University of Central Florida

Senior Design I

L.U.D.S. - Light-Up Drum System
Infrared Vibration Sensitive LED Drum and Metronome

Group 10

Aaron Holloway, E.E, Power and Renewable Energy Track
Ajay Nattanmai, E.E, Comprehensive Track
Elijah Peterman, E.E, Comprehensive Track
Malcolm Donaldson, Photonic Science and Engineering

Due: 10/07/2022

Divide and Conquer 2.0
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Ajay Nattanmai
Elijah Peterman
Malcolm Donaldson

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1. Project Description

1.1 Motivation

In the modern day music industry, there is an ever growing number of independent musicians who are trying to find a way to make their live performances stand out. There are many products/techniques that singers, bassists, and guitarists can do to improve their stage presence because of the mobility given by their instruments. Drummers however are constrained to stay in the seat behind their drum kit. Without expensive stage lights or rotating drum cages, there are not a lot of ways to improve a drummer's stage presence. A solution to these problems is a LED drum system that lights up when each drum is hit.

For drummers, timing is very important. To practice staying on beat, drummers often use auditory metronomes that tick on to the beat of the song to help the drummer know when the next beat is taking place. The problem with auditory metronomes is that the sound of them is often drowned out by the loud percussion of the drum set. One solution is to use headphones but those do not allow the other practicing band members to hear the beat. This LED drum system will resolve this issue by having an option to act as a visual metronome where the lights will flash on beat allowing each musician to utilize the rhythm of the metronome. While most songs use a single rhythm, some drummers like to play in what's called a polyrhythm. A polyrhythm is two contrasting beats at the same time. Polyrhythms are infamously difficult to master so, unlike most metronomes, this device will offer options for polyrhythmic time signatures.

1.2 Description

The “Light-Up Drum System”, or “L.U.D.S.” for short, is a device with an LED light strip that can be attached to any musical drum. The led strip can be placed wherever the user desires but placing it within the shell of a clear drum head is the intended placement. It will be designed for a 7” radius snare drum. The LED strip will be attached via an adhesive on the back of the light strip. The LED lights will be activated via an array of vibration sensitive infrared (IR) sensors which will be attached within the shell of each drum. The light strip and the sensors will be wired to a computational unit, which would ideally be able to handle a large number of inputs so multiple drums, with their own lights and sensors can be used. When the drum is struck, the sensors will send a signal to the computational unit which will then cause the desigered lights to become active. The sensors will measure vibration to indicate when the light should light up, as well as where and how hard the drum was struck. This additional data will be stored in a separate computational unit to create replay data. Other inputs into the computational units will be given by the user via a controller. These inputs include the color selection of the user, the beats per minute (BPM) of the song, whether the light should always be dimly lit or completely off when idle, and whether the light should flash or if it should slowly fade. The beats per minute of the song will determine how fast the lights flash or fade. The adhesive of the light strips and the sensors must be strong enough to ensure that the components do not fall off during performance or after considerable use. In other words, the components must be durable.

The controller will also offer the user an option for a metronome mode. Where the user input BPM and the time signature of the song. This mode will flash all the lights on the drum kit on beat with the time signature and BPM of the song. The controller will be attached to the PCB along with the MCU. The control will consist of a knob to choose the BPM of the song along with a corresponding LCD display to show the chosen BPM, a collection of 10 switches which will control which LED colors are active,and then three switches to choose the other adjustable parameters. (flash lights or fade lights, idle on/off, and metronome on/off) There will be a second section to the controller to control the metronome mode. This second section will include a switch to turn on/off a polyrhythm mode, and six dials to set the time signature and BPM of the metronome rhythms. Three dials for the main rhythm and three for the polyrhythm. One knob will choose BPM, one knob will choose beats per measure, and one knob for the number of measures. (These terms are defined in section 2.1.3) The system shall be powered via a standard 60Hz AC GFCI outlet. The power supply will run to the computational unit and any other components that require an external power source.

1.3 Competitive Products

There are currently several products on the market with similar functions each with their own features and drawbacks. Table 1 shows each product and the features they possess.

