University of Central Florida

Senior Design II

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

Group 10

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1. Executive Summary

To begin with, the overall conclusive goal of the project design is to use an infrared sensor to detect vibrations from the drum beats and provide certain outputs. The LED flashes based on the time signature and the displayed values on the LCD are the primary outputs. In order to complete the project and achieve the desired outputs, the hardware design and software design are planned accordingly and provided in step by step details throughout the documentation.

For the design of the project, comprehensive research has been made on the required components and previous projects related to the chosen topic. Various options and types for each component planned to be implemented in the project have been researched to well fit in the design. The research for components includes the options for LEDs, monotone or RGB displays, microcontrollers, infrared sensors, batteries, etc. Along with the components, the software design and coding for the microcontroller has also been researched to fit well with the project.

The device described within this document is an attachment to a drum kit to provide the user with tools to become more proficient at drumming and provide a visual component to playing live shows. The device uses infrared sensors to record when, where, and the velocity of each drum strike in order to play back data, using LEDs, so that the user can see their own mistakes and improve upon them in the future. The device will be equipped with a metronome mode to periodically light up the LEDs to provide a visual temp for the rhythm. The last main feature of the device is the interactive drum kit mode. This mode will cause the drum to light up immediately after being stricken. This mode's main purpose is to provide a visual effect to drumming for live performances.

To construct the overall hardware design, various types of standards and realistic design constraints need to be tested which includes economic, environment, social, political, ethical, health and safety, manufacturability, and sustainability. Each type of constraints are thoroughly explained in their respective sections. After the preliminary research completion, each constraint is clearly examined to observe all possible limitations along with ideas to overcome them. Also, the standards created by the NSSN organization are also taken into consideration for the overall project development.

2. Project Description

2.1 Problem Statement

It's a running joke in the music world that everyone forgets about the drummer of the band and how could they not? While the singers and guitarists run around the stage hogging the limelight and play the part of the song everyone's going to be humming on the way out of the show, the drummer sits in the back and makes sure everyone is keeping on rhythm. Not to mention that, with all that trashing and bashing, it can be hard for drummers to make sure that they are keeping. This project hopes to address both issues by creating a drum that can be used for flashy presentation and practical utility at the same time.

2.2 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. Along with the lights flashing, the drummer can change a few variables that allow the flashes to be in different patterns and colors.

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. The 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 at various different values.

2.3 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 desired 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 and housed inside a control box. The control box 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) The 10 switches used for selecting the light color may not be necessary if the LEDs have the option for a separate pre-made color selecting controller. 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 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.

2.4 Core Goals

- Drum should be able to detect the vibration and force of each strike.
- Modes and specified values should be accessed through a user interface.
- Microcontroller should take inputs from the drum and user interface and react appropriately.
- Devices should be equipped with a metronome mode.
- Metronome mode should light up the LEDs periodically.
- Data measured from the drum beats is stored and can be exported to create replay data.
- Device should be able to be powered by a wall adapter and battery pack.

2.5 Core Objectives

The individual objectives of the project are pretty straight forward. Each goal poses a challenge and the objectives are how the team plans on overcoming those challenges. The core goals presented above are the ones necessary for the project to function, thus the steps laid out in this section are of the highest priority for the project.

2.5.1 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 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. These sensors will not only trigger the LEDs flash in presentation mode, but can also pinpoint where the drum was.

Another set of IR sensors will also be installed on the outside of the drum that will be used to detect force. Instead of reflectance sensors these IR sensors will be beam break sensors, similar to the ones that keep garage doors from closing on obstructions. Instead of the LED and detector being next to each other, they are on opposite sides of a gap, in this case the head of the drum. When an object passes in front of the LED, the detector reacts. This will allow the LUDS to change the brightness of the flash based on how hard the drum is hit, adding to its visual presentation.

2.5.2 User Interface

In order to utilize the features of the L.U.D.S. device, the user must have a way to control the system's features, this is called the control interface. The interface is a collection of switches, knobs, and an LCD display positioned on the control box which houses the device's circuits and non-peripheral components. The LCD display is located at the top of the control interface and will display which features are currently active and any numerical settings that are currently active such as BPM or time signature. Underneath the LCD display, the interface will be separated into two sections with a two-position switch in between to switch between modes. The left section will have the controls for the vibration sensitive LED mode and the other section will have the controls for the metronome mode. The vibration sensitive LED mode will have one switch to change between the fast and fade features, another switch to toggle the idle LED on and off, and a knob to increase or decrease the flash/fade speed. The Metronome side will have two knobs, one for changing the current BPM of the metronome and another knob for controlling the time signature to indicate when the LED should flash extra bright to indicate the start of the new measure.

2.5.3 Microcontroller Implementation and Coding

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.

2.5.4 LED Strip 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 so bright that they may damage the users eyes. They also need to be bright enough to be visible from a distance of forty feet away so people in the audience of a show can view them. There should be LEDs encircling the inside of a 7” radius snare drum so the strip will be at least 30 LEDs per meter. The LED strips will be mounted with double sided tape so less holes need to be drilled 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 unless the side-emitting LEDs are determined to be a health risk to the user's eyes. If the side-emitting LEDs cannot be used for health reasons, then the project will use a brighter (1080 lumens per meter) LED strip without the side-emitting so the light will still be visible from forty feet away without the LEDs shining in the user’s eyes. 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. An operational amplifier will be needed in order to amplify the output of the MCU into the input of the LED strip.

2.5.6 Metronome Functionality

The L.U.D.S. metronome feature will function similarly to a regular auditory metronome except it will use LED 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 calculations for the flash timing are shown in the equations below.

$$Beat\ Flash\ Rate\ =\ \frac{BPM}{60sec} \quad (1)$$

$$Measure\ Flash\ Rate\ =\ Beat\ Flash\ Rate\ *\ Beats \quad (2)$$

$$Metronome\ Percent\ Error\ =\ \left|\frac{Expected\ Flash\ Rate - Measured\ Flash\ Rate}{Expected\ Flash\ Rate}\ *\ 100\%\right| \quad (3)$$

These equations show how to take the inputs from the user interface (BPM and time signature) and transform them into a more mathematical representation for the MCU. The variable name “Beat Flash Rate” represents how much time passes between each flash of the LEDs. “Beat Flash Rate” is calculated in equation (1) by dividing the BPM by 60 seconds. The variable name “Beats” represents the top number of the time signature. “Beats” in the number of flashes that make up a full period of the metronome. “Measure Flash Rate” is how much time passes between an extra bright flash to represent the start of the new period (or measure). “Measure Flash Rate” is calculated in equation (2) by multiplying the top number of the time signature, “beats”, by the “Beat Flash Rate”. Finally, equation (3) shows how to calculate the percent error of the metronome which will be used in the testing section of this report to test the accuracy of the metronome. The “Metronome Percent Error” is calculated by subtracting the actual measured flash rate from the experimental expected flash rate calculated in equation (1) and then dividing the difference by the expected flash rate and multiplying by 100% to get a percent error. The absolute value of the result is the metronome percent error.

2.5.7 Replay 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 (time difference of arrival), which is the length of time it takes between a vibration reaching two fixed points.

The data collected by the sensor will mostly be used for generating replay data, making it a more subtle feature of the LUDS. This replay data will be saved to either an external memory or an internal memory in an exportable format. This data may also be used in performance mode, possibly to coordinate multi-colored displays.

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.

Unlike the positional data, the force of impact data will not only be used to create replay data, but also in the performance mode. The LEDs will flash with a different intensity based on how hard the drum is hit. The harder the hit, the brighter the LEDs will light up.

2.5.8 - Power Supply Connection

The power supply is responsible for powering both the power amplifier and the microcontroller. In addition, the L.U.D.S system will allow a user to switch between battery power and the power received from an outlet. Therefore the power supply must be able to receive 120V AC and a stable regulated output from the battery. An AC adapter will transform the higher rated voltage to a more manageable DC voltage.

The battery supplies a stable output of 12V, while the AC adapter will also supply a stable output of 12V when plugged in. In order to shift power between the adapter and battery, a switch will be necessary. Clearly establishing the three positions so that an input source isn't being unknowingly drawn is a key component. A two pole three position switch allows for the on-off-on positions. Allowing the user ease of control when switching between power sources and establishing a position in which no power is being drawn.

That regulated output of 12V is then split between the power amplifier and the buck boost voltage regulator.The buck boost converter will have a regulated output of 3.3 V. The power amplifier needs the supply voltage of 12V in order to amplify the output signal coming from the microcontroller. In addition to the 12 V signal the power amplifier circuit also requires a negative 12 V signal. Therefore the project requires an inverting buck boost converter. The inverting buck boost converter will have an input voltage of 3.3 V from the previous buck boost converter and produce a regulated output of -12 V The amplified output signal is then sent to the L.E.D strip, where it also needs an input voltage of 12V. The microcontroller's original output voltage signal would have been too low for the L.E.D strip to operate. In addition, the output dictated by the various user inputs and features offered by the L.U.D.S system will need an amplification in order to see the results reflected through the L.E.D.S.

Microcontrollers usually have a small range of low input voltages. Therefore a voltage regulator is needed to step down the voltage to a more manageable level. Majority of microcontrollers have an upper supply voltage of approximately 3.8 V. Consequently the voltage regulator will be able to transform a regulated 12 V DC input to a maximum of 3.8 V regulated output. There will only be one regulator necessary for this system. The microcontroller serves as the only component in need of a reduced DC voltage in order to operate.

The microcontroller is then responsible for powering the other peripherals within the system. Peripherals such as the IR sensors, break beam sensors and LCD display. Depending on the amount of input/output ports the microcontroller could arrange for even more peripherals.

2.6 Advanced Goals

- Make the LED’s color changeable.
- Add a flash and fade options to the sensing mode.
- Create automatic reply option
- Add polyrhythm functionality to the metronome mode.

2.7 Advanced Objectives

The objectives discussed in the following section are less important than the core goals discussed above, but are still within the scope of the project. They are what the team hopes to achieve with the LUDS, but not an integral aspect of the project needed for the LUDS to function. It is highly likely that some of these objectives are completed and even possible that all are accomplished.

2.7.1 Color Changing

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.

2.7.2 Flash and Fade Options

“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.

2.7.3 Automatic Replay

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.

2.7.4 Polyrhythms

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. 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 equations X-Y, where R1 represents the main rhythm and R2 represents the polyrhythm. To indicate which beat of the metronome corresponds to which rhythm, each rhythm will be denoted by a different color LED. The system should allow for the polyrhythm to flash fast enough for most traditional song BPMs and should have an error typical to most auditory metronomes.

$$R1_{meter\ period} = \frac{BPM}{60sec} * R1_{beats} * R1_{measures} \quad (4)$$

$$R2_{meter\ period} = R1_{meter\ period} \quad (5)$$

$$R2_{measure\ flash\ rate} = \frac{R2_{meter\ period}}{R2_{measures}} \quad (6)$$

$$R2_{beat\ flash\ rate} = \frac{R2_{measure\ flash\ rate}}{R2_{beats}} \quad (7)$$

These equations represent how to transform the musical representation of BPM and time signatures into a more mathematical representation to be used for the MCU. Variables denoted by R1 will represent variables related to the main rhythm and variables denoted by R2 will represent variables related to the secondary rhythm. Equation (6) shows how to calculate the period of a full meter by multiplying the beat frequency by the number of beats and by the number of measures. Because the two beats make a polyrhythm, equation (7) shows how both meter periods are the same for both the primary and secondary rhythms. Next, equation (8) expresses how to calculate the period length of the secondary rhythm (R2's measure flash rate) by dividing the meter period by the number of measures in the secondary rhythm. Finally, equation (9) expresses how to calculate the beat flash rate of the secondary rhythm by dividing the secondary rhythm's measure flash rate by the number of beats in each measure in the secondary rhythm.

2.8 Stretch Goals

- Integrate LUDS into a full drum kit
- Generate MIDI files based on replay data

2.9 Stretch Objectives

The objectives given below are ones that are outside of the scope of the project as it currently exists. They are what the team would do in a more ideal scenario where there are not as many constraints on time and resources. It is unlikely these objectives will be met, but not impossible.

2.9.1 Full Drum Kit Integration

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.

2.9.2 MIDI File Creation

Another possible avenue for expanding the project's scope is to have the LUDS generate MIDI files based on the replay date it collects. Musical instrument digital interface or MIDI files are one of the most compact forms of digital music storage because they do not actually contain audio data. Instead, the file tells the computer to give the computer a series of notes to play in a sequence at a specific volume. Essentially, it gives a computer sheet music to read, allowing the computer to synthesize the song, instead of playing the original recording.

The metrics that MIDI files give to the computer are the exact same as the LUDS records in its replay data. The drum records the pitch, volume, and timing of each hit by tracking the position, force of the impacts, and how long between each impact with the IR sensors. To allow the LUDS to create a MIDI file would require that code is written that takes position and force of each and correlates that data to a pitch and volume, then inputting those notes into a synthesizer program. This program would export a completed MIDI file onto a flashdrive.

2.10 Project Specifications

- The project will be designed for a standard 7” (inch) radius snare drum.
- Drum head will have a 170 Hz fundamental frequency
- Drum skin will have a vibration wavefront velocity of 92.87 m/s.
- The L.U.D.S. will be designed to operate using the battery mode for a minimum of 2 hours.
- The L.U.D.S. should weigh less than 5lb (pounds) in total weight including peripherals but not including the drum itself.
- The project prototype components should cost less than $700 total.
- The MCU will operate in the power mode with a VCC voltage level of 3.3V.
- The user interface will have 4 switches and 3 knobs.

