscilloscope and measure voltage ripple for each situation. b. Save image of resulting voltage ripple waveforms.

2.2 Motor System

Motor: A brushless DC motor acts as the driving element to spin the LED bar. It will be mechanically coupled to the PCB, a slip ring, and a hall sensor to act as a tachometer. If the motor does not operate properly at the target RPM, then we would not be able to fulfill our first requirement.

Requirement	Verification
1. Must be able to spin consistently at the target of 720 +/- 1% RPM in order to achieve 24FPS using two blades.	1. a. Create a test environment with the motor and working hall effect sensor mounted onto a test PCB. b. Measure the RPM from the data of the hall sensor and record the results.

Hall Sensor: The external hall sensor will be used to gauge the speed of the motor. This signal will be fed to the microcontroller for calculating the current speed. If this does not operate correctly we will not be able to accurately measure the speed of our motor and move on to controlling it and therefor we would not be able to meet our first requirement.

Requirement	**Verification**
1. Must produce a 1.9 - 2.1V differential passing over a magnet at 26.5 - 27.5 m/s.	1. a. Create a test armature on the motor with a magnet. positioned 7.5 inches away. b. Put the output voltage pin into an oscilloscope and measure the voltage drop.

Motor controller: The motor controller will adjust the speed of the motor according to a PWM pulse generated by the microcontroller. This will ensure that the motor will be given a constant voltage to produce a stable RPM for our display. If the motor controller is not able to provide enough power to the motor, then the motor will not be able to operate consistently and we would not be able to fulfil our first requirement.

Requirement	**Verification**
1. The motor controller should be able to consistently output the target RPM of 720 +/- 1% from a consistent PWM signal.	1. a. Connect motor controller to the power supply and the motor. b. Connect the PWM cable of the motor controller to a signal generator. c. Generate a consistent square wave and test with the hall sensor to see if the output of the motor is stable.

2.3 Control Unit

Microcontroller: The microcontroller is the central hub of the project. The controller will generate the control pulses for the motor control circuit as well as generate the spectrogram of the music. If the microcontroller does not operate fast enough then we will not be able to successfully control our motor or process our input signal fast enough to alter our LED display. So if this doesn't operate properly, we will not be able to satisfy any of our requirements. We should also insure that there is no crosstalk between the different control I/O.

Requirement	Verification
1. The microcontroller inputs and outputs must have less than 10% of Vcc(3.3V) in coupling noise.	1. a. Probe neighboring output/input pins with the oscilloscope using one channel per output/input. b. Supply a 3.3V square wave to the input pins. c. Measure the coupled signal on the unused pins. d. Generate, from software, 50% duty cycle PWM on the output pins. e. Measure the coupled signal on the unused pins.

2.4 LED Display

LEDs: Individually addressable RGB LEDs will be used as they are easy to feed data into, can be cascaded, and offer a wide spectrum of colors. The LEDs will be connected in cascade with one another and will then be controlled by the controller unit. These LEDs need to be able to refresh within 1.2 - 1.3ms. If they are not able to we will not be able to satisfy our second requirement. If we want 24 full revolutions per second (minimum speed that creates a persistence of vision) or 48 half revolutions per second and we want 16 frequency bins to be displayed within 1 half revolution, then the math follows as such for how fast the LEDs must refresh themselves:

$$[2]\ T_{delay} = RefreshRate / FFTBins$$

$$T_{delay} = (1/24Hz)/32$$

$$T_{delay} = 1.3\text{ ms}$$

Requirement	Verification
1. Each LED must have a refresh time of 1.2 - 1.3ms	1. a. Create a simple load resistor, LED, voltage source circuit and probe the input and output data lines of the LED with oscilloscope probes. b. Compare the waveform for the input and output and measure the time difference and record the measured results and save the resulting waveforms.