Comparison List

Product/Feature	Function Type	Color Options	Adjustable Parameters	# of Lights	Metronome	Approximate Price
Galaxy Meteor	Vibration Sensative	Fixed	No	1	No	$30
AirBeez	Vibration Sensative	RGB Spectrum	Global	1	No	$140
DrumLite	Fixed on/off	RGB Spectrum	Global	4	No	$240
Tour-10	Vibration Sensative & Fixed on/off	RGB Spectrum	Inividual Channel Controls	10	No	$1,850
Crash 'N Flash	Vibration Sensative & Fixed on/off	RGB Spectrum	No	32	No	$275
L.U.D.S.	Vibration Sensative & Fixed on/off	RGB Spectrum	Global	1	Yes	$485

Table 1 - Comparison with Similar Equipments

Aaron Holloway
Ajay Nattanmai
Elijah Peterman
Malcolm Donaldson

2. Design Specifications and Constraints

2.1 Primary Goals

2.1.1 LED Integration

In order to light up the drum kit, this device uses LED light strips which will be controlled by the MCU using either the metronome mode or the vibrational input. These lights will be shining directly towards the user so they must not be too bright. They also need to be bright enough to be visible from forty feet away so people in the audience of a show can view them. For this reason, the project will use LED light strips which are 540 Lumens per meter. The LEDs will need to be able to flash at a speed of at least at 7 Hz. There should be LEDs encircling the inside of a 7" radius snare drum so the strip will be at least 60 LEDs per meter. The LED strips will be mounted with double sided tape so the drum doesn't need to be drilled into in order to secure the LEDs to the drum. Since the strips will be facing the center of the drum, the LEDs will be side-emitting so the light comes out of the drum head. A 7" radius snare drum will need at least a 44" inch long strip. In order to provide color control to the LEDs they will require a 4-pin RGB connector. The strips will require a 12V DC power input and use no more than 10 Watts per meter. Depending on which MCU is used for the project, the LEDs may require a dimming/flashing module to control the behavior of the lights. One part that meets these specifications is the "RGB LED Side Emitting Strip Light" from LEDsupply part number R6060-IP20-RGBS. *Table 2* below shows the product details on the "RGB LED Side Emitting Strip Light".

Product Details

LED Density: High Density - 60 LEDs/M	**Colors:** RGB
LEDs: 020 Side View LEDs	**Power:** 12VDC
Wattage: 12 Watts/M (36/Reel)	**Mounting:** Doubled-Sided 3M Tape
Cuttable: Every LED (0.625")	**Custom Lengths:** 3-Foot Increments up to 16.4-Feet (Full Reel 5M)
Size: 10mm Wide X 1mm Tall	**Connection:** 4-pin RGB connector

Table 2 - R6060-IP20-RGBS product details

2.1.2. Beat Detection

The LUDS has to be able to detect when the head of the drum is hit because the reactive nature of the LEDs is a key feature of the LUDS. This will be accomplished with a sensor array housed inside the drum head along with the LEDs. This array will comprise six QRE1113 optical reflectance sensors. The reflectance sensors emit an infrared beam that is aimed at the top of the drum, which reflects the IR beam back at the sensor. When the drum is struck the vibration alters the path of the IR beam, signaling a change for the detector.