- The switches and knobs will use 35k Ohm pull-down resistors unless specified otherwise.
- The user interface will use USB-A 2.0 for data transfer.
- The power to the LED strips will travel through 2.1mm (millimeter) power cables.
- The LED array will have a minimum of 5 levels of brightness.
- The LEDs should be bright enough to be visible from 40 feet away.
- The project will use LED light strips rated at 540 Lumens per meter if the LEDs are pointing outside of the drum head.
- The project will use LED light strips rated at 1,080 Lumens per meter if the LEDs are pointing inside of the drum head.
- The LED strips will be composed of at least 30 LEDs per meter.
- The LED strips will be a minimum of 44" (inches) long.
- The LED strips will be connected for a standard 4-pin RGB connector.
- The LED strips will be powered with a 12V DC power supply.
- The LED strips will consume no more than 10 watts of power per meter.
- The LEDs will need to be able to flash at a speed of at least at 7 Hz.
- The L.U.D.S. will provide the user with a minimum of 10 color options for the LED array.
- The metronome will be implemented using an SMCLK clock at 1 MHz frequency for highest accuracy possible.
- The system should allow for a minimum of 400 LED flashes per minute with a metronome timing error of less than 2%.
- The polyrhythm will also be implemented via SMCLK clock at 1 MHz frequency on the MCU.
- IR sensors cannot have a response time greater than 2.5 ms.
- Reflectance sensors must be positioned 3.5" or 88.9 mm from the center of the drum head.
- Reflectance sensors must be positioned 60 degrees apart from each other.
- Reflectance sensors must have assigned x and y values corresponding to their distance from the center and angle from the x axis (see equations X and X on page Y).
- Reflectance sensors must be approximately 3mm from the skin of the drum
- Phototransistor in the reflectance sensors must output at least 1.25 V.
- Reflectance sensors must detect vibrations between 140 and 200 Hz in frequency.
- Reflectance sensors must detect vibrations moving at 93 m/s.
- Reflectance sensors must be able to locate the origin point of vibrations within 5 mm of accuracy.
- Beam brake sensors must have an effective range of close to than 14" or 355.6 mm.

- Beam break sensor must be placed 30 degrees apart, alternating between emitter and detector.
- Beam break sensors must be able to detect 66.67% or all strikes.
- Replay data must be saved in an exportable format, either a text or MIDI file, to a USB 2.0 drive.
- MCU must perform six time difference of arrival calculations per hit
- MCU must perform a force calculation once per hit

2.11 Quality of House Analysis and 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 1 - House of Quality Chart

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

Figure 2 - House of Quality Legend

3. Research Related to the Project Concept

3.1 Snare Drums

As long as the snare drum is 14” in diameter, the acoustic properties of the drums shouldn’t matter too much. The main factor to look for is the prices and the size. The cheapest snare drums seem to be around $200, with some reaching prices as high as $1500. The team will likely choose the option that is the lowest price that meets the size requirements of the project.

The physical dimensions of the drum vary based on design and sound. Some drums are taller than others, which does not seem to be correlated in price. More volume to work with in the drum would be a convenience, but nor a necessity. The most important dimension, however, is one that is rarely considered, which is the height of the ridge around the edge of the drum. This needs to be as tall as possibly to best support the beam break sensors.

Figure 3 - Pearl Sensitone Heritage Alloy Snare Drum

With these factors in mind the drum that best meets these conditions is a Pearl Sensitone Heritage Alloy snare drum shown in figure 3. It is a 14” snare drum that is 6.5” tall, giving plenty of room for the sensors and wiring to be installed. It also has a high ridge around the edge that appears like it can support the sensors for the most part. It also comes in at a reasonable 329 dollars, putting it in the project's price range.

3.2 Reflectance Sensors

There are several important factors to look for in the reflectance sensors. Firstly, there are the basic electric elements. This includes the forward voltage, which determines how much power it takes for the LED to emit light and would ideally be as low as possible. There is also the saturation voltage, which is the voltage threshold where the transistor. This voltage is determined by the IR beam being detected, and since the IR LED is built into the sensor, it should not be a problem to satisfy.

Another electrical aspect of concern is the current through the transistor. When there is no light detected, the collector-emitter dark current is passing through the transistor, which is usually very small. This current turns into the collector current when the light hits the detector. It is important to know both values because these are the extremes that the processor will check for.

On the other hand there are the optical aspects to consider. The wavelength emitted by the LED determines the color of the beam, which is good to know so we can check for any possible interference from other sources. While it is unlikely that the LUDS will have to factor in interference from other IR sources, it may become relevant.

Finally, there is the effective range. This is the range at which the IR beam from the LED reflects back directly on to the detector. The IR sensors in this array will have short ranges, being placed directly below the drum head, but even a slightly longer range could be an advantage.

3.2.1 QRE1113

Starting with the sensors that were already used in an experiment to track drum hits. QRE1113 is the go to option for this project. This sensor has a great number with a low forward voltage, making it energy efficient, a moderately high collector current, meaning it can send out a detectable signal with little issue, and a decently fast response time. This is the standard that the LUDS was conceptualized around and with the only weakness being that it has a short range of only 3 mm. Below is table 1 which details the specifications for the QRE1113.

Specification	Value	Synopsis
Forward Voltage	1.2-1.6 V	Low operating voltage
Emission Wavelength	940 nm	Standard LED wavelength
Collector-Emitter Dark Current	100 nA	Low dark current
Collector Current	0.9 mA	Standard collector current
Saturation Voltage	0.3 V	Low saturation
Rise Time	20 μs	Average response time
Effective Range	3 mm	Short range

Table 1 - QRE1113 Specifications

3.2.2 RPR-220

The RPR-220 is a solid secondary choice. What makes it appealing as a secondary choice is its fast response time as well as its long range. In most other regards it is comparable to the QRE1113. The exception being the higher than average dark current, which may require a slight adjustment in the code to prevent issues. These sensors are slightly more expensive than the QRE1113, but it is an overall negligible price difference. Below is table 2 which details the specifications for the RPR-220.

Specification	Value	Synopsis
Forward Voltage	1.34-1.6 V	Moderate operating voltage
Emission Wavelength	940 nm	Standard LED wavelength
Collector-Emitter Dark Current	500 nA	High dark current
Collector Current	0.3-0.8 mA	Low collector current
Saturation Voltage	0.1-0.3 V	Low saturation
Rise Time	10 μs	Fast response time
Effective Range	6 mm	Long range

Table 2 - RPR-220 Specifications

3.2.3 OPB745

The OPB745 is another option for the reflectance sensor array. Its most attractive feature is its extremely high collector current, which will make reading the inputs from the sensors extremely easy. It unfortunately does not have a rise time listed on the data sheet, which is far from ideal in a project where the response time needs to be fast. Below is table 3 which details the specifications for the OPB745.

Specification	Value	Synopsis
Forward Voltage	1.8 V	Moderate operating voltage
Emission Wavelength	890 nm	Short LED wavelength
Collector-Emitter Dark Current	100 nA	Low dark current
Collector Current	5-26 mA	Very high collector current
Saturation Voltage	1.1 V	High saturation
Rise Time	n/a	Rise time is not listed on the datasheet
Effective Range	3.81 mm	Short range

Table 3 - OPB745 Specification

3.2.4 CNY70

The CNY70 is the most budget friendly option of the sensors listed here. It also has a decently long range compared to the QRE1113, but in other regards is comparable. It shares the weakness of an unknown response time, which leaves a lot or room for error. Below is table 4 which details the specifications for the CNU70.

Specification	Value	Synopsis
Forward Voltage	1.25-1.6 V	Moderate operating voltage
Emission Wavelength	940 nm	Standard LED wavelength
Collector-Emitter Dark Current	200 nA	Moderate dark current
Collector Current	0.3-1 mA	Standard collector current
Saturation Voltage	0.3 V	Low saturation
Rise Time	n/a	Rise time is not listed on the datasheet
Effective Range	5 mm	Long range

Table 4 - CNY70 Specifications

3.2.5 Reflectance Sensor Power Consumption Comparison

When it comes to power consumption efficiency, the QRE1113 is the clear favorite. It uses almost a third of the power of the next most efficient option. This means that it will create the least amount of burden on the power supply and make the LUDS run the most efficient of all the sensors. Below is table 5 which details the power consumption of the various reflectance sensors.

Sensor	Forward Operating Voltage (V)	Forward Current (mA)	Power Consumption (mW)
QRE1113	1.2	20	24
RPR-220	1.36	50	68
OPB745	1.8	40	72
CNY70	1.25	50	62.5

Table 5 - Reflectance Sensor Power Consumption Values

3.2.6 Reflectance Sensor Cost Comparison

While the QRE1113 is not the cheapest option available, the lack of information on the response time of the CNY70 and extremely minimal price difference between the two sensors, make the QRE1113 the favorite in this category as well. The OPB745 also shows a major weakness. While not as expensive as the QRE1113 for a single unit, it cannot be ordered in a pack of 10, meaning that it is overall the most expensive. Paired with its undisclosed rise time, it is the least attractive option of the four sensors discussed. Below is table 6 which details the price of the various reflectance sensors.

Sensor	Unit Price	System Price (x10)	System Price increase
QRE1113	$3.50	$13.35	0%
RPR-220	$2.25	$18.24	36.62%
OPB745	$3.14	$31.40	135.2%
CNY70	$1.41	$11.03	-17.37%

Table 6 - Reflectance Sensor Power Consumption Values

3.3 Beam Break Sensors

The beam break sensors are very similar to the reflectance sensors in terms of what specifications are being investigated. However, the sensors are on a different scale, what is considered a good value when choosing a reflectance sensor could be a weakness for the beam break sensors. Most notably the range must be much greater because the beam must cross a 14 inch or 355.6 mm drum to reach the detector.

3.3.1 OPB100Z

The OPB100Z is the main choice for the beam break sensor of the LUDS. It has an operating voltage similar to the QRE1113, making them very comparable in a circuit. It also has more than enough range work for the LUDS. Its main weakness is the fact that it does not have a listed response time, which is unfortunate, but it is still the best option compared to the other beam break sensors. Unfortunately the effective range is a little too small to cross the drum, this could be worked around but finding a longer sensor might be better. Below is table 7 which details the specifications for the OP100Z.

Specification	Value	Synopsis
Forward Voltage	1.7 V	Moderate operating voltage
Emission Wavelength	880 nm	Short LED wavelength
Collector-Emitter Dark Current	100 nA	Low dark current
Collector Current	5 mA	High collector current
Saturation Voltage	0.4 V	Low saturation
Rise Time	n/a	Rise time is not listed on the datasheet
Effective Range	304.8 mm	Short range

Table 7 - OPB100Z Specifications

3.3.2 OPB856Z

The OPB856Z is from the same manufacturer as the OPB100Z. As such it is virtually identical. The main draw of these options is that the LED and sensor are housed in a much nicer casing, shown in figure 4. This could be good for two reasons: the aesthetics, the functionality, and the shape. Firstly but less importantly, the LUDS is supposed to be a performance piece in theory, so for a component that will be mounted outside the outside of the drum looking nicer is a strength. More importantly, the casing is designed in a way that is conducive to mounting to the edge of a drum. Finally, the L-shape of the casing can be used to compensate for the slightly short range of the sensor. These sensors are a bit more expensive, their advantages could be worth spending more. Below is table 8 which details the specifications for the OP856Z.

Figure 4 - Special casing of the OPB856Z's detector (left) and emitter (right)

Specification	Value	Synopsis
Forward Voltage	1.7 V	Moderate operating voltage
Emission Wavelength	935 nm	Moderate LED wavelength
Collector-Emitter Dark Current	100 nA	Low dark current
Collector Current	1.8 mA	Moderate collector current
Saturation Voltage	0.4 V	Low saturation
Rise Time	n/a	Rise time is not listed on the datasheet
Effective Range	304.8 mm	Short range

Table 8 - OPB856Z Specifications

3.3.3 SEN0503

The SEN0503 strengths are that it is cheaper and has much longer range then other sensors. However its datasheet is heavily simplified making it hard to compare to the OPB100Z and 856Z directly, as well as having many values completely absent, though it does have a listed response time. Its additional range is also not a major asset since the previous two options already had a surplus of range to work with. Below is table 9 which details the specifications for the SEN0504.

Specification	Value	Synopsis
Working Voltage	3-5 V	Moderate operating voltage
Emission Wavelength	n/a	Wavelength is not listed on the datasheet
Collector-Emitter Dark Current	n/a	Dark Current is not listed on the datasheet
Output Current	100 mA	Very high collector current
Saturation Voltage	n/a	Threshold is not listed on the datasheet
Rise Time	2 ms	Moderate response time
Effective Range	500 mm	Long range

Table 9 - SEN0503 Specifications

3.3.4 WF225-B4150

An extremely high end option for the beam break sensor. The only strength is that it has a shorter response time than the SEN0503, at least as far as the information given is concerned. It's not impossible to work around not having a datasheet, but when there are other options it's not a worthwhile endeavor. Most of the relevant specifications are not listed as there is no data sheet. One of the few data points listed is the effective range, which is shorter than the other options, making it a bad fit for this project.. This fact, combined with the extremely high price, makes this by far the least appealing option of any sensor discussed. Below is table 10 which details the specifications for the WF225-B4150.

Specification	Value	Synopsis
Forward Voltage	n/a	Operating/forward voltage is not listed on the datasheet
Emission Wavelength	n/a	Wavelength is not listed on the datasheet
Collector-Emitter Dark Current	n/a	Dark Current is not listed on the datasheet
Collector Current	n/a	Collector current is not listed on the datasheet
Saturation Voltage	n/a	Threshold is not listed on the datasheet
Rise Time	1 ms	Fast response time
Effective Range	225 mm	Short range

Table 10 - WF225-B4150 Specifications

3.3.5 Beak Break Sensor Power Consumption Comparison

Being incredibly similar components, the OPB100Z and the OPB856Z will consume virtually the same amount of power. With not much information available on the WF225-B4150, that only leaves the SEN0503 to compare to the other two sensors. The OPB100Z and 856Z both have much better efficiency than that sensor, being consuming less than half the energy of the SEN0503. Below is table 11 which details the power consumption of the various beam break sensors.

Sensor	Forward Operating Voltage (V)	Forward Current (mA)	Power Consumption (mW)
OPB100Z	1.7	20	35
OPB856Z	1.7	20	35
SEN0503	3	25	75

Table 11 - Beam Break Sensor Power Consumption Values

3.3.6 Beam Break Sensor Cost Comparison

In terms of price, the SEN0503 has the advantage, being closer to half the price of the still quite affordable OPB100Z. The OPB856Z sees a big jump up in terms of price. While this price increase is pretty large, almost quadrupling the cost of beam break sensors, they are not strictly out of the project's budget and the advantages this model will provide could be worth the cost. The WF225-B4150 is entirely out of the project's budgetary constraints, with one unit more expensive being more expensive than a whole order of OPB856Zs. It should be noted that none of these sensors can be ordered in bulk. Below is table 12 which details the price of the various beak break sensors.