2.5 Audio Interface

ADC: The ADC will be used to sample the audio signal from the user input. The audio spectrum ranges from 20Hz to 20KHz. However, a majority of people can only hear from 20Hz to 16-17KHz. For this reason we will sample at a rate greater than 32 KHz in order to satisfy nyquist criterion in equation [3]. However to get an accurate representation of the audio we propose to sample at 44.1 KHz; a common audio standard. If the ADC is not able to sample the signal at a fast enough rate then we may run into microcontroller processing speed issues and therefore would not be able to fulfil our second or third requirements.

$$[3] \quad F_s > 2BW$$

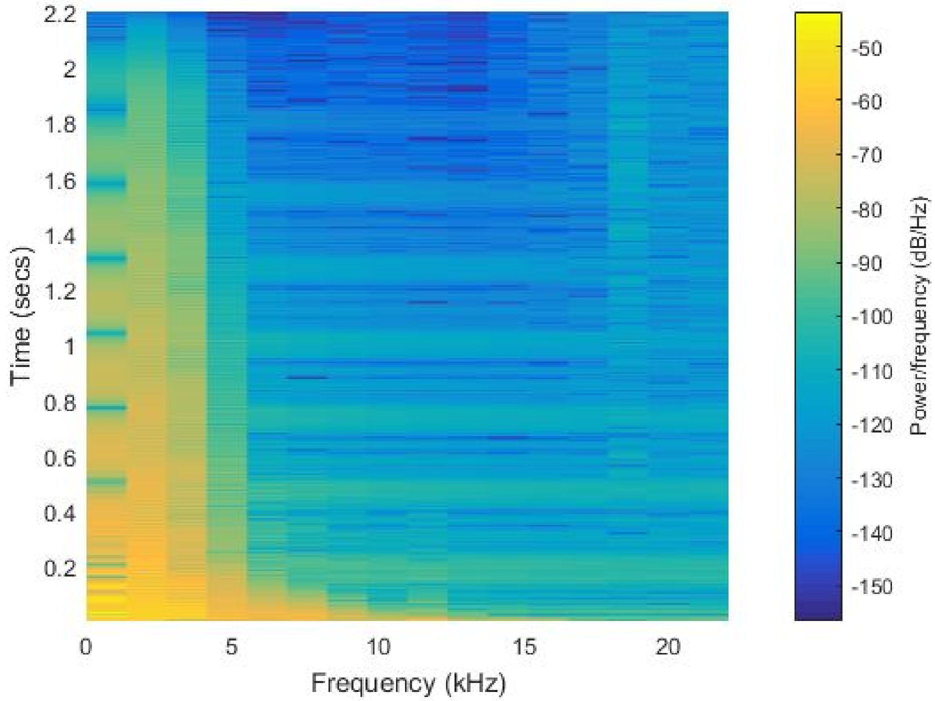

Figure 4. 16 bin FFT spectrogram

Figure 4 serves as a visual example of how we would setup our frequency bins for the display. At a fixed time the yellow / orange color indicates that a maximum amplitude for a particular frequency bin is occurring and so during that 1/16th portion of the half rotation, most of the LEDs should be turned on.

Requirement	**Verification**
1. The ADC must be able to communicate with the microcontroller. 2. The ADC must sample an arbitrary analog signal of 16 - 17 KHz without aliasing.	1. a. Create a serial monitor to print out ADC data. b. Create print statements with the data as an input to see if connection was established. 2. a. Produce a 17 KHz sine wave using a function generator as an input to the ADC. b. Use frequency detection software on the MCU to make sure the frequency is correct.

2.6 Schematics

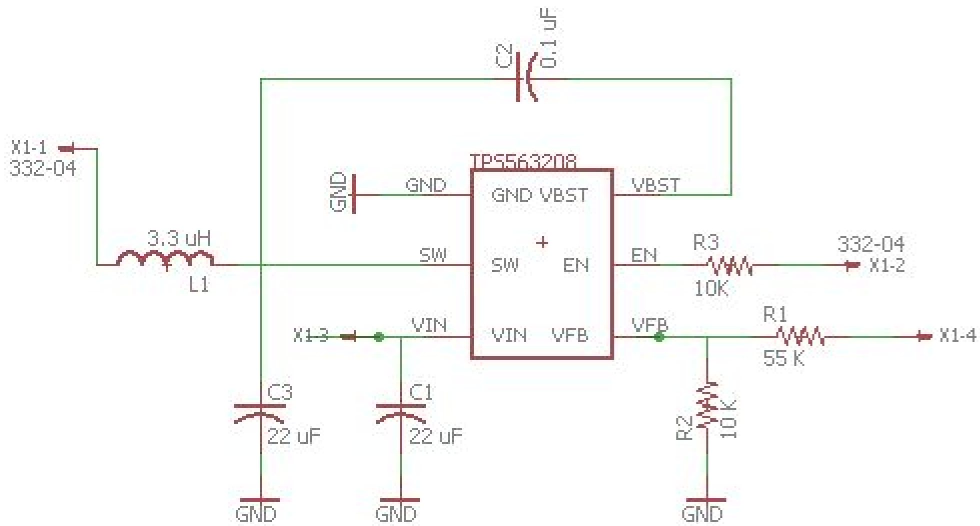

Figure 5. Design of power converter circuit for 5V [2]