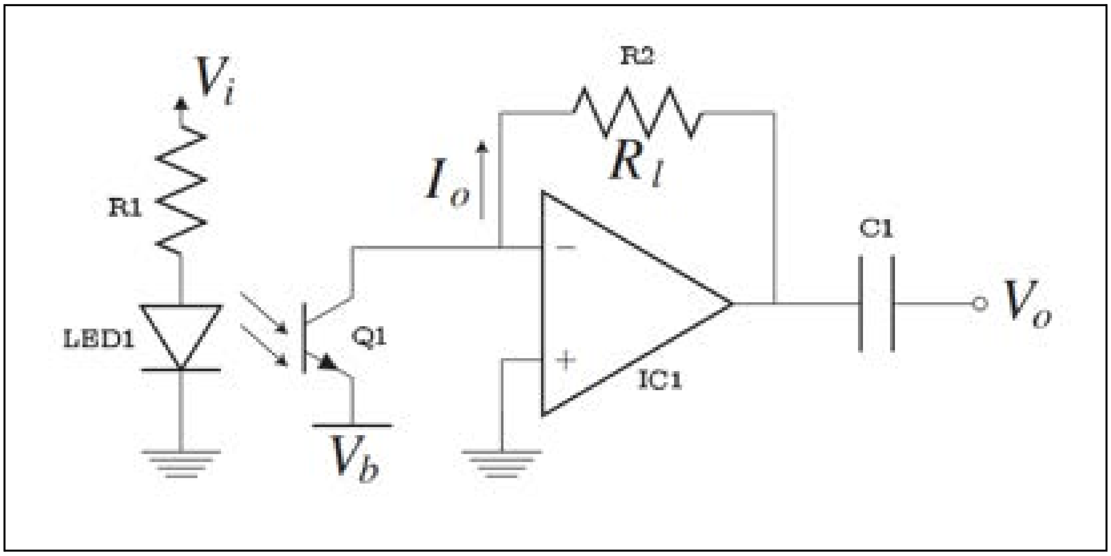

Figure 1 - Diagram of the QRE1113 optical reflectance sensor

$$V_o = - I_o * R_l \quad (1)$$

The reflected beam is detected because it hits a phototransistor, an optoelectronic component that can change the amount of current flowing through a circuit based on the light level. As shown in figure 1, the phototransit transistor (Q1) is connected to a simple circuit made up of a resistor (R2), a transimpedance amplifier (IC1), and a capacitor (C1). The vibration alters the light level by slightly changing the path of the beam, which alters the current in the circuit. IC1 then converts the current to voltage based on the relationship shown in equation (1).

2.1.3 Metronome Functionality

The L.U.D.S. metronome feature will function similarly to a regular auditory metronome except it will use L.E.D. flashes instead of auditory clicks. A metronome clicks at the same rate as the beats per minute (BPM) of the song. So this metronome will flash at the same rate of the BPM. To understand fully how this metronome will function, it is important to understand how musical time signatures work. A time signature is composed of two numbers placed on top of each other. The top number has how many beats are played in each measure, and the bottom number is how many measures are played in one meter. A beat is a basic unit of time in music, beats make up the pulse of the song, a measure is a fixed number of beats, and a meter is one full cycle of a time signature. Typically, a metronome will click louder at the start of each measure so this metronome will flash brighter at the beginning of each measure.

The L.U.D.S. metronome feature will have the user input the BPM and time signature of the desired rhythm that will be used. The BPM will be selected using a knob on the controller that will be wired to the MCU which will then display the selected BPM on an LCD display also located on the controller. Next the user will select a time signature by turning two separate knobs. One knob will choose the beats per measure and the other knob will choose the number of measures. Upon changing the dial, the selected value will appear on the controller's LCD display. The MCU will use these input parameters to calculate how often it should light up and when it should light up brighter for the start of each measure. The metronome will be implemented using an ACLK clock at 32 KHz frequency for highest accuracy possible. The calculations for the flash timing are shown in *Figure 2* below. The system should allow for a minimum of 400 L.E.D. flashes per minute with a metronome timing error of less than 2%. [2] (How to Check a Metronome for Accuracy)

$$Beats = Top\ number\ of\ time\ signature$$

$$Measures = Bottom\ number\ of\ time\ signature$$

$$BPM = Beats\ per\ minute$$

$$Beat\ Flash\ Rate = \frac{BPM}{60\ Seconds}$$

$$Measure\ Flash\ Fate = Beat\ Flash\ Rate * Beats$$

$$Metronome\ Percent\ Error = \left|\frac{Expected\ flash\ rate - measured\ flash\ rate}{Expected\ flash\ rate}\right| * 100\%$$

Figure 2 - Metronome timing and accuracy formulas

2.1.4 Microcontroller

The microcontroller will be programmed to measure the vibration via the infrared sensor with a configuration of ACLK clock at 32 KHz frequency. According to the design specifics, this clock might be a good option compared to the other clocks. This could be changed based on the situation of the vibrations and LED flashes during the testing stages. The other option that would also best work with this design is the SMCLK clock. This control mode will be set to continuous mode in this instance rather than up mode and no dividers will be used in this case. The clock will be configured to Timer A0 to read the infrared signals.