Sensor	Unit Price	System Price (x10)	System Price increase
OPB100Z	$7.08	$70.80	0%
OPB856Z	$34.28	$342.80	384.18%
SEN0503	$4.50	$45.00	-36.44%
WF225-B 4150	$501.96	$5019.60	6989.83%

Table 12 - Beam Break Sensor Power Consumption Values

3.3.7 Digital vs. Analog Sensors

The LUDS's configuration makes it important that the reflectance sensors be analog sensors because the photodetector needs to be able to distinguish between multiple light levels. Digital sensors would be easier and cheaper to work with, but can only detect if the light is hitting the sensor or not. With the sensors being placed directly under the skin of the drum, the beam is going to hit the detector while at rest and since the drum head does not deform noticeably, the beam will only be slightly deflected from the detector. This means that the phototransistor will never be all the way off. Using an analog sensor means that the sensor may have to be connected to the PCB by an Analog to Digital Converter (ADC), shown below in figure 5.

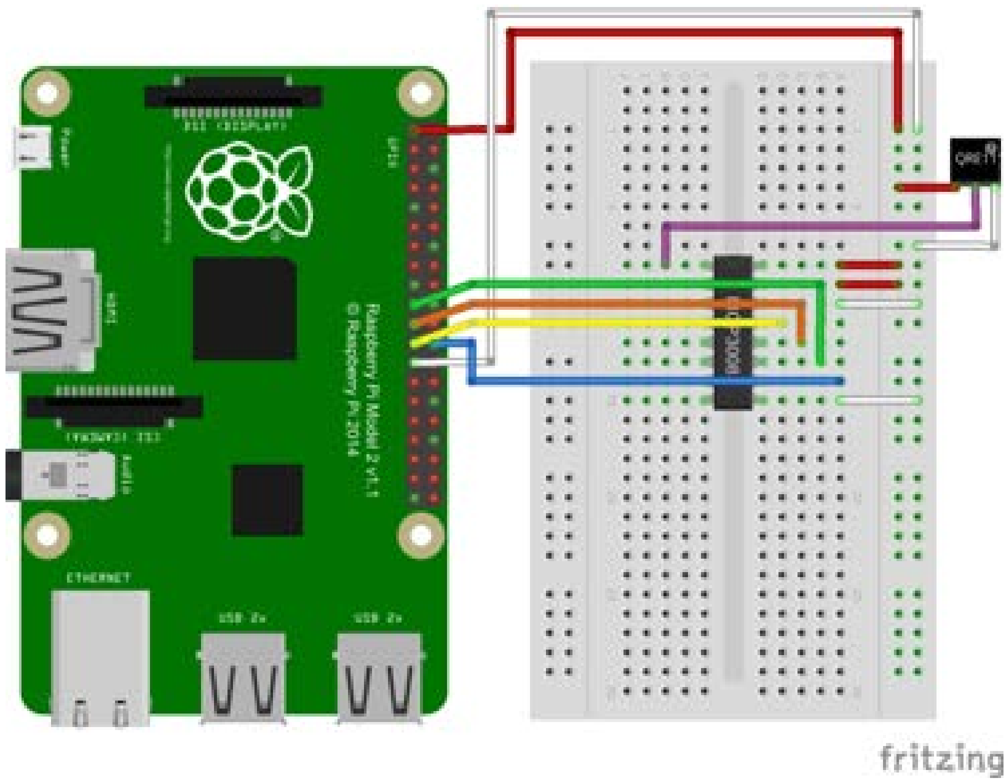


Figure 5 - A simple circuit with one analog QRE1113 sensor connected to a Raspberry Pi via an ADC chip. Raspberry Pi not representative of the LUDS PCB.

The beam break sensors, unlike the reflectance sensors, do not need to be analog. The beam being broken or not is an entirely binary condition, thus digital sensors will be sufficient. This will lower the price and make the programming much easier compared to the reflectance sensors.

3.3.8 Optical Fiber Alternative

Using an optical fiber attached to the bottom of the drum could be an effective solution as an alternative to detect vibrations. A few meters of fiber and a small transceiver unit are relatively cheap at the low end and can prove to be sturdier than the reflectance sensors. Though higher quality fibers and transceivers could end up costing the project much more. The biggest hurdle is that it would be a fundamental change to the project, so this alternative solution is for if the reflectance sensor design completely fails.

3.4 Microcontroller Options

There are a variety of features that the L.U.D system offers but the key component would be the microcontroller. The information from the array of sensors will be processed within the MCU and output the desired results. The scale for the L.U.D.S is proportional to only one snare drum, therefore only one microcontroller necessary.

In order to efficiently limit costs in bulk, an optimal microcontroller will have a low cost. Other characteristics of an optimal microcontroller include low power consumption while maintaining a good power efficiency. As well, selecting a microcontroller that doesn't have limited availability is key. When scaled up to a real production the availability of parts is an essential aspect that should be considered.

There are a huge assortment of microcontrollers to choose from. Texas Instruments is a prevalent company that designs and sells a plethora of microcontrollers. Majority of students are well experienced with microcontrollers from that company due to the various classes taken. Another prevalent company creating microcontrollers would be Arduino. Many characteristics were considered including price and power consumption. However, after comparing a variety of companies only 2 seemed to be the most optimal .There were other microcontroller brands considered however Arduino and Texas Instruments seem to be the best fit for the project.

Within these two microcontroller brands are key aspects to consider when picking the optimal MCU. The number of input/output ports is a very key component, especially when estimating the number of peripherals a project may have. These ports are essential for communication and allow the microcontroller to connect to a number of essential components such as the power supply.

Another fundamental aspect in relation to the microcontroller is the RAM. RAM serves as the primary storage for the MCU and the main space for temporary data to be rewritten as normal operation ensues. Ensuring a quality amount of space allocated for the RAM will allow for faster calculations and help to optimize battery life.

3.4.1 MSP430G2253

The MSP430G2253 was considered due to the familiarity from past classes. This microcontroller can be bought individually or with the MSP430G2 LaunchPad kit. The microcontroller offers a very quick time of 1 microsecond to wake from being in standby mode. It uses .230 milli amps at 1 Mhz while in active mode. This MCU also offers 5 different power saving modes while being a part of the company's ultra low power consuming family. It also boasts a low operating voltage of 1.8 V. Below is table 13 which details the specifications for the MSP430G2253.

Specifications	Value	Synopsis
Low Power Modes	5	Allows for a reduction in power consumption
Primary Storage	256 B	Possibly insufficient size for the amount of data
Secondary Storage	2 KB	Would serve as a better memory but is still isn't adequate
Communication Module	2 eUSCI	A great amount of options for communication
Main Clock Speed	16 MHz	Seems to be adequate speed

Table 13 - MSP430G2253 Specifications

3.4.2 ATMega328P

Originally the ATMega microcontroller was made by Atel but since then Microchip has acquired its manufacturing. The ATMega series of microcontrollers are renowned for their reliability and low power. Therefore the resources and information concerning this MCU will be . massiveSimilar to the ATMega328P this MCU premieres on the Arduino Uno.

The operating conditions for this MCU at 1 MHz is 1.8 V . This microcontroller offers 6 different sleeping modes. Those modes include idle, ADC noise reduction, powersave, power-down, standby and extended standby. In addition, the ATMega328P boasts a total of 23 I/O pins. There are 8 analog pins and 15 digital pins. This should serve as an adequate number of pins to support the beam break sensor and optical reflectance sensor.

The starting cost for this MCU is $2.92, which is approximately 6 times less than what is being offered for the ATMega2560 chip. Effectively making this MCU worthy for consideration from an economic standpoint. However the ATMega328P has the second highest power consumption compared to the rest of the microcontrollers listed. This will remove ATMega328P from being considered for the L.U.D.S due to its lower power efficiency. Below is table 14 which details the specifications for the ATMega329P MCU.

Specifications	Value	Synopsis
Primary Storage	2 KB	Relatively small and must be optimized for use
Secondary Storage	32 KB	Good amount of storage allows more advanced code
Main Clock Speed	16 MHz	Seems to be adequate speed
Low Power Modes	N/A	There were no low power modes reported

Table 14 - ATMega328P Specifications

3.4.3 ATMega2560

The ATMega2650 is a bigger and more powerful MCU when compared to the ATMega328P. The 2560 MCU provides better performance, a much bigger memory and more pins at its disposal. As a consequence of the overall better performance and memory, means there will be a proportional increase in price in comparison to the 328P. The 2560 chip starts at $17.79 which is more than times what is originally priced for the 328 chip. Similar to the ATMega328P this MCU premieres on the Arduino Mega.

At 1 Mhz the operating voltage is 1.8 V and the current is 0.3 milliamps. Similar to ATMega328P this microcontroller offers six different power saving modes. One of the main differences between this microcontroller and the ATMega328P is that the ATMega328P can only be surface mounted. Another significant difference would be the power consumption between the two MCU's. ATMega2560 being the more powerful MCU its power consumption is approximately 2.5 times that of the ATMega328P microcontroller.

ATMega2650 is a very powerful MCU boasting a total of 54/86 programmable input/output lines. 54 of those pins are digital while the other 16 are analog pins. This is a great feature however due to the scope of the project the additional pins wouldn't be used. As well, the significant increase in power consumption especially paired with its high end cost compared with other microcontrollers will automatically disqualify ATMega2560 from moving forward. Below is table 15 which details the specifications for the ATMEGA2560.

Specifications	Value	Synopsis
Primary Storage	8 KB	An adequate amount of storage
Secondary Storage	256 KB	A substantial amount to help alleviate the work
Main Clock Speed	16 MHz	Seems to be a moderate clock speed
Low Power Mode	N/A	There were no low power modes reported

Table 15 - ATMega2560 Specifications

3.4.4 MSP432P401R

This microcontroller is a part of the ultra low power family that Texas Instrument offers. Similar to the MSP4306989 the microcontroller offers up to 16 KB of flash information memory and 256 KB of flash main memory. It uses 83 micro amps at 1 Mhz while in active mode. As well, this particular microcontroller offers the lowest operating voltage than any MCU considered. Its operating voltage is 1.6 V. MSP432P401R low operating voltage paired with the lowest power consumption makes this MCU the most optimal choice. Below is table 16 which details the specifications for the MSP432P401R.

Specifications	Value	Synopsis
Low Power Modes	4	Not great but good for power efficiency
Primary Storage	64 KB	A large amount of storage
Secondary Storage	256 KB	Allows for advanced code to help facilitate the work
Communication Module	2 eUSCI	Good amount of options for communication control
Main Clock Speed	48 MHz	A substantial clock speed

Table 16 - MSP432P401R Specifications

3.4.5 MSP430FR6989

Similar to the MSP430G2253 this particular microcontroller is among the family of ultra low power consuming microcontrollers offered by Texas Instruments. The microcontroller offers up to 256 KB of flash main memory and 16 KB of flash information memory. This MCU also offers multiple low power saving modes. It uses 100 micro amps at 1 Mhz while in active mode. In comparison to the other microcontrollers, the MSP430FR6989 boasts the second lowest power consumption making it worthy of consideration. Below is table 17 which details the specifications for the MSP430FR6989 MCU.

Specifications	Value	Synopsis
Low Power Modes	7	Good amount for reducing power consumption
Primary Storage	2 KB	Small amount of storage for the computation necessary
Secondary Storage	128 KB	Sizable amount for code lookups
Communication Module	2 eUSCI	A good amount of options aiding in communication control
Main Clock Speed	16 MHz	Modest clock speed

Table 17 - MSP430FR6989 Specifications

3.4.6 Microcontroller Power Consumption Comparison

Below is Table 12 comparing potential microcontrollers for the L.U.D.S with the according power consumption associated with the MCU. The MSP430G2553 would be the least likely microcontroller that is chosen. MSP430G2553's power consumption is the highest of all the microcontrollers and wouldn't be the optimal choice. As well, the MSP430 controller is among the majority of microcontrollers that have a higher low operating voltage. Majority of microcontrollers have a low operating voltage of 1.8 V. The ATMega2560 offers a low power consumption however it doesn't offer the lowest operating voltage. The final considerations for the top microcontrollers were the MSP430FR6989 and MSP432PP401R. The MSP430FR6989 comes in at a close second, boasting the second lowest power consumption paired with a median low operating voltage o 1.8 V. MSP432PP401R offers the lowest power consumption while boasting the lowest operating voltage of all the microcontrollers considered for the L.U.D.S. Below is table 18 which details the power consumption of the various microcontrollers.

MCU	Low Operating Voltage (V)	Current @ 1MHz (mA)	Power Consumption (mW)
MSP430G2553	1.8	0.23	0.414
ATMega328P	1.8	0.2	0.36
ATMega2560	1.8	0.3	0.9
MSP432P401R	1.62	0.08	0.129
MSP430FR6989	1.8	0.1	0.18

Table 18 - MCU Power Consumption Values

3.4.7 Microcontroller Cost Comparison

Below is the cost comparison of the potential microcontrollers being considered for this system. The MSP430G2553 is by far the least expensive per unit. In contrast, the ATMega2560 boasts the most expensive price out of the group. The estimated budget for a microcontroller was $15.00. All of the MCU's under the Texas Instrument Family are viable under the budget. The ATMega328P is also viable and sit as the second least expensive at $2.92

In preparation for testing and other unforeseen circumstances, it would be wise to get at least two of everything. Therefore comparing double the system price was essential. The MCU's below are so cost effective that even at double the system price, they cost less than the projected budget. One microcontroller from the Texas Instrument family is slightly above the estimated budget sitting at $16.76. All of the microcontrollers considered below are feasible options besides ATMega328P. Below table 19 details the comparison of the various microcontrollers considered.

Microcontroller	Unit Price ($)	System Price (x2)	System Price Increase (%)
MSP430G2553	$1.08	$2.16	0%
ATMega328P	$2.92	$5.84	170.37%
ATMega2560	$17.79	$35.58	1547.2%
MSP432P401R	$8.38	$16.76	675.93%
MSP430FR6989	$4.99	$9.98	362.04%

Table 19 - MCU Cost Values

3.5 LED Strip options

Since there are so many well designed LED strips currently on the market, there is no need to redesign an LED strip for the L.U.D.S. device. This section covers the different LED strips that will potentially be used for this project. The main features and attributes that will make for a good candidate are as follows: Price efficient, meeting the design specifications listed in the specifications section of this report, linearly changing luminosity from linearly changing power input, cuttable, and compatibility with dimming/color control modules.