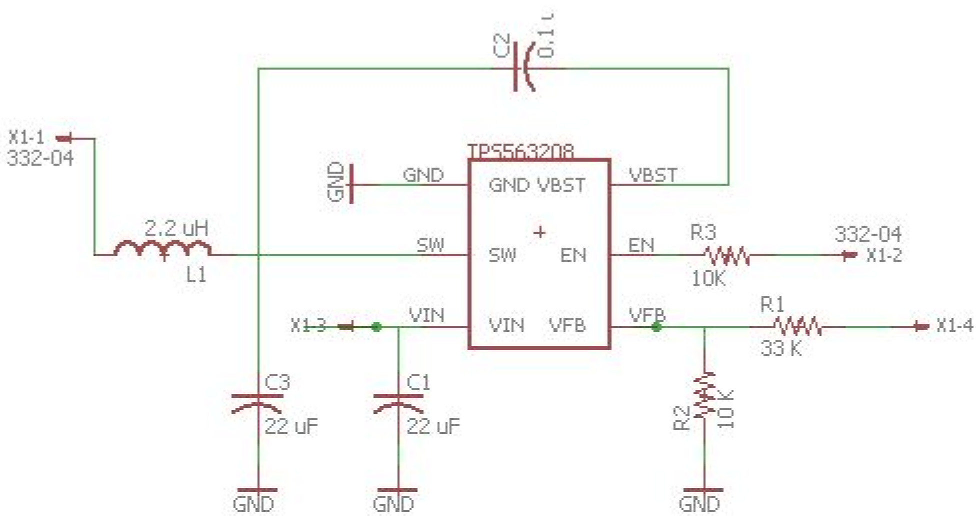

Figure 6. Design of power converter circuit for 3.3V [2]