The LCD display will be configured by the MCU to display the force of each beat or the vibrations. The LCD can display digits and letters in monotone which will be programmed by the MCU via the output pins in the LCD.

Aaron Holloway
Ajay Nattanmai
Elijah Peterman
Malcolm Donaldson

2.1.5 Power System

The power supply for the L.U.D system has to be able to handle an input of 120 V alternating current and output at least 15 watts. An AC/DC power supply can take higher voltage levels and rectify the signal to a more manageable input voltage level for most devices. Majority of microcontrollers and low power devices have an input voltage of 5V. TMPS 15-112 meets these specifications and is in accordance with the marketing requirements set. The supply is compact light and can be surface mounted to a PCB. The details of thi

Power Supply Approvals:	ITE, Household & Transformers	Power Supply Output Type:	Fixed
No. of Outputs:	1 Output	Input Voltage VAC:	85V AC to 264V AC
Output Power Max:	15W	Width:	52.4mm
Output Voltage - Output 1:	12V	Height:	23.5mm
Output Current - Output 1:	1.25A	Depth:	27.2mm
		Product Range:	TMPS 15 Series

Table 3 - TMPS 15-112 product details

2.1.6 Positional Data Collection

A secondary feature of the LUDS is saving data on how that drum is played. The vibration detection could be done with just one IR sensor, but for the replay data, there will need to be an array of sensors. Where on the surface of the drum the drumstick makes contact will affect the sound the drum produces, which means that to be able to accurately recreate a play session, positional data needs to be recorded. Having six sensors will allow a program to calculate where the vibration originated from by calculating the TDOA, which is the length of time it takes between a vibration reaching two fixed points.

$$\sqrt{(x_t - x_1)^2 + (y_t - y_1)^2} - \sqrt{(x_t - x_2)^2 + (y_t - y_2)^2} = c(t_1 - t_2) \quad (2)$$

TDOA can be represented by the equation (2). In the equation, [x_t, y_t] represents the the location of the strike, [x_1, y_1] represents the location of the first sensor and [x_2, y_2] represent the location of a second sensor, c represents the speed of the wave in with in the medium and t_1 - t_2 is the time difference between the first and second sensor. With six sensors, the unknown location of the strike can be calculated by solving for [x_t, y_t] and stored as a 2D coordinate.

The TDOA calculations are performed with a separate processor from the main MCU. This will reduce the lag between detecting the drum beats and the MCU activating the LEDs. The results of the TDOA calculations for each strike are stored in the memory of the processor along with the time between each strike. This memory can be extracted and used by a third party to recreate a performance on the LUDS as a musical instrument digital interface (MIDI) file.

2.1.7 Force of Impact Data Collection

In addition to collecting positional data to generate replay data, the LUDS will collect data on the force of each strike. This data is important because the force of each impact changes the volume of the sound created. The force is measured by an array of six IR beam break sensors, which are positioned around the outside of the drum. Each sensor is made of two parts: a transmitter, which projects an IR beam, and a receiver located opposite to the transmitter. If the receiver stops detecting the IR beam, the program will count that as a strike.

To calculate the force of each impact is simple. The force of an object is just the velocity of that object times its mass. The mass of a drumstick's head is unlikely to change drastically between sets of stick, meaning that it can be treated as a constant based on the type of drum being played. The brake beam sensors measure the velocity by tracking how long the beam was broken, then dividing the width of the drumstick's head by that time. This velocity is then multiplied by the mass of the drumstick's head and that number is stored in the processor's memory. Like the positional data, this data is calculated and stored on a secondary processor.