Option 1: One part that meets the specifications for the LED component is the "RGB LED Side Emitting Strip Light" from LEDsupply part number R6060RGB LED Side Emitting Strip Light-IP20-RGBS. Table 20 below shows the product details on the "RGB LED Side Emitting Strip Light". This side-emitting LED may be useful because the LEDs will sit against the inside of the drum head so having the LEd pointing sideways will allow them to shine straight out of the drum head.

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 20 - R6060-IP20-RGBS Side Emitting product details

Option 2: Another part that may work is the “Non-Waterproof IP20 LED Flex Strip” from LEDSupply.com part number: R6060-IP20-RGB-06. These LEDs are not side-emitting but are offered with a high density 60 LEDs per meter. This means that even though the LEDs won’t be pointing out of the drum head, they should still supply enough light to be visually impressive as our goals have stated. These high density LEDs will be used in the case that the side-emitting LEDs could be harmful to the drummer's eyes. Table 21 below shows the specifications for this LED strip.

Product Details

LED Density: Standard (SD) = 30 LEDs/M, High (HD) = 60 LEDs/M	**Colors:** RGB, Ultra Violet (UV) & Warm, Neutral and Cool White (3000K-6000K)
Lumens: SD 540/M / HD 1080/M	**Power:** 12VDC
Wattage: SD 7.2Watts/M / HD 14.4Watts/M	**Mounting:** Doubled Sided 3M Tape, or Clips
Cuttable: Every 3 LEDs (SD 4", HD 2")	**Custom Lengths:** 3-Foot Increments up to 16.4-Feet (Full Reel 5M)
Size: 10mm Wide X 2mm Tall	**Connection:** 6-Inch Wire Harness, 2.1mm Plug

Table 21 - R6060-IP20-RGBS product details

3.6 Operational Amplifier Options

Option 1: One option for the operational amplifier used for the LED power is the TL084CN. This operational amplifier has four amplifier circuits inside which could be useful in the case of other parts of the L.U.D.S. needs a voltage amplifier. It has a high slew rate of 13V/μs which is particularly useful since the delay between the drum strike and the LED flash should be as short as possible. It has a voltage supply range of 10V to 30V which is sufficient for the 12V supply required for the LED strips. One drawback of the amplifier is the 3mV offset voltage. This 3mV should be negligible for the purpose of the L.U.D.S. because it requires a full 12V to reach the maximum voltage of the LEDs. This amplifier costs 0.62 cents per unit.

Option 2: A second option for the operational amplifier is the LM358DR. This is a two circuit operational amplifier which still gives the option for a second amplifier circuit in the case of another part of the L.U.D.S. needing an amplifier. It has a slew rate of 0.3V/μs which is not nearly as high as the TL084CN. It has a voltage supply range of 3V to 30V which is sufficient for the 12V supply requirement. This amplifier has the same 3mV offset voltage of the TL084CN. This amplifier costs 0.39 cents per unit.

The TL084CN appears as the best option because of the high slew rate and the higher number of amplifier circuits.

3.7 Dimming/Color Controller Options

Option 1: The LED strips require some form of control so the user can choose what color they want the LEDs to flash while using the L.U.D.S. device. The first option is the “RGB Remote Control RF Dimmer for LED Strips” PART #: DIMMER-3CH-12A. This is a very small controller that is placed in line between the power supply and the LED strip. It connects to the power supply via a 2.1mm female plug and connects to the LED strips via a 4-pin male or female RGB connector. The device works with 12V input LED strips. The controller is managed by an infrared remote with a range of about 15M. The controller has a variety of options to control the way the LEDs behave. These options include 20 static and 6 direct color options, 5 levels of brightness, and three behavioral modes including flash, strobe, smooth, and fade, and 10 a level speed control for each mode. Since the flashing/fading will be controlled by the MCU, the most important feature of the dimmer/color control module is the color options, but the other features can still add to the use of the L.U.D.S. device.

Option 2: The second option for the color controller is the “LED Flex Strip - RGB Controller” PART #: DIMMER-3CH. This dimmer/color controller is placed in line between the LED strip and the power supply. The power input is a 2.1mm female plug and the output has the option for both a 2.1mm plug and a 4-pin RGB connector. This project will use the 4-pin RGB connector because the LED strip is RGB. This module is much bigger than the other with dimensions of 50mm X 35mm X 22mm. It has the same combination of features as the other color controller, flash, strobe, fade, and smooth, speed control, and brightness level but it has 16 color options. This device's infrared remote allows for multiple color options at a time so the LEDs will shift between colors and it has a feature which allows the user to program new combinations of colors to fully utilize the RGB spectrum. The larger size is a drawback but it can be hidden inside the L.U.D.S. control box so the device does not have unnecessary loose parts. The multiple color option and the programmable colors makes this an optimal part to use on the L.U.D. system.

3.8 USB ports

The technology investigation of different potential USB 2.0 ports for the L.U.D.S. is explained in this section. Below, are different parts that have been considered for the device, their pros, cons, and specifications. The main specifications and features required for this project are that the part is in stock, price efficient, and reliable for data transfer. A few different ones are considered but the chosen

USB port will be described in greater detail in the Project Hardware and Software Design Details section of this report.

Option 1: One option is the BOB-12700 female USB-A adapter. This adapter is currently in stock and costs $4.95 per unit. It comes attached to a small chip with through holes for mounting and labeled connections for soldering wires from the adapter to the MCU. The adapter is 1.020" L x 0.900" W (25.90mm x 22.90mm) in size. The adapters data sheet recommends using two 15KΩ pull-down resisters for the D- and D+ pins to reduce contact noise and ease data transfer. The VCC terminal requires a 5V power supply. The VCC of the chosen microcontroller is at 3V so if this component were to be used, it would require power from the USB host device.

Option 2: Another option is the USB1046-GF-0190-L-B-A from GCT on mouser electronics. The part is currently in stock for $0.65 per unit. Unlike the above option, this is just the female USB receptacle. This means the pins on the back would have to be carefully soldered to ensure no connections are shorted when connecting to the microcontroller unit. Since this one does not have the chip attached to the back end like the above option, it will save room within the control box of the L.U.D.S. unit. The manufacturer does not have any recommended pull-down resistors so the pull-down resistors will be the 35kΩ recommended by the MSP430FR6989 that we are using for the microcontroller. This receptacle has four pins coming out of the back, one ground pin, one VCC pin, and two pins for data transfer which will be connected to pins on the MCU. Like all USBs, the connection between the host and the device requires a 5V power supply which cannot be supplied by the microcontroller. This means that the connection will need to be powered by the host device no matter which adapter is chosen. This also implies that only powered USB devices can connect to the L.U.D.S. and no USB drives can be used to interface with the L.U.D.S. device.

3.9 Competitive Products

There are currently several products on the market with similar functions each with their own features and drawbacks. Table 22 shows each product and 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 22 - Comparison with Similar Equipmentations

Another similar device to the L.U.D.S. is the Yamaha DTX10K-X BF electronic drum set, Shown in Figure 6. This drum set utilizes a piezo sensor to detect the various inputs from the drumsticks. When the drum is hit a certain amount of voltage is produced and recorded to its module. Depending on the intensity of the hit there will be a corresponding voltage level. That information is then sent to the various piezo sensors strategically placed throughout the drum set.

Figure 6 - Yamaha DTX10K-M a product similar to the LUDS

There are piezo sensors placed throughout the drum set. They are placed on and under the head of snares, pads and more. The pads even have two sensors to distinguish whether a drum was hit on its head or on the outer rim of the pad. Depending on the module settings this could produce two different sounds that affect the user performance or enjoyment.

Yamaha's drum system has wires connecting from the various piezo sensors to the module where this information is stored. Depending on the cable used, the amount of information that the module can receive will differ. The "tip/sleeve" cable is only able to send information from one sensor. However the "tip/ring/sleeve" is able to send information from 2 sensors. This allows the module to read data from the head of the drum and the outer rim.

The module takes the incoming voltage levels from the multiple sensors and is able to distinguish the intensity of the hits. This resulting information allows the module to allocate which sound should be played and at what intensity. A hard hit on the drum will have a corresponding loud sound issued from the module. The module also has the capability of storing and playing back recordings of the drums.

The Yamaha electronic drum is quite similar to the L.U.D system. Both systems offer the capability to save data and replay at a later date. However there are some key differences between these two. The main difference between these two electronic drum systems is the output from the module. The L.U.D system output would be the L.E.D. instead of the sound created from the module in the Yamaha set. Yamaha's drum set is also a full drum set compared to the L.U.D.S one snare drum. However the comparative price between the two sets is drastic. The Yamaha set is approximately $5,169.99, which is considerably more than what the L.U.D system projected costs are.

Similar to the Yamaha system the intensity of the drum hit will have a direct affect on the intensity of the L.E.DS. L.U.D.S also provides a number of different features with respect to the LED's. The user will have up to sixteen color options while being able to adjust the brightness to their liking. The system also allows the user to decide if the LEDS are on while idle or not. Another key feature that the L.U.D.S offers is the metronome. The user will be capable of inputting the BPM and the time signature of the song. The L.U.D.S LED array will also feature a setting allowing the user to fade, flash, and strobe to their liking.

An inconspicuous device similar to the L.U.D system is the Retro-Reflective Photoelectric Sensor Entry Alert System. This alert system's main component utilizes a break beam sensor. The main components include a reflector, a break beam sensor and a speaker. Break beam sensors are infrared sensors that can simply and efficiently detect motion. The emitter side of the sensor sends a beam of infrared light invisible to the human eye to a receiver or reflector. When something interrupts or breaks the beam the information is then sent to the speaker. The speaker then makes a chime or whichever preloaded noise response due to the interruption.

Similar to the Retro-Reflective Photoelectric Sensor Entry Alert System, The L.U.D.S also uses a break beam sensor. Unlike using the sensor to gain insight as it pertains to the door's status, instead the L.U.D.S uses the sensor to detect hits from the drum. An interruption of the infrared light sensor will be one of the most important aspects when determining if the drum was hit. Another difference would be that the output from the door alarm system is a chime, the output would instead be an L.E.D with the L.U.D.S. Also the sound output would instead be coming from the source of the hit, which would be the drum. Although quite simplistic, Retro-Reflective Photoelectric Sensor Entry Alert System base principles are somewhat Similar to the L.U.D.S.

3.10 LCD displays

Based on the design of this project, there are many variables and numericals that can be displayed on the LCD. These various contents include the type of mode, LED strip light colors, user input BPM, type of flash, velocity, etc. Even though there are multiple of these variables, only two of them will be displayed since those will be fundamentally important for the overall design. These two are the type of mode of the entire system and the BPM that will be set by the user using the rotatable knob.

The type of mode will be metronome or sensing, which will be displayed on the first line. Then, the second line displays the BPM of the light flashes. Rest of the variables will not be ignored but rather shown in a different form physically, such as the light flashes. Based on the design plan, the project requires a LCD display that can display two lines or more. Along with that basic requirement, it should be able to display all numbers and alphabets in both uppercase and lowercase.

There are many available options for the LCD displays, which are analyzed for the best fit for the overall project design. The LCD shown in the image below can display two lines at a time with both characters and numbers. The LCD chosen can only display in monotone meaning that it shows everything in a white font on blue screen, which is also preferred in this case. There is no usage in having to display in color font and it would also make power consumption more efficient. Overall, it should be enough if the LCD has the capability to display just numbers and alphabets in monotone. There are other options available with being able to change the font colors of the individual characters. These kinds of displays also will require extra storage room for the programmed code to be stored.

There are many sizes available for this LCD and the small size chosen for this design requirement. The small size can display a total of 16 characters in one line which is more than the requirement of the project scope. The brand name of the LCD is HiLetgo and the model name is HD44780 which is a display module of DC 5V. Along with all of the specifications, the LCD is also blue backlit, which makes it more visible during the night or dark rooms. For each character in the LCD display, there are a total of 5 x 8 pixels which is a total of forty pixels to be used to display each number or alphabet. Even though there are this many pixels for each of the characters, the numbers and alphabets will be displayed with only 5 x 7 pixels because an odd number seems to make them appear more symmetrical.

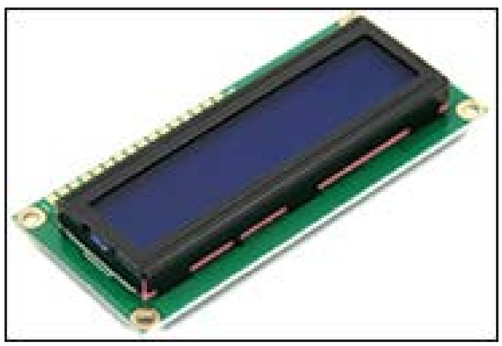


Figure 7 - HiLetgo 16x2 LCD Display Module

Since there are only sixteen characters that could be displayed in one line, the character counts of each word needs to be precise for what will be shown on the LCD based on the user input. The first line has only two options which is the type of mode of the entire system. Basically, the sentence “Mode: Metronome” is 15 characters long and the sentence “Mode: Sensing” is 13 characters. Since both of these sentences are less than 16 characters, the first line should be able to fit perfectly in the LCD with no errors in the code. Both of the options are shown in the example below. The second line should display the beat per minute value set by the user and also the units “bpm” so it can perfectly be displayed as well.

Line 1 - `[Mode: Metronome]` or `[Mode: Sensing]`
Line 2 - `[xxx bpm]`

Since the overall size of the display is small, it only has a total viewing area of 64.5 mm x 16 mm which makes it harder for the user to be viewable from a longer distance. This could only be a minor concern since the user has to stand closer in order to beat the drum and look at the display simultaneously.

Another concern for this LCD is that it doesn't have pin headers, so it cannot be attached to the breadboard. So in this case, the pin headers with 16 slots need to be acquired for attaching the LCD. This will be obtained from the engineering labs so there is no need for purchasing it separately. Also, the pin headers needed to be soldered on the top which makes it attached firmly.

Observing the LCD display, it has 16 pins as mentioned earlier and all of them might not be used. The most important pins are the input voltage pin (VDD) and ground pin (VSS) because the display receives power from these. The next primary pins are the V0, RS, RW, and E. The eight slots from D0 to D7 are all connected with the microcontroller to receive inputs that will be displayed on the LCD. The A and K pins are the 3.3V/5V voltage pin and ground pin, respectively.

Also, there is an LCD display on the microcontroller itself which also has many of the similar quantities as the other available options but it can only display one line and with much smaller amount of pixel density. These are not the only constraints because it can only show certain symbols which is completely unnecessary in this case.