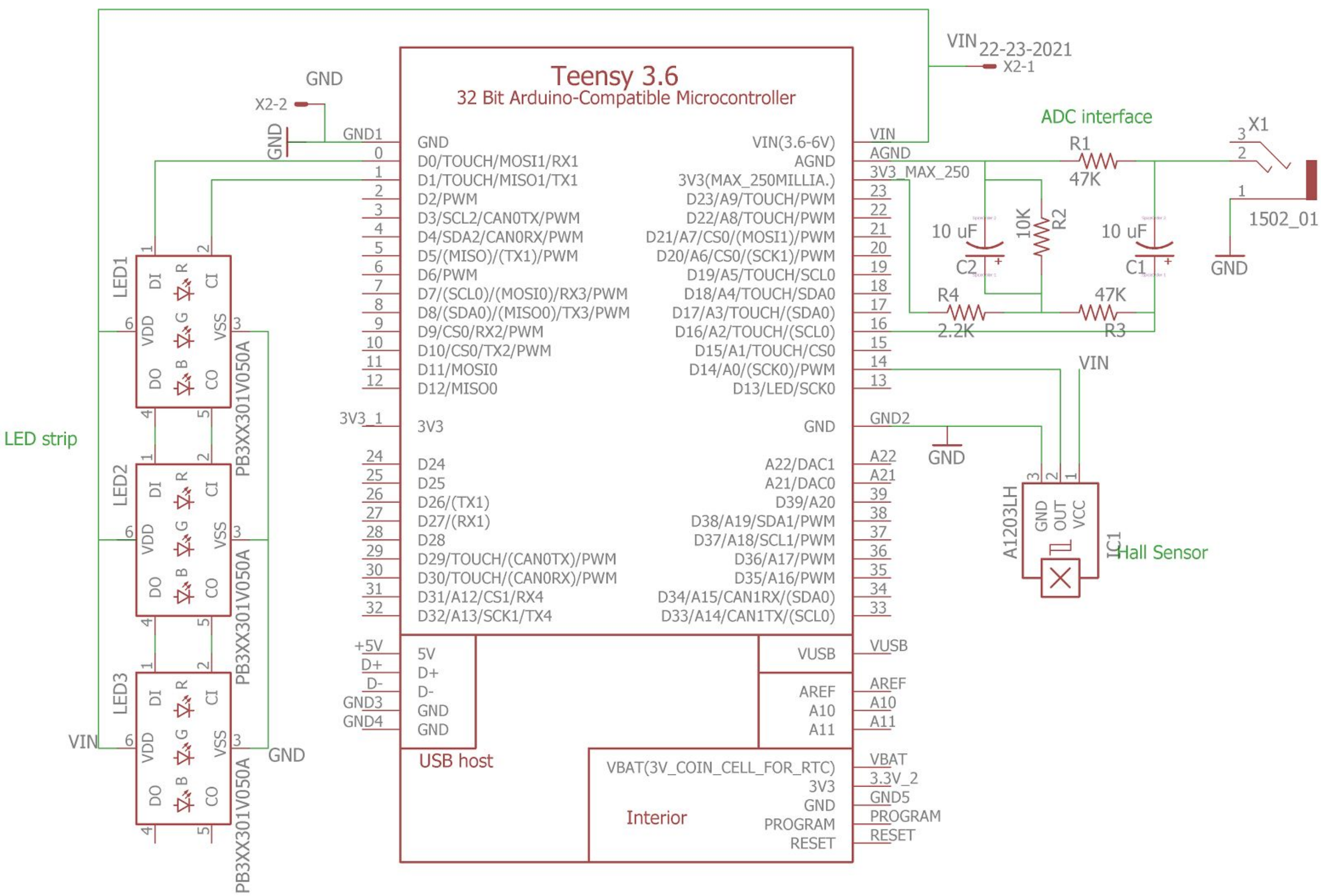

Figure 7. MCU with sensor, ADC conditioning, and LED strip

2.7 Tolerance Analysis

The persistence of vision effect is essentially an optical illusion tailored to human perception. This illusion can be broken if our system is not in steady state and thus requires a balancing act between all the components in our system. Specifically, the interaction between the motor and the LEDs provides hard cutoffs for the minimum and maximum motor speeds allowed.

The minimum motor speed isn't governed by any technical specs or documents but by human biology. 10-12 frames per second is the minimum frame rate that the human eye can perceive as some sort of continuous real time motion [3]. However, the minimum frame rate for today's media is 24 FPS which will be our minimum target FPS. This 24 FPS target corresponds to motor speed of 720RPM for a dual armature set up. Therefore, our minimum target RPM for the motor will be 720RPM.

The maximum motor speed is dictated by the data throughput of the LEDs. The LEDs use an SPI protocol to communicate color and brightness information. Given the SPI clock for the microcontroller is 24MHz and we have 50 LEDs each with 32 bit color information we can calculate the data propagation delay as:

$$[4] \quad T_{prop} = \frac{\#ofBits * \#LEDs}{SPI\ Clock\ Speed}$$

From equation [4] we see that Tprop becomes 60 µS which would provide a theoretical max motor speed of 900,000 RPM. For many consumer grade motors this max RPM is out of the scope and the sheer amount of power to achieve this RPM is, from a design aspect, unreasonable. Due to this, our LEDs theoretical max refresh rate should not "bottleneck" our motor system.

3. Cost and Schedule

3.1 Cost Analysis

Labor:

$$3 \cdot \$40\ per\ hour \cdot 10\ hours\ a\ week \cdot 16\ weeks \cdot 2.5 = \$48,000$$

Parts cost:

Parts	Quantity	Total Price
Adafruit DotStar Digital LED Strip - Black 144 LED/m - One Meter	1	$74.95
Intocircuit 6ft 80W Aluminum Alloy LED Power Supply 12 Volt DC Output	1	$31.99
TI 4.5V to 17V Input, 3A Output, Synchronous SWIFT Step-Down Converter (TPS563208)	2	$2.68
TrackStar 1/18th Scale 14T Brushless power System (4300kv)	1	$37.99

Turnigy TrackStar ESC Programing Car	1	$8.55
Adafruit 6 wire Slip Ring	1	$14.95
Unipolar Hall sensor - low sensitivity (US5881)	1	$2.00
Teensy 3.6 - ARM cortex M4-F microcontroller	1	$29.99
Total Price:		$203.10