2.2 Advanced Goals - Advanced Performance and Metronome Customization

2.2.1 Performance Customization

To maximize the LUDS potential to create striking performances, it will ideally have multiple additional settings to fine tune the visual presentation of the drums. These settings include color selection, "flash vs fade", and "idle glow". Color selection changes the color of the LEDs. LEDs naturally produce a single color of red, green, or blue light depending on the LED, but can be designed to have all three or combine these colors to form other colors. The LUDS will only include these three primary colors. "Flash vs. fade" is a setting that adjusts how fast the LEDs turn off. When set to flash, the LEDs will quickly flash on then off, while setting the LUDS to fade will cause the LEDs to dim down after flashing on. How fast the LEDs fade away is also controlled by the BPM setting of the LUDS. "Idle glow" causes the LEDs to stay on even when the drum is not being hit. Basic LEDs can only be on or off, but more advanced LEDs can be dimmed down and using dimmable LEDs will be a must for both of these settings. The advanced settings are controlled by a set of switches on the controller.

In addition to these settings, the LUDS may include a setting that allows it to play an automated light show based on the replay data collected. This could be accomplished by modifying the code that governs the metronome mode to alter the timing, then extracting the replay data from the secondary processor and loading it into the modified code. This would allow the LUDS to be an impressive visual display element even when no one is actively playing it.

2.2.2 Metronome Customization

Ideally, this L.U.D.S. will offer the user an option for a polyrhythm mode. A polyrhythm consists of the combination of two simultaneous contrasting rhythms. Contrasting rhythms are rhythms where the number of beats in each measure cannot be divided evenly. [4] ("Polyrhythms") There will be a button located on the controller, in the metronome section, that will activate the polyrhythmic mode. The controller will then have two dials to set the time signature of the polyrhythm. The polyrhythm BPM is not needed as an input parameter because the duration of the main rhythm and the polyrhythm meters are typically the same. The MCU will take the time signature of the polyrhythm and the time signature and BPM of the main rhythm to calculate the period of the polyrhythmic beat. These formulas for these calculations will be shown below in *Figure 3*. To indicate which beat of the metronome corresponds to which rhythm, each rhythm will be denoted by a different color LED. The polyrhythm will be implemented via a second ACLK clock at 32 KHz frequency on the MCU. The system should allow for the polyrhythm to have a minimum of 400 L.E.D. flashes per minute with a metronome timing error of less than 2%.

$$R1 = Main\ Rhythm$$

$$R2 = Polyrhythm$$

$$\text{BPM} = \text{Beats Per Minute}$$

$$\text{Beats} = \text{Top Number of Time Signature} = \text{Beats per Measure}$$

$$\text{Measures} = \text{Bottom Number of Time Signature} = \text{Measures per Meter}$$

$$R1\ Meter\ Period = \frac{BPM}{60\ Seconds} * R1\ Beats * R1\ Measures$$

$$R2\ Meter\ Period = R1\ Meter\ Period$$

$$R2\ Measure\ Flash\ Rate = R2\ Meter\ Period\ /\ R2\ Measures$$

$$R2\ Beat\ Flash\ Rate = R2\ Measure\ Flash\ Rate\ /\ R2\ Beats$$

Figure 3 - Polyrhythm timing formulas

2.3 Stretch Goals - Full Drum Kit Integration

Given this project's time and financial constraints, it may not be possible to complete all of the goals desired for this project. Thus some goals are termed "Stretch Goals". Once the rest of the project is complete, then the focus will be on scaling the design up to have infrared sensors and LEDs on a full drum kit. For this project, a full drum kit is categorized as a kick drum, two toms, a floor tom, a high hat, a ride cymbal, and a crash cymbal, in addition to the snare that was included in the main goals. Each individual drum type has its own characteristics such as material, size, acoustic resonance, and location that will require the infrared sensor to be tuned to that specific drum. This extra level of complexity is why this is listed as a stretch goal. In case this goal is viable, the PCB board, MCU, and controller will be designed with additional input ports to plug in more sensors and output ports to plug in more LEDs. A seconds stretch goal is to include individual channel controls for each drum. This will allow the user to adjust specific parameters for each individual drum to give the user full control over how the L.U.D.S. operates.

2.4 Project Constraints

2.4.1 Time and Budget

- The project needs to be completed within approximately a time period of eight months, which is two full semesters (Fall 2022 and Spring 2023).
- The project concept/design cannot be too long or short which includes from developing the initial project idea to showcasing the project at the end.
- Most importantly, the equipmentation and the materials required for the construction should not be too expensive which might cause it to be delayed or unable to be completed fully.
- Also, the unavailability of the materials can also delay the construction of the project. Thus the project components must be currently available for purchase.
- Acquired materials can have manufacturing defects or malfunctions which could make the output of the project have errors.