3.11 Battery Options

The UB1208 is a maintenance free rechargeable battery capable of outputting 12 V for 20 hours at 0.04 A. The battery also meets the dimension specification due to its relatively small size. It is concise and small enough to fit within the housing which will be a 6 inch wide, 6 inch tall, and 3 inch deep aluminum box, as specified in section 9.1

Although the UB1208 exceeds all physical design requirements it still wouldn't be the most optimal choice for a battery. The calculations for the maximum average current consumption is located in section X. From those calculations it can be proven that the given battery capacity for the UB1208 would be insufficient. The average max current consumption from all components in the L.U.D system is approximately 2.147 A.

Another more appropriate option would be the BW 1250 recharge battery. The battery boasts a nominal voltage of 12 V and has a capacity of approximately 5 Amp hours. This would allow the system with a current consumption of 2.147 A to run about 2.33 hours. This is a quality amount of time that the system can be powered without being connected to an outlet.

Although the BW 1250 battery allows for prolonged battery use, the dimensions may stop this battery from moving forward. The battery is a sealed lead acid with overall dimensions of 3.54 x 4.21 x 2.76 inches. That would be 3.54 inches in length, 4.21 inches in height and 2.76 inches in width. The housing for this system is six inches wide, six inches tall and 3 inches deep. Therefore the dimension of the battery will be feasible to fit in the estimated sized control box housing.

Additionally the weight that battery provides is a constraint that should be minimized as much as possible. The BW 1250 has an overall weight of 3 pounds. The target engineering requirement as it pertains to weight is less than or equal to 25 pounds. This battery's weight contribution would be about 12 percent of the projected maximum project weight.

Another rechargeable battery option that could be considered is the BW1270F1. This is similar to the other batteries featured above, they all share the same chemistry as a sealed lead acid battery. The BW1270F1 serves as a larger battery capable of extending the portable life of the L.U.D. system drastically. However the increase in battery capacity has a correlating increase in almost every metric besides capacity.

BW1270F1 is able to provide a nominal voltage of 12 V and has a battery capacity of 7 amp hours. With the estimated current consumption to be 2.147 A, the battery would be able to power the device for approximately 3.26 hours. This is the longest amount of time that any of the batteries considered would be able to produce. Although the battery capacity is great the BW1270F1 also boasts the largest dimension of all batteries. It currently sits at 5.94 inches in length, 3.7 inches in height and 2.56 inches in width. The battery is quite sizable and will most likely take a lot of unforeseen space within the control box housing.

The 18650 battery pack from BATTERYINT provides a nominal voltage of 12 V similar to the battery discussed above. It is a lithium battery with a nominal capacity of 6000mAh. The estimated current consumption for the project is approximately 2.147 A. This approximate current consumption would allow the battery life to be about 2 hours and 47 minutes. Compared to other batteries this does not boast the highest nominal capacity and therefore it wouldn’t have the longest battery life. However the 2 hours and 47 mins that the18650 battery pack provides would be more than enough to satisfy the projected span of 2 hours. In addition the battery pack is significantly smaller than the BW1270F1. Therefore the battery would be able to fit within the control box enclosure.

3.12 Voltage Regulators

Voltage regulators serve as a key component within the power supply of any electrical product. Regulators are responsible for efficiently supplying a steady regulated voltage. They're able to regulate both AC and DC voltages to fit whichever design specifications. The L.U.D.S system will only require 2 different voltage regulators. The first regulator will be required to handle an input of 12 V and output a voltage of 3.3 V. The second regulator will be required to convert an input of 3.3 V to -12 V signal.

Texas Instrument offers an excellent program that allows custom requirements for power supply design. That program is called Webench Power Designer and it serves as the primary program to help compare different power supplies. The program even highlighted that a switching regulator may not be the most optimal choice for this project.

In fact the voltage regulator used will be a linear voltage regulator with a buck topology. Switching regulators in comparison with linear regulators have a higher average bill of materials cost. They are more expensive and usually have a more complicated design.

3.13 Power Related Switches

One of the main goals for this project was to have this device be capable of being powered by two different input voltage sources. Specifically one source inputting a regulated DC voltage and the other source inputting an AC voltage. Therefore the L.U.D.S system needs to be able to switch power from the battery pack and from the outlet. In order to do this safely and efficiently, a switch will separate the two distinct incoming voltage sources. The output from the switch, which will be a regulated DC voltage will then be sent to the corresponding voltage regulator and the power amplifier .

There should be three distinct power states or positions for this project. The main two positions will deal with the powered on state for the battery back and AC adapter output, respectively. An AC adapter is necessary due the very nature of the switch. Switches are able to switch from one DC voltage source to an AC voltage,however the voltage received from the voltage regulator and power amplifier must be DC voltage. The final position will be an off position for both the battery and AC adapter. Therefore a two pole three position switch will be an ideal fit for this system.

The switch must be able to interrupt 12V DC coming from the battery and AC adapter, respectively. It should also be small enough to align with the design constraints set for the project. In the effort to make the system more portable and light the switch should be relatively small in size but sizable enough to not interfere with usability. The Baomain Momentary rocker switch is a quality 3 position switch that is worth consideration.

The rocker switch is capable of interrupting voltages higher than 125V AC and has a current rating of at least ten amps. Since the switcher will be interrupting a regulated DC output from both the battery and AC adapter, ensuring the switch can be compatible with interrupting DC voltage is essential. The switch is capable of interrupting and switching positions at 12 V DC which is perfect for the supply voltage used for this system.

Effectively making this switch well suited due to the voltage scope of this system. The switch has a length of 21 mm, a width of 15 mm and a height of 25 mm. As a consequence, the space used at the back of the control box housing will be relatively small. This will help keep the system within its design constraints especially as it pertains to the overall weight. The Baomain Momentary rocker switch also clearly illustrates for the user the three possible positions it has.

Although the Baomain Momentary rocker switch is a solid consideration from a technical and design constraint standpoint, there are still possible issues that may affect this part. The usability of the switch is not the most optimal characteristic that it offers. The rocker switch certainly provides 3 distinct positions, however they may not be pronounced enough to help eliminate user error. Consequently the small nature of this switch could obstruct a user from switching the device to its intended power source.

Similar to the Baomain Momentary rocker switch is the Walfront momentary toggle switch. The toggle switch is a three position on-of-on switch. This switch is able to handle a high operating voltage of 250 V AC. The previous rocker switch also had a high AC operating voltage, however the DC compatibility of the switch was unavailable. Thankfully the Walfront momentary toggle switch allows for an interruption of 12 V DC. This meets with the standards necessary for the switch to operate effectively.

The design of the momentary toggle switch is quite different to the Baomain Momentary rocker switch. Its main switching mechanism utilizes a toggle instead of a rocker. The momentary toggle's dimensions are also much bigger than the rocker switch. In fact the switch has a length of 2.36 inches, a width of 1.26 inches and a height of 0.79 inches. The toggle allows for more pronounced and distinct positions to help aid the user. Protrusion from the toggle switch grants the user more space and usability to distinctly switch between power sources. The switch also efficiently labels the three separate modes the L.U.D.S system will allow.

The A40315RNZQ power switch is somewhat different from the previously discussed switches. It is a rotary switch unlike the momentary toggle or rocker switch. The 2 previous switch designs wouldn't be the best to ensure the easy transition and distinction of the 3 positions. The A40315RNZQ has4 poles and 3 positions. The 4 poles allow for 4 distinct circuits to possibly connect if need be. The switch is rated to interrupt DC voltages ranging up to 125 V. The protrusion from the rotary switch will enable the user to easily switch between the 3 positions.

3.14 User Interface Toggle Switches

The user interface requires four switches to control which modes and features are currently active on the L.U.D.S. device. Each of these four switches have the same basic requirements because they are all just control switches to wire into the MCU. The switches all need to be single pole double throw (SPDT) switches with an on-on configuration. They need to be single pole because they only need to activate one input at a time and they are double throw because they only need two positions, on-on, since they will activate one feature or another feature. This section will show the research done on some of the potential switches that could be used for this project.

Option 1: One option is the (SPDT) switch from TEConectivity part number "3-1825136-7". This is a toggle switch with a long baton toggle switch with through hole mounting. It has a 5A contact rating with 10mΩ contact resistance. It is rated for up to 28V DC which is well above the voltage needed for an input into a microcontroller. This switch would easily be mounted onto the aluminum frame of the control box because of its 0.28 inch through hole mounting with a screw on nut. The main drawback of this switch is the price. This switch costs $8.68 per unit, and considering the L.U.D.S. needs four switches, that would add a significant cost to the project. A lifetime cycle rating could not be found on the device datasheet.

Option 2: Another option is the 100SP1T1B1M1QEH switch from Digikey Electronics. This is another SPDT toggle switch but with panel mounting. It has the same 28V DC voltage rating and 5A current rating. It would also be very easy to mount to the control box. This switch has a couple benefits that the above switch does not. This switch costs only $2.88 per unit, almost a quarter of the price of the other switch. This switch also has an electrical lifetime rating which was not found in the datasheet for the above switch. This switch has a lifetime rating of 20,000 cycles meaning it can be used for a long time before its electrical capability breaks.

3.15 Rotary Encoders

Since the knob controlled inputs into the MCU are digital and don't necessarily need max and minimum stopping points, the best knob type for the L.U.D.S. are rotary encoders because they have a full 360 degree turn radius while potentiometers only have a 270 degree turn radius. Because the inputs just need to know which direction the knob is turning but does not need to know the exact position of the knob, this project is going to use incremental encoders instead of absolute encoders. The encoders don't need high resolution so the L.U.D.S. just needs to use encoders with 2-bit quadrature. Below is a list of different rotary encoder options that might work for this project.

Option 1: One option is the PEC11R Series 12 mm Incremental Encoder from Bourne Pro Audio Electronics. This encoder uses 2-bit quadrature, has a contact rating of 10mA at 5VDC, and has a max operating RPM at 60. It has a pushbutton capability which may come in handy in case a need for a button arises during the prototyping phase of the project. The rotational lifetime is 30,000 cycles and the pushbutton switch lifetime is 20,000 cycles. The datasheet for this encoder also has a recommended filter circuit which will help with the design of the circuit to connect the encoders to the MCU. Some users of this device have reported some contact noise even with the recommended noise filter so some design will still be required for the filter circuit. This circuit costs $4.50 per unit which is a midrange price point for an encoder.

Option 2: A second option is the ACZ11BR1E-20FD1-12C from CUI Devices found on DigiKey Electronics. This encoder has a 2-bit quadrature square wave output, 10mA 5VDC current and voltage rating, and max operating RPM of 60. This encoder also has a push button switch built-in to the device. This encoder has a longer lifetime than the above option with a push button lifetime of 50,000 cycles and a rotational lifetime of 30,000 cycles. This encoder is also a bit cheaper than the above option at only $3.58 per unit.

4. Project Related Standards and Realistic Design Constraints

4.1 Standards

Standards are a set of practices, methods or operations that help promote reliability and safety. They help establish technical requirements and specifications while promoting public safety and ensuring an efficient product. Manufacturers and developers look to standards to provide reliable instruction when fabricating a product. Negligence of the numerous standards and criterion could lead to significant liabilities and possibly a violation of public safety. There are numerous standards and government regulations that need to be considered before designing the L.U.D.S. Standards

Numerous standards from IEEE will be considered when designing the L.U.D.S, especially due to the amount of electrical components. A lack of scrutiny could lead to a serious hazardous environment. Standards for the power supply, battery and microelectronics will be considered.

The safety standard for long term exposure IR LEDs, or greater than 1000 seconds, is that the LED must have an intensity 100 W/m^2 when the observer is 200 mm away from the light. The IR LEDs fall well below this standard, only having power in the milliwatt range. It is still best to avoid looking at the LEDs directly, as they will be exposed with the beam break sensors, but should not present a safety issue.

The wall outlet or AC Adapter has to follow the safety standards set by UL or Underwriters Laboratories. UL is responsible for helping to mitigate injury and risk by highlighting the process through standards. They have created a variety of safety standards since 1903. The UL 60950-1 standard deals with electrical equipment not exceeding a level of 600 V. The AC adapter chosen has a high rated voltage that falls well below the standards established limit.

Another standard set by the UL is the UL 817. This standard deals with power supply cords and other cord sets considered. All cords considered will have a max rating of 600 V. In addition the cord's intended environment should be non -hazardous. The AC adapter chosen is in accordance with standard, as there will be no foreseen hazardous environment for the L.U.D system to premiere at in the future.

The UL 1310 standard deals with the categorization of class 2 power supplies. Class 2 has a maximum current output of 8 amps and a maximum voltage output of 30 V DC. The AC adapter for this project will have a maximum output voltage of 12 V supplying a maximum of 4 amps to the system. The adapter falls within the classification of a class 2 power supply while not violating the standard set.

4.2 Realistic Design Constraints

There are different factors that constrain what the team can actually do with the LUDS project. These limitations are imposed by either the stakeholders or society at large, but either way are mostly out of the team's control. These limitations include the timeframe of the project, access to resources, and adherence to certain guidelines to ensure the project has a positive impact on society.

4.2.1 Economic, Time, and Budget Constraints

- The overall project design and construction is required to be completed within approximately a time period of eight months, which is about two semesters (Fall 2022 and Spring 2023).
- For the time allotted, the project concept/design cannot be too long or short so from the development of the overall project topic until the demonstration of the project could be scheduled much simpler.
- 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 due to the budget limitation.
- The unavailability of the components can also delay the construction of the overall hardware design.
- Acquired materials could have manufacturing defects such as malfunctions which could emit incorrect outputs to the LEDs and the LCD display.
- Software design requires coding for each individual part of the design and should take the most amount of the allotted time for the overall construction.

4.2.2 Environmental, Social, and Political Constraints

- 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 destructive.

- Socially, the people involved in this project and others watching during the demonstration should need to agree for testing of the final product because design could be agreeable only by certain individuals.
- The design of the product including both the hardware and the software part should not contain any materials that others might believe to be offensive.

4.2.3 Ethical, Health, and Safety Constraints

- 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.

4.2.4 Manufacturability and Sustainability Constraints

- 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.