Grand Total: $48,203.10

3.2 Schedule

Week	Adam	Alex	John
2/27	Purchase hall sensor and passive components. Test out the functionality of the micro	Purchase LED strip and 12V Power supply and Converter chip, start working on PCB design	Purchase motor subsystem components. Start theoretical signal tests and CAD.
3/6	Revise the PCB design and verify component compatibility. Write code to communicate to LEDs and sensors	Finish PCB design and order prototype and start verification of Power supply / Converter chip / LED strip as they arrive	Program motor controller and experiment on PWM signal generation.
3/13	Configure ADC for 44.1 KHz Write code to process audio signal	Start working on and debugging the converter circuit and assemble parts of prototype PCB	Work with hall sensor timing. Work on motor speeds and timing with LED.

3/20	Write code to calculate motor speed and generate motor timings	Find issues with prototype, revise and resubmit for final PCB design	Add input into PCB design. Work on delegated micro controller code.
3/27	Finish system integration code and breadboard prototype Debug code to control prototype precisely	Work on assembling final PCB and ensuring that power is delivered to PCB while it operates / spins	Work on physical installment of the project with motor subsystem.
4/3	Integrate Micro and sensors onto PCB	Debug any issues related to power transfer and LED operation	Finish work on physical installment of project. Debug subsystems.
4/10	Mock demo prep. Optimize code to run quicker.	Prepare for mock demo and help with communications with the controller, audio interface, and the LED strip	Mock demo work. Debug system communications issues from the motors. Help is LED and microcontroller debugging.
4/17	Final debugging and working with teammates to finish other sections of the project	Final debugging of entire system, helping teammates with their sub systems and ensure that everything is operating correctly	Debug system communications issues from the motors. Help is LED and microcontroller debugging.
4/24	Work on presentation and paper	Work on final demo presentation and final papers	Work on powerpoint and final papers.
5/1	Finish up final papers	Finish up final papers	Finish up final papers.

4. Ethics and Safety

Having considered the scope of our project and having read the IEEE Code of Ethics we can say for sure that there are a few ethical codes that should be addressed.
#1 of the IEEE Code of Ethics states: “To accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment” [4]. Our product is going to be using strobing lights, though they may not be too intense, it is important to consider any audience members that are prone to epilepsy and seizures and warn

them promptly. Also, our final product will likely be rotating at a significant speed and thus could cause harm to anyone who comes into contact with the rotating member and so a warning should be administered. Finally, our product's power supply will be plugged into a wall outlet and is in contact with a large source of power and could cause harm to anyone who operates the device improperly and so a warning should be administered.

#7 of the IEEE Code of Ethics states: "To seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others" [4]. The important portion to take from this is that we should properly credit the contributions of others. Persistence of Vision screens have been done many times in the past be it in this class or online. It is important to consider that our system should stay unique and if outside documentation is utilized that we credit the source appropriately.

#9 of the IEEE Code of Ethics states: "To avoid injuring others, their property, reputation, or employment by false or malicious action" [4]. This is a crucial point of consideration in our final product. As discussed previously, our product has the potential to cause physical harm to others. It is important that during the implementation of our project that we incorporate appropriate safety standards. In order to prevent the occurrence of someone coming in contact with the spinning member of our project we are likely to implement a safeguard in a similar sense to how the department of labor requires safeguarding for rotating parts [5]. Another thing to take into consideration is proper housing of the power supply as it is plugged into a wall outlet and therefore could cause significant harm to others if improper contact is made. One final important factor when considering safety is to ensure that the power supply that we choose meets the appropriate safety standards and has the necessary safety marks [6].

References

[1]Nvidia (2017). High-Resolution Antialiasing (HRAA). [Online].Available:http://www.nvidia.com/object/feature_hraa.html [Accessed: 7- Feb- 2017]

[2]TI(2015).TPS56320x 4.5-V to 17-V Input, 3-A Synchronous Step-Down Voltage Regulator in SOT-23. [Online].Available:http://www.ti.com/lit/ds/symlink/tps563208.pdf [Accessed: 23-Feb-2017].

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[4]IEEE (2017). IEEE Code of Ethics. [Online].Available:http://www.ieee.org/about/corporate/governance/p7-8.html [Accessed: 1- Feb- 2017].

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