2.4.2 Performance (manufacturability) and Maintenance (sustainability)

- To be able to function in a performance setting, so components built into the drums can't compromise the integrity of the drums and that the kit holds up to the wear and tear of performance.
- It also has to be easy to assemble/disassemble and relatively compact so it can be transported effortlessly.
- Only the build/construction of the project is started, it requires maintenance everyday until the day of showcase.

2.4.3 Safety (health effects) and Reliability

- In this project, safety is very important because drum beats create sound/vibration which could cause negative hearing effects to people who are sound sensitive to loud noises. It is recommended that this device is used with ear protection such as earplugs or noise reducing headphones.

- The materials and equipment such as the drums and LEDs should be reliable so that it doesn't behave involuntarily.
- The battery should be constantly monitored by someone so that it doesn't overheat and explode during the demonstration or even during the initial stages of construction and testing.
- The lights should also be monitored because high voltage input or overheating can fuse the LEDs which can also discharge harmful odor.

2.4.4 Social and Economic (environmental effects)

- For the environmental protection, the project should not create pollution such as toxic waste and hazardous smoke/smell. In this case, the project might cause noise pollution but not enough to be considered as economic destruction.

3. Block Diagrams

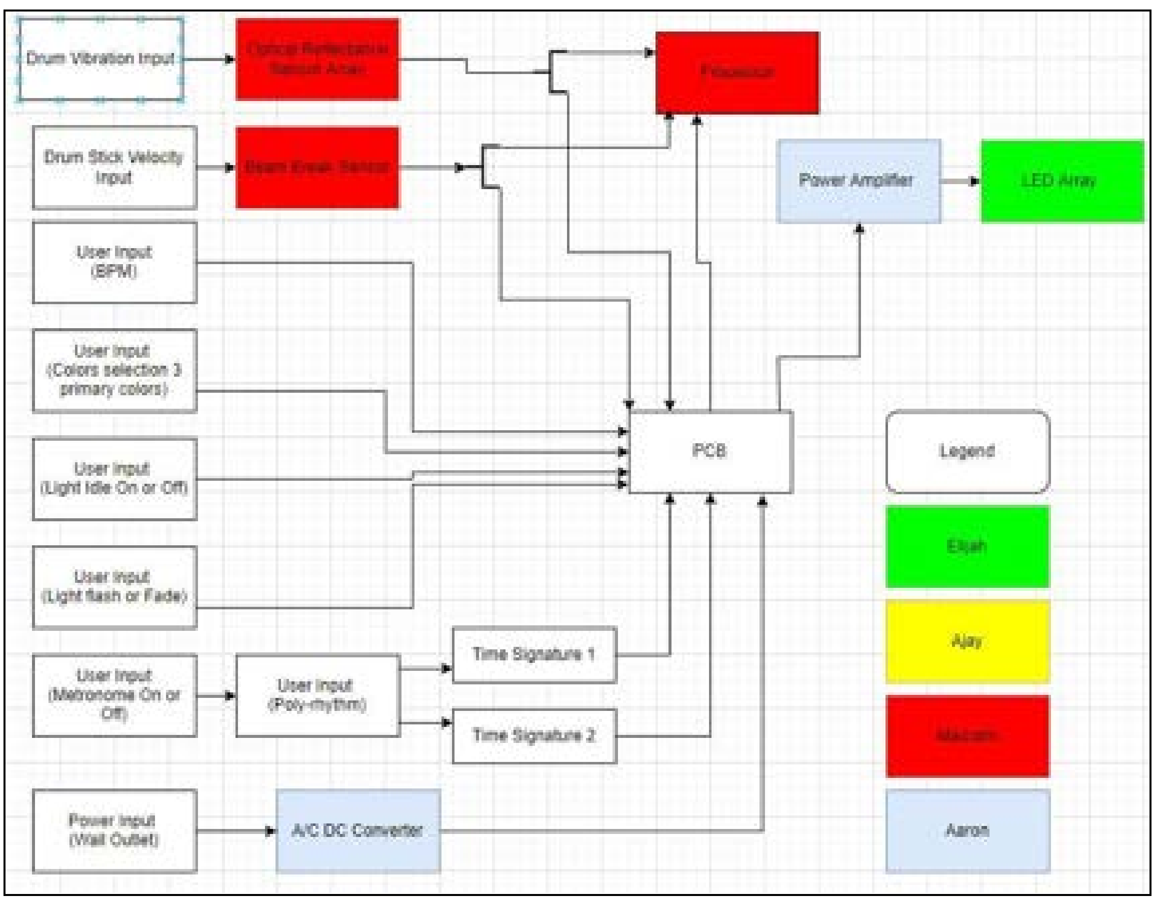

Figure 4 - Project Design Block Diagram

Aaron Holloway
Ajay Nattanmai
Elijah Peterman
Malcolm Donaldson

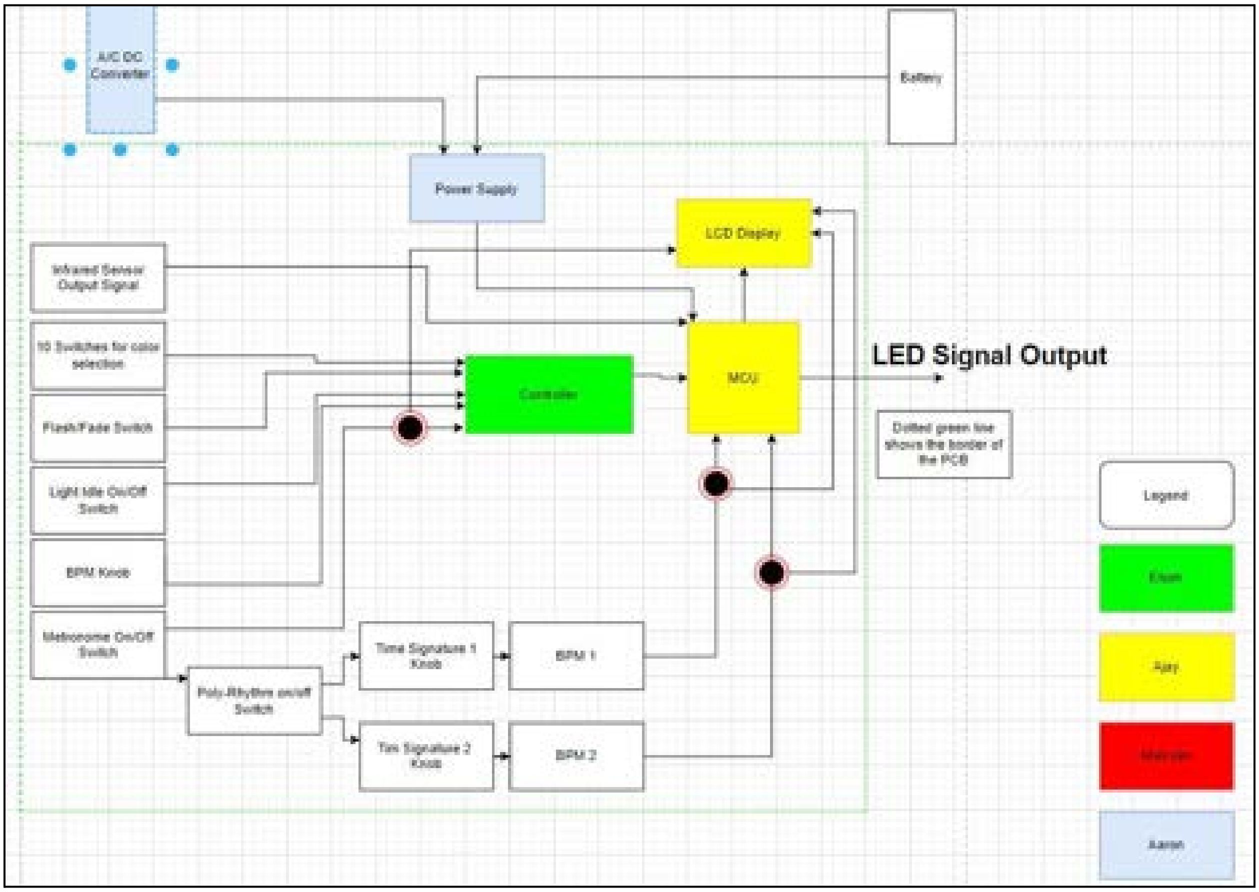

Figure 5 - PCB Block Diagram

4. Budget Specifications