5. Project Hardware and Software Design Details

5.1 Hardware Design and Role of Team Members

Moving through the LUDS linearly, first comes the power supply. There will be two options for power supply: a battery pack and cord that can be plugged into a wall outlet with an AC/DC transformer. The power supplies feed into the PCB. The PCB is controlled with a series of switches and knobs that will determine the LUDS's current function.

The first input is a switch that changes the LUDS between its two primary modes. These are the default presentation mode for performing and metronome mode for practicing. There will be a third setting on this switch that activates polyrhythm mode, a more advanced metronome mode.

The next two inputs are for customizing performance mode. They are switches that change how the LEDs behave when reacting to drum hits. FIrst comes the “flash or fade” switch, which determines how fast the LEDs turn back off when the drum is hit. The default will have the LEDs quickly flash, but they can be set to slowly fade off to better fit with slower or quieter songs. Next is a switch to change the LEDs so that they will be left idle when no notes are being played. They will rest in a dimmed state, allowing the drum to always be visually engaging at the cost of more power.

The following set of inputs are customization options for metronome and polyrhythm mode. Chief among these is the knob that changes the BPM of the metronome mode. The BPM is what the entire metronome function is built around and dictates how fast the LEDs will flash. The other two knobs will set different time signatures, one for the main rhythm and another for the polyrhythm, which are both mainly used in polyrhythm mode.

The final set of inputs is the IR sensor array. This is how the drum reacts to hits in presentation mode. The reflectance sensors under the drum sense the vibration of the drum skin during each hit, sending a signal to the PCB to flash the LEDs on. The beam break sensors above the drum are used so the PCB knows how brightly to flash the LEDs.

With all these inputs going into the PCB, the PCB determined the output. By knowing when and how often the LEDs should be on, it can send a signal to tell the LEDs how they should light up. The outgoing signal goes through an amplifier to make sure it has enough power to activate all the LEDs. With the signal amplified, the LEDs flash and the whole process repeats. Figure 8 below shows the project design block diagram.

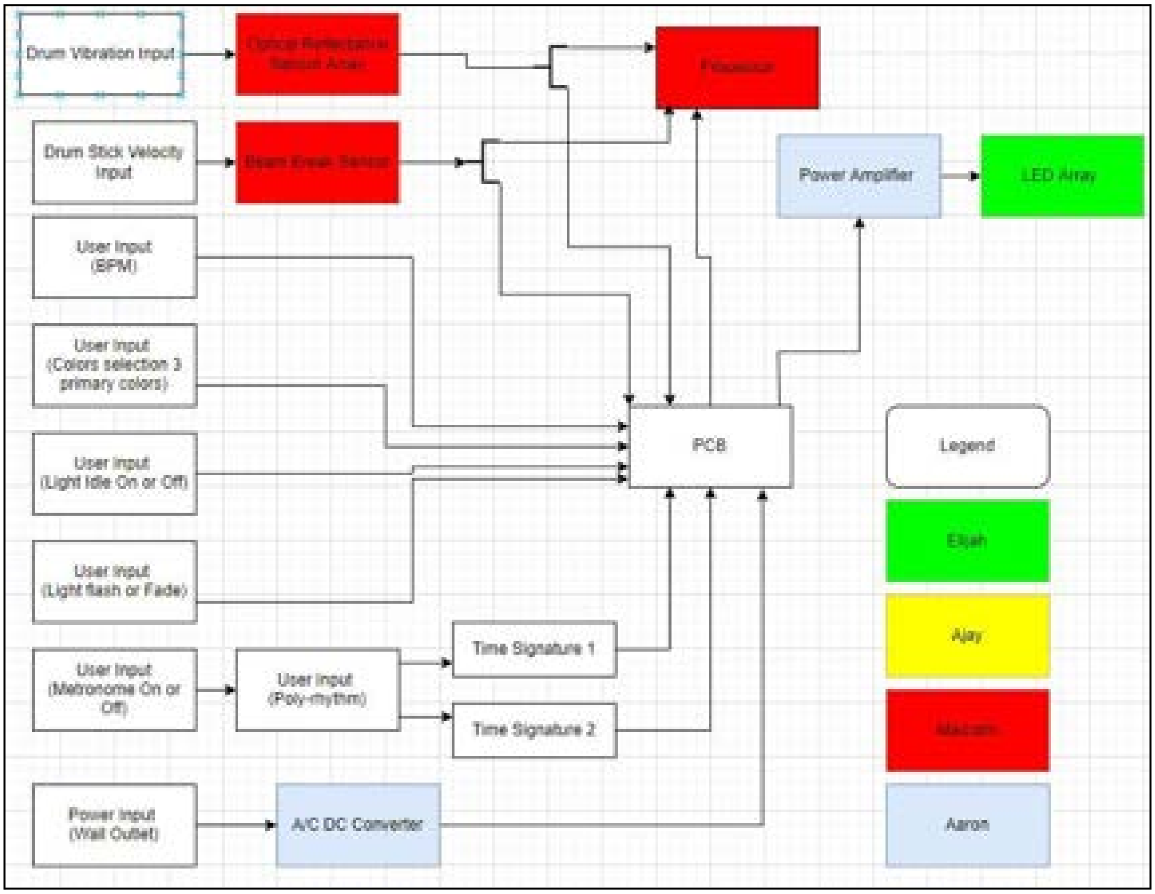


Figure 8 - Project Design Block Diagram

5.2 Software and Control Interface Design

The below diagram shows the wide scope logic flow of the user control interface for the project device. The user interface is part of the housing of the device where all non-peripheral parts will be placed. All inputs, excluding the infrared sensor's output and the battery, are switches and knobs that will be controlled by the user of the device. The author in charge of each block is also in charge of the inputs leading into each block. If the input flows into blocks of two different authors, then both authors will collaborate on the design of the inputs. Details of the design of each block in the diagram are explained in the rest of this section. Figure 9 below shows the user interface block diagram.

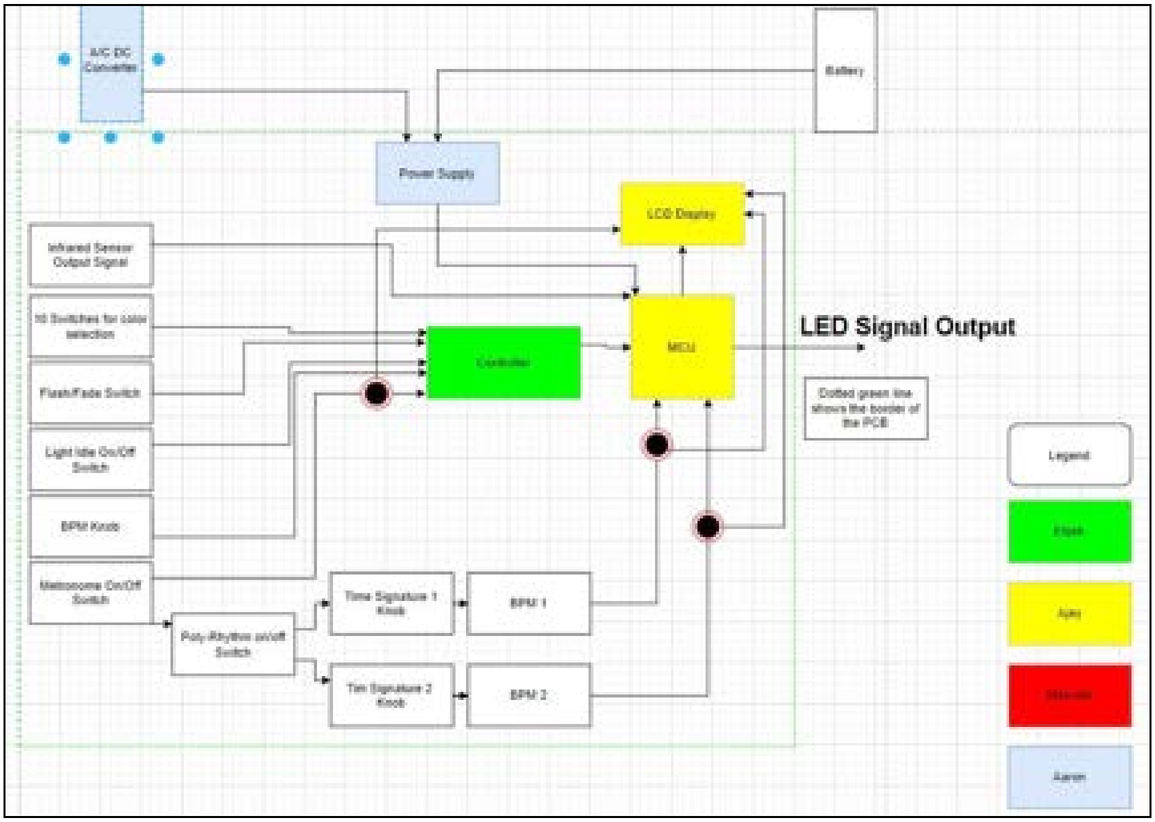


Figure 9 - User Interface Block Diagram

5.3 Description of Typical 7" Radius Snare Drum

Most drums are composed of a few basic components. From the bottom up, there is the stand that holds the drum up, the bottom rim, then the bottom drum head (also known as the bottom skin), the shell, the top drum head, and the top rim. Other, less integral parts include the fasteners that hold it all together and allow the drum to be tuned, the snare switch, and snare, and air pressure hole. Figure 10 below shows a diagram of a snare drum with each of the parts labeled.

Figure 10 - Snare Drum Head Assembly Diagram (Figure Created using copyright free image from https://www.pexels.com/ and Microsoft Paint 3D)

5.4 LED Array

This section covers the details of the LED array design. The LED array is the LED strip that will light up inside the drum head in which the L.U.D.S. is attached. The MCU will output a voltage signal whenever the LEd is supposed to light up. That signal will move through a voltage amplifier, into a color/dimming control module, and to the LED strip. Parts of the LED design include the general attachment method, LED integration, LED strip amplifier, LED Strip Amplifier Resistors, LED color and dimming control, and information on the individual LEDs on the LED strip. In all, this section covers everything about the LED array design from the luminous output of the LEDs up to but not including the MCU output signal. All parts mentioned in this section are listed in Chapter 3: Research Related to the Project Topic.

5.4.1 General details and attachment method

The LED strip this project uses is the “Non-Waterproof IP20 LED Flex Strip” from LEDSupply.com part number: R6060-IP20-RGB-06. This part is chosen because it meets all of the design specifications and constraints from section

5.4.2 LED Integration

According to the manufacturer of the LEDs, it is unsafe to have LEDs pointing at the user’s eyes so the part chosen is not side-emitting but has more LEDs and lumens per meter so the light will still shine bright enough to be seen from forty feet away. This LED strip is 10mm wide and 2mm tall allowing ample room for the sensors and wires to still be placed in the drum. The individual LEDs the strip uses are 5050 emitters. Since the project requires a 44 inch long strip, the strip purchased will be the 6 foot long version and will be cut down to the appropriate size. According to the product details, the LED strip can be cut every 2 inches allowing the strip to be cut to a size of 43 to 45 inches long. This ±1 inch of freedom can make up for any minor imperfections in the placement of the LED strip. The strip's double sided adhesive will be adhered to the inside of the drum's shell directly below the top rim. Wires will need a route to run from the controller to the LEDs. While the drum will already have an air pressure hole in the side, it must not be obstructed so the air pressure can still be regulated. Thus, a second hole must be drilled in the drum shell. This hole can also act as a path for the wires from infra-red sensors to the controller.

5.4.3 LED strip power

The 12V strip is powered via a 6 inch wire harness with a male 2.1mm plug. To connect this plug to the controller, a 2.1mm extension cable will run from the LED strip to a 2.1mm power plug pigtail cable. The loose wires of the pigtail cable will then be soldered to the outputs on a dimming module (see section 8.3). The input wires of the dimming module will then be soldered to a male pigtail connector that can be plugged into the L.U.D.S. controller. The maximum power needed to supply the strip is 4.8W per foot. So at 44" (or 3.67 feet) the strip needs 17.62W of power. This means the strip will need 1.46A of current. The controller uses an MSP430-fr6989 MCU which, according to the device datasheet, has an output voltage from 0 to 3.3V. Since the LED strip is powered with 0 to 12V, an amplifier must be used to amplify the voltage range to match the LED strip. To accomplish this, the device will use a TL084CN operational amplifier configured in a non-inverting circuit. The input to the amplifier circuit will be the output of the MCU. The output of the amplifier circuit will be a female 2.1mm plug mounted on the controller which can be plugged in by the male pigtail cable leading from the dimming module. The amplifier must have a max gain of 3.6. The gain of an amplifier is determined by one plus the ratio of R2 to R1 so R1 will be 2.6KΩ and R2 will be 1KΩ. Since the input signal to the amplifier will be a digital DC voltage, the frequency attenuation/gain does not affect the behavior of the amplifier. The amplifier calculations are shown below in equations 8 through 11. The amplifier configuration is shown below in figure 11.

$$LED\ Power\ and\ Operational\ Amplifier\ Calculations$$
$$V = Voltage\ Required = 12V$$
$$V_s = Voltage\ Supplied = 3.3V$$
$$A = Gain$$
$$P = Power\ per\ Foot = 4.8W/ft$$
$$I = Current\ Required$$

$$L = Length\, of\, LED\, Strip = 44" = 3.67ft$$

$$P_T = Total\, Power = P \times L = 3.67ft \times 4.8W/ft = 17.62W \quad (8)$$

$$I = P_T \div V = 17.62W \div 12V = 1.46A \quad (9)$$

$$A = \frac{V}{V_s} = \frac{12V}{3.3V} = 3.6 \quad (10)$$

$$A = 1 + \frac{R1}{R2};\ R1 = 2.6k\Omega;\ R2 = 1k\Omega \quad (11)$$

Above the calculation are the constants derived from the LED strip and MCU data sheets. Equation (8) takes the known power per foot and the length of the LED strip to find the total power required to bring the LEDs to full brightness. Equation (9) calculates the current needed to supply that power using the total power and the voltage required. Equation (10) uses the ratio of the required voltage to the supplied voltage to calculate the required gain on the amplifier. Finally, equation (11) calculates the values of R1 and R2 by using the characteristic equation of a non-inverting operational voltage amplifier configuration. This amplifier's positive rail will be powered by the device's main power supply and the negative rail will be powered by the device's buck booster circuit.