The budget displayed below is an estimated budget using technology investigation of potentially needed components, similar products, and past senior design projects. The prices of similar components were found and rounded up to choose the price for the budget. The quantities of some items have been increased in case the component does not work within the project, faulty components, or broken components during prototype assembly.

Component	Quanitity Needed	Quanitity to be Purchase	Unit Price	Total Price
LED light strips	1	3	10	30
Infrared Reflectance Sensor	6	7	3.5	24.5
Infrared Beam Break Sensor	6	7	2.95	20.65
DSP Chip	1	1	35	35
Microcontroller	1	2	10	20
PCB Manufacture	1	2	75	150
Cable and Accessories	-	-	50	50
Enclosure	1	2	25	50
LCD Display	1	N/A	Already Acquired	-
Controller switches/knobs	18	25	2	50
Battery	1	1	15	15
Power Supply	1	2	20	40
Test Drum Kit	1	N/A	Already Acquired	-
Total Expenses				485.15

Table 4 - Preliminary Budget Estimate

5. House of Quality Diagram

The diagram is quite helpful when trying to determine potential tradeoffs between marketing and engineering requirements. Discerning these tradeoffs allow for better potential solutions and helps to identify upcoming problems. Below is the matrix for the L.U.D system.

			Engineering Requirements					
			Weight	Dimension	Output Power	Cost	Efficiency	Quality
			−	−	+	−	+	+
Marketing Requirements	Portability	+	↑↑	↑↑		↓↓		
	Easy to Install	+	↑	↓		↓		
	Durability	+	↑			↓		↑
	Low Cost	−	↓↓	↓↓	↓		↓	↓↓
	Sound Quality	+	↓↓	↓↓		↓↓		↑↑
	Targets for Engineering Requirements		<25 lbs	3x2 Feet	> 15 Watt	<= $485.15	> 70%	> 70%

Figure 6 - House of Quality Chart

Legend	
+	Positive Polarity
−	Negative Polarity
↑	Positive Correlation
↑↑	Strong Positive Correlation
↓↓	Strong Negative Correlation
↓	Negative Correlation