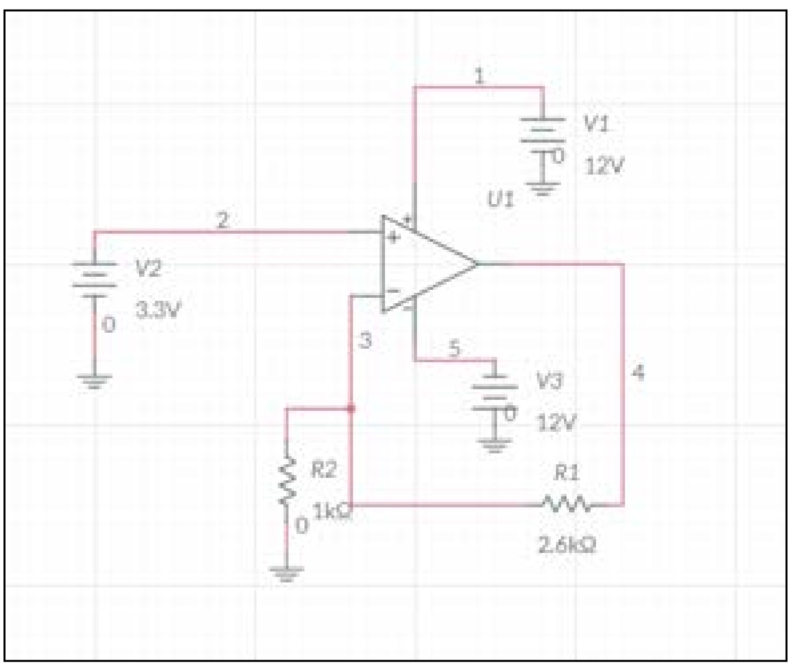


Figure 11 - LED Power Operational amplifier configuration (Figure Created using Multisim Live)

5.4.4 LED Strip Amplifier Resistors

It is recommended to use resistors with power rating equal to at least twice the max dissipation power of the resistor. R1 has a max voltage of 3.599V and R2 has max voltage of 8.3861V. The dissipation power of each resistor ($P = V^2 / R$) will be 0.013W and 0.07W respectively. This means that resistors R1 and R2 must have power ratings of at least 0.026W and 0.14W respectively. Using these parameters and the search function on digikey website, the exact resistors are as follows: Resistor R1 will be the RC0402JR-071KL, 1KΩ, 0.063W, 1.00mm x 0.50mm, surface mounted, 5% tolerant, thick film resistor. R2 will be the RM04F2601CT, 2.6KΩ, 0.0625W, 1.00mm x 0.50mm, surface mounted, thin film resistor. It is important to note that both of these resistors are currently in-stock at digikey electronics.

5.4.5 LED Color and Dimming Control

Instead of providing color selection options via the main L.U.D.S. controller, the device will use a LED Flex Strip - RGB Controller (Part number DIMMER-3CH). The RGB controller is a dimming module that will be placed between the operational amplifier and the LED strip. The dimming module has its own LED remote that will provide the user with sixteen color options along with flash, fade, strobe, and smooth features. The remote also has features for customizable colors, expanding the color palette greatly. It should be noted that these flash, fade, strobe, and smooth features can be used as the user desires but will be separate from the flash and fade features of the L.U.D.S., as they will not be programmed to oscillate at the same rhythm as the selected BPM by the user. The dimming module uses a 12V power input and a 6A maximum current input which will be supplied by the L.U.D.S. power supply via a 5/2.1mm Center Positive Barrel Plug Connection that will plug into the female barrel plug coming from the operational amplifier. The LED strip signal for the dimming module uses a 4-wire RGB output that will be connected, via soldering, to the 4-pin RGB input to the LED strips. The dimming module is 50mm X 35mm X 22mm in size and will be mounted to the inside of the L.U.D.S controller housing to reduce the number of loose parts of the device and increase the portability. The dimming module will be mounted via a strong adhesive glue. The dimming module can power up to 10 meters of led strips which is more than required by the L.U.D.S.. The module has an operating temperature of -20℃ to 60℃ which is well within the expected operating temperature. The dimmer’s infra-red color/feature selecting remote uses CR2025 Coin Cell Batteries.

5.4.6 Individual LED information

The individual LEDs the Non-Waterproof IP20 LED Flex Strip uses are SMD 5050 RGB emitters. The datasheet for these LEDs states that the emitters are high efficiency but do not specify the percent efficiency. Investigating other LEDs, most modern LEDs are 85% efficient. This means 85% of the power is used transformed into light while the remaining 15% of power is dissipated as heat. With the LEDs using 17.62W of power, only 2.642W is dissipated as heat which is an insignificant amount and will not overheat the inside of the drum head. The I-V curves, found in the SMD 5050 RGB LED datasheet, have a linear response. Knowing that LED luminosity is linearly proportional to the current, the LEDs will be able to vary in luminosity provided a varying voltage level of the power sources. This allows the LEDs to light up brighter when the IR sensors detect a drum strike with more velocity and light up less when the sensors detect a strike with lower velocity. Any changes in voltage needed in order to tune the luminosity such that the LEDs light level is matched with the drum strike velocity can be later accomplished within the programming of the MCU.

5.5 Control Box Details

The L.U.D.S.'s control box is the housing box that contains all the different computational parts, control parts (buttons and switches), and any loose parts that must be contained in a uniform location so the device does not have any unnecessary loose parts. This section covers the details of the box itself, the knobs, the buttons, and ports that will be used to connect components that are located outside the box to the inside of the box. These details include the dimensions of components, the part numbers, the voltage, current and temperature ratings of the components, and the circuit designs used to interface the components with the MCU. A picture of the control box from the completed design can be seen below in figure 12.

5.5.1 Housing Details

The L.U.D.S.'s PCB, LCD display, battery, buttons, switches, and dimmer module must have a box housing to keep the components compact and easy to handle. This housing will be a 7.87 x 4.72 x 2.95 inch ABS box purchased from amazon.com. (In the original design, the housing was going to be made out of an aluminum box fabricated by "CFL Metal Works" but unfortunately the contact who offered the sponsorship left the company before being able to deliver on the housing.) The left and right sides of the housing will have small 1/8th inch holes to allow the escape of heat. The control box is expected to be placed on a music stand and placed near a drum kit. The control box will also have a metal tab that can be attached to the box via four 1/4 inch bolts on the bottom of the box sticking out 2 inches with a 5/8 inch hole so the box can also be secured to a standard microphone stand with a microphone clip. The LCD display, feature knobs, and feature switches will be placed and labeled on the top side of the box. The back of the box will have a through mounted 2.1mm female plug for the LED power cable and a second plug for the sensor cables, and a third plug for power coming from the wall outlet. The LED dimming module, PCB, and battery will be arranged inside the control box in a manner that will not block the heat vents on the side of the box.

Figure 12 - Picture of control box / housing from completed project

5.5.2 Switches

The four switches used for the control box will be 2-position toggle switches (part number 1-1825136-7). These switches are through hole mounted and will attach to the control box via 0.28 inch holes drilled in the surface of the box. The switches are rated for 28VDC and 5A contact current. They are single pole, double throw switches (on-on). Double throw was chosen because the switch will activate one feature or another and do not need an “off” position. They have a 10mΩ contact resistance which should be negligible for our purposes. The switch also has a 6,000 cycle electrical lifespan. The contact base material is copper which will allow for the parts to be soldered to wires leading to the PCB. The figure below (figure 12) shows the pin functionality of this switch. These switches will be connected to the input pins of the MCU to indicate when each feature will be active at a given time.

Switch Purpose	Function
System Mode	To change metronome or sensing mode
Light Idle on/off	To have light dimly on or off in sensing mode (Not implemented in final design)
Flash or Fade	To make LED flash or fade for each drum beat (Not implemented in final design)
Power	To switch on or off the entire system

Table 23 - Breakdown of switches and functions

5.5.3 Switch Circuit Designs

The toggle switches will be connected to digital input pins on the L.U.D.S. MCU. Because of this, they require pull resistors to prevent the pins from turning into “floating pins” that fluctuate between on and off. According to the MSP430FR6989 datasheet, the threshold for reading a high input, Vit+, is between 1.65V and 2.25V. The threshold for reading a low input, Vit-, is between 0.75V and 1.35V. The datasheet also provides a typical pull resistor resistance of 35KΩ. This information is used to design the switch circuit below is figure 13. In the circuit diagram, DI1 and DI2 represent example digital input pins of the MSP430FR6989.

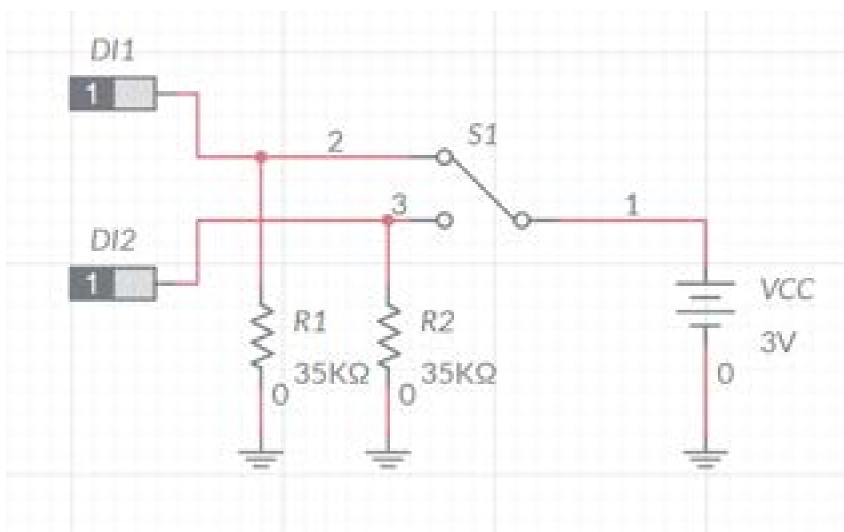


Figure 13 - On-On toggle switch design with pull down resistor

The resistors used in the toggle switch circuit will be the RC0402FR-0735KL 0402 resistor from YAGEO on digikey. This resistor is chosen because of its low power consumption of 1/16W, its affordable price of 10 cents per unit, and its current availability. The resistor is 35KΩ with a tolerance of ±1%. The operating temperature is -55° to 155° celsius, well within the operating range of the L.U.D.S. device. The resistors are surface mounted and made of moisture resistance thick film.

5.5.4 Knobs

The L.U.D.S. has a number of features with a wide variability of input that will require seven knobs to control. Because of this wide variability, the knobs used to control these parameters need to be rotary encoders. These rotary encoders will be connected to input pins to the MCU to tell it when to raise or lower certain parameters. When the MCU detects a change in these parameters, it will display the numerical change on the L.U.D.S. LCD display. The part chosen for the rotary encoders is the PEC11R Series - 12 mm Incremental Encoder. An incremental encoder is used because the L.U.D.S. will need signals telling it if a parameter is changing in one direction or another but does not need to know the number of rotations or the current position of the encoder. These incremental encoders function with 2-bit quadrature code output to be read by the MCU (see figure 15 below for quadrature output table). They have a 360 degree turning radius allowing the wide variability in input while also having discrete positioning so the output can also be discrete. They have a contact rating of 10mA and 5VDC. The operating and storage temperature ranges are -40 to +70 degrees celsius, well within the range of use for the L.U.D.S. device. Because encoders often create contact noise while being operated, the design will require an RC noise filter to ensure the MCU does not pick up unwanted noise from the signal.

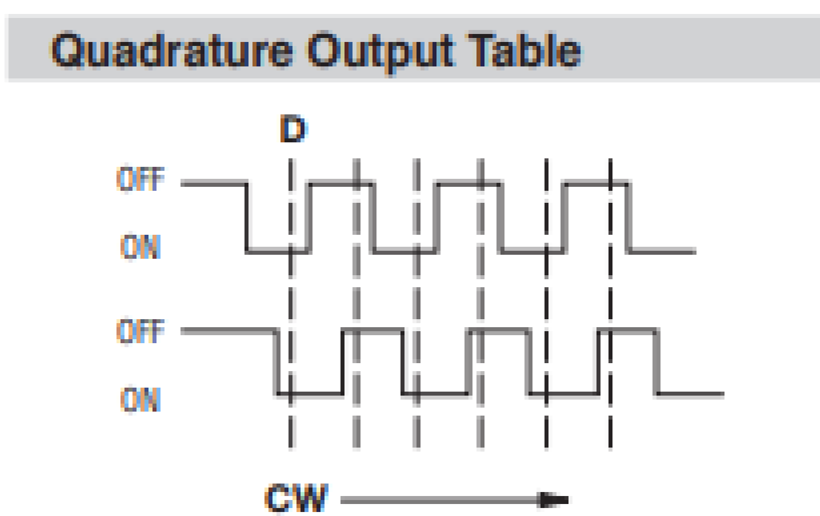


Figure 14 - PEC11R Series - 12 mm Incremental Encoder quadrature output table (From device data sheet)

Knob Purpose	Function
BPM	To change the beats per minute in metronome mode
Time signature	Difference between the brightness of first flash and rest of the flashes (Not implemented in final design)
Time to Flash or Fade	The time in seconds for flash or fade (Not implemented in final design)

Table 24 - Breakdown of knobs and functions

5.5.5 Rotary Encoder RC Filter Circuit Designs

When a rotary encoder moves, it often creates contact noise on the rising and falling edges. This requires two RC filter circuits to smooth out waveforms by preventing current flow while the capacitors are charging. The datasheet for the PEC11R Series encoder has a suggested filter circuit shown below in figure 15. This suggested filter will serve a base for the design of the circuit, although a few changes may be necessary. The 5V DC terminal must be replaced with the 3V VCC terminal of the MSP430FR6989 microcontroller used in this project.

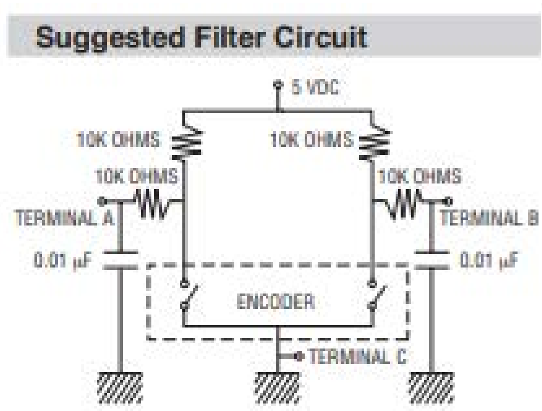


Figure 15 - PEC11R Series - 12 mm Incremental Encoder Suggested Filter Circuit (From device data sheet)

Many reviews of the PEC11 series encoders have expressed that the encoders have a more consistent signal if the amperage moving through the contact is closer to the 10mA rating. To achieve this, the resisters in the actual filter circuit will be equal to about 300Ω. This change in resistance will account for both the change in amperage and the change in the VCC voltage. Terminals A and B will be connected to digital input pins on the MCU and terminal C will be connected to the MCU ground. Below, figure 16 shows the actual filter design that will be implemented into the L.U.D.S. device. In the case that this design does not work during the testing phase of the project, the original suggested design will be tested.