6. Project Milestones

6.1 Fall 2022 - Senior Design I

Milestone	Expected Completion Date
Form a group based on the initial project ideas	*Completed*
Review existing projects from previous semesters for more clarification	*Completed*
Decide on a project topic and start preparing the design ideas, budget management, team member role	*Completed*
Establish the goals required to complete the assigned tasks	*Completed*
Complete divide and conquer 1.0	*Completed*
Update and complete divide and conquer 2.0	*October 7, 2022*
Mid-term Demonstration: vibration detection via IR sensor	*October 25, 2022*
Complete the initial 60-page SD draft report documentation	*November 4, 2022*
Update the initial draft to 100-page report documentation	*November 18, 2022*
End-term Demonstration: Demonstrate L.E.D. activation via vibration detection	*November 22, 2022*
Complete the final report documentation	*December 6, 2022*

Table 5: Fall 2022 Milestones

6.2 Spring 2023 - Senior Design II

Milestone	Expected Completion Date
Perform PCB research for the project	*Early January*
Start ordering parts that are required immediately and order other parts later that are not very crucial	*Early Before the Start of the Semester*
Construct the initial setup of the design idea	*Early February*
Complete programming the infrared sensor to detect the drum beats	*Late February*
Complete programming to flash the LEDs and brightness based on the sensed vibrations from the beats	*Early March*
Test the user inputs that includes factors such as BPM, light colors, flash/fade, fixed on/off.	*Early April*
Complete all the tasks and produce the final product	*Late April*
Final project demonstration to professors, eli^2 interns, etc.	*End of the Semester*

Table 6: Spring 2023 Milestones

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