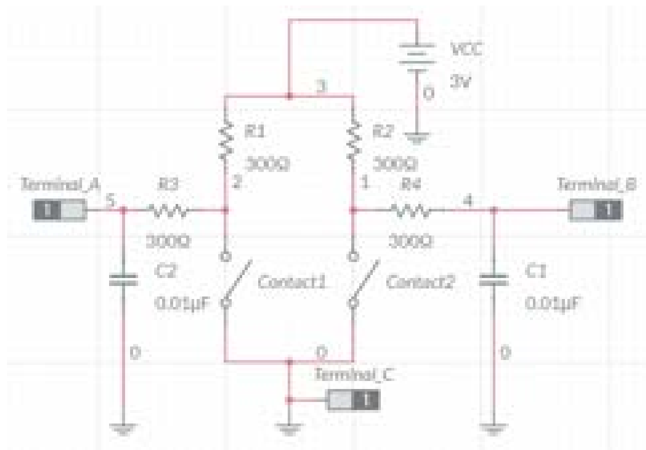


Figure 16 - PEC11R Series - 12 mm Incremental Encoder Filter Circuit Design (Created using MultisimLive circuit simulation software)

The resisters used in the encoder RC filter circuits need to be 300Ω with a small tolerance of ±1%. The resistor chosen for these circuits is the RC0402FR-07300RL resistor made by YAGEO and found of digikey. The resistors are surface mounted and made of moisture resistance thick film. They belong to the 0402 package which is important because the small size will save room on the PCB. They have a low power consumption of 1/16W and operating temperature of -55° to 155° celsius, well within the operating range of the L.U.D.S. device.

5.5.6 USB Port

The control box must have a female USB-A port in order for replay data collected by the microcontroller, using the infrared sensors, to be transferred to a computer. As stated before, the USB port will be located on the backside of the control box so all the connecting cables are located in the same place. The USB port chosen is the USB1046-GF-0190-L-B-A from GCT on mouser electronics. This port is a USB-A 2.0 receptacle with 4 pins on the back for power supply and data transfer. One pin will be wired to the ground on the microcontroller unit, one pin is used for power supply which will be supplied by the host device and will not need to be connected to the PCB, and the remaining two pins are the data transfer pins which will be wired to the micrcontroller's digital input/output pins through pull-down resistor filter circuit. All connections will be tested using a breadboard and implemented via soldering. The design for the pull-down resistor filter circuit is shown below in figure 17.

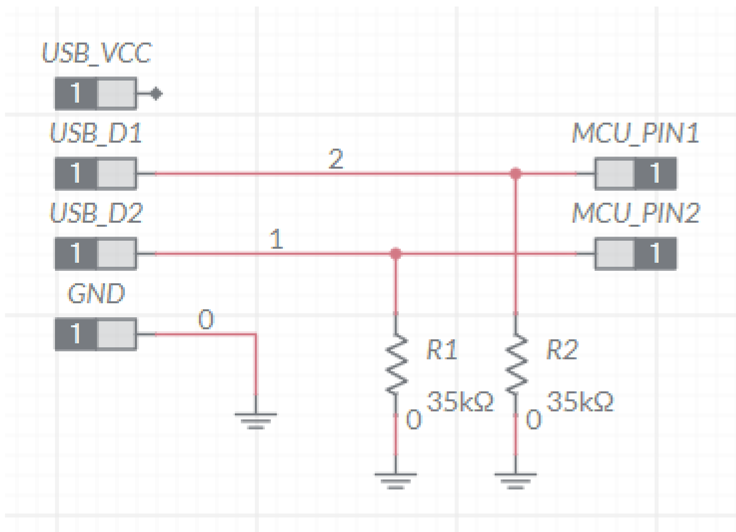


Figure 17 - Pull-down resistor circuit to connect USB port to MCU (Created using MultisimLive circuit simulation software)

5.6 Sensor Array

The array of IR sensors are the key to many of the LUDS most unique features. They are what allow presentation mode to create dynamic performances, which is the biggest draw of the system on a surface level. By combining two different types of sensors it not only detects drum hits but also where the drum is hit and how hard, which further increases the dynamism of presentation mode. This data is also stored as replay data and could be used to generate different types of recreations of performances, such as MIDI files or automated light shows.

5.6.1 Reflectance Sensors

The first set of sensors in the array are Onsemi QRE1113 analog reflectance sensors. These sensors will detect both when and where the drum is hit. Six of these sensors will be placed in a ring, which will be suspended just under the head of the drum. The QRE1113 is designed to work at a very short range of about 3mm. The power input voltage can be between 3.3 and 5 volts and the phototransistor outputs a current of 100 nanoamps when activated. Janis Sokolovskis and Andrew P. McPherson used this method when testing how to track the location of drum strikes. The drum they used can be seen below in figure 19, though the ring in the LUDS will likely have to be smaller than the one they constructed so as to not interfere with the sound quality of the drum.

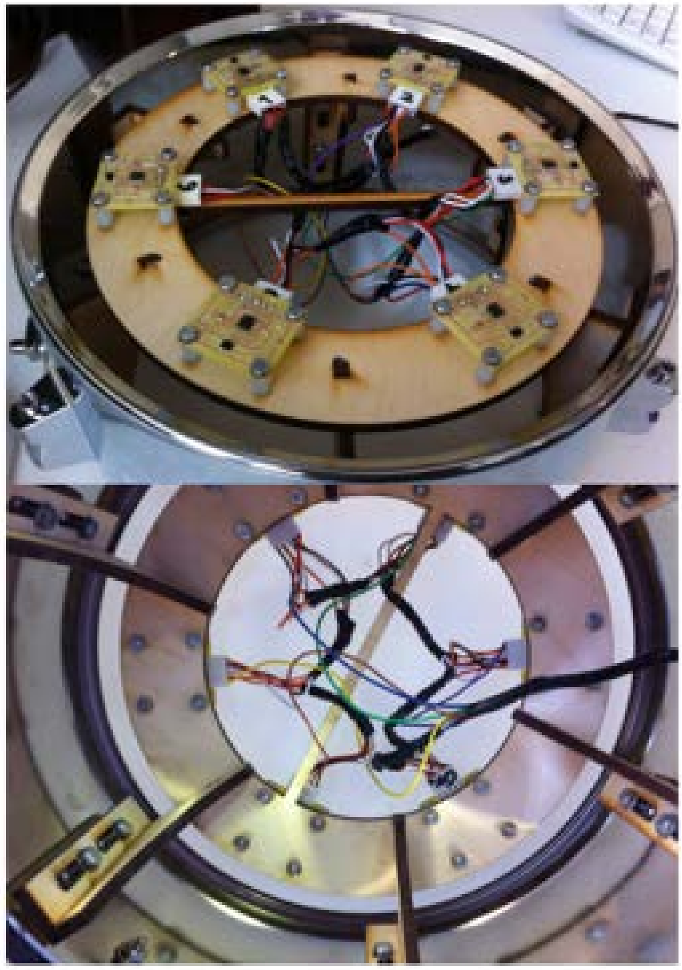


Figure 18 - Sokolovskis and McPherson's drum pictured from above with no skin (top) and below (bottom)

The sensor works by projecting an IR beam from an LED, which is reflected into a phototransistor immediately next to the LED. The range on the sensor is so small because it is so compact. As shown below in figure 19, the sensor can be placed at the right height so that, when at rest, the IR light will not reflect into the photodetector, but the deformation of the drum skin activates the sensor. This is how Sokolovskis and McPherson set up their sensors, but the LUDS will have a slightly different set up, shown in figure 20.

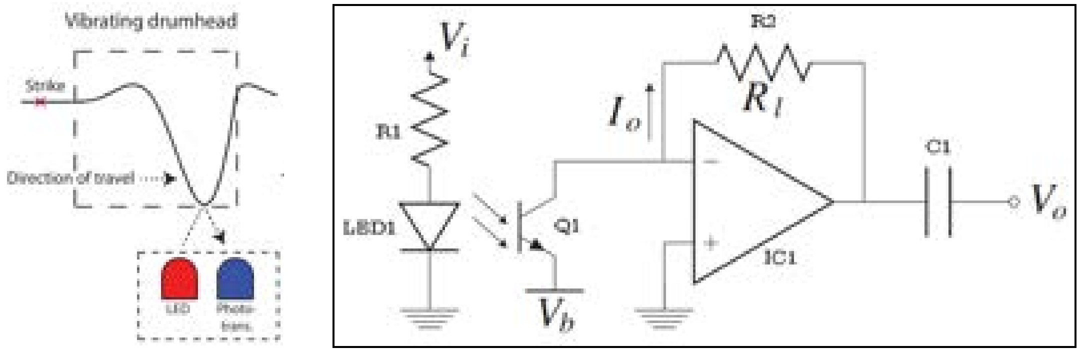


Figure 19 - Interaction between Sokolovskis and McPherson's drum head and IR sensors (left) and QRE1113 optical reflectance sensor (right)

$$V_o = - I_o * R_l \quad (12)$$

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 19, 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 (12).

Figure 20 - Diagram of the LUDS's optical design (left) and close up of a reflectance sensor (right)

The configuration differs from Sokolovskis and McPherson’s due to the drums in the LUDS potentially not deforming enough to make their model feasible while maintaining sound quality. The threshold for how large a vibration triggers the sensors will have to be tested and a filter may have to be implemented to stop the LUDS from being over sensitive.

5.6.2 Digital Beam Break Sensors

The other aspect of the sensor array is a set of beam break sensors which will track how hard the drum is hit. These sensors will be constructed of 12 units, six OPB100-EZ LEDs and six OPB100-SZ IR detectors placed opposite each other. The arrangement of the LED and detectors is shown in figure 21. These sensors work fundamentally in the same way as the reflectance sensor, with the beam from the LED being detected by a phototransistor, though on a larger scale. Besides the scale, the biggest difference between the reflectance and beam break sensors is that these detectors only have to detect if the light is on or off, meaning they can be digital sensors and don’t need to be routed through an ADC.

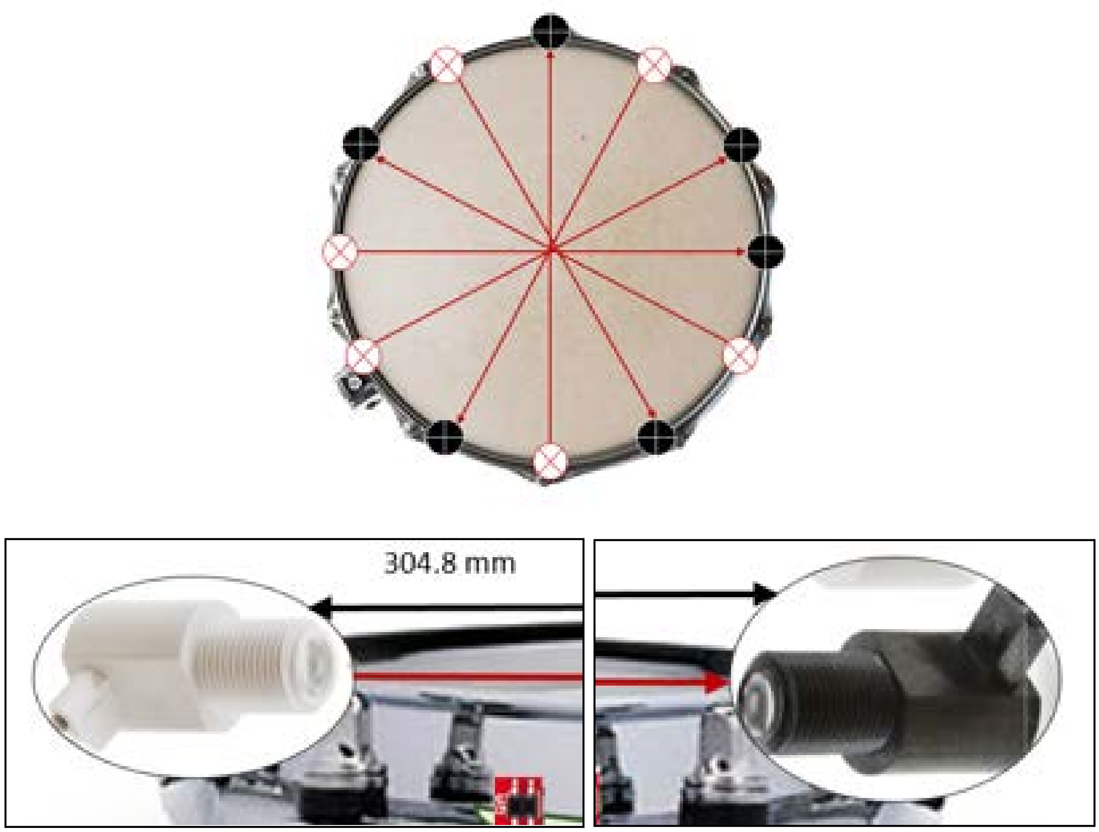


Figure 21 - Diagram of beam break sensor array formed of emitters (white) and detectors (black), with both an overhead view (top) and profile (bottom)

The beams will cross the drum, though since they don't cover every point, it is possible that some strikes will not be detected by these sensors. However, with six beams, it seems unlikely that the majority of the strikes will not be detected because the ideal place to hit a drum is usually closer to the center where the beams are closely grouped together. Since the possibility does still exist, there will need to be a backup solution for if these sensors miss any strikes.

The special design of the OPB856 will allow it to be more easily mounted on the side of the drum and close the gap between the emitter and detector. Of the sensors listed in section 3, they are really the only effective sensors for this array.

5.6.3 Replay Data Collection

The primary calculation the LUDS will prefrome to generate replay data is with the time difference of arrival calculation. Sokolovskis and McPherson also used this method to calculate position in their experiment and were able to place the origin of the sound wave within 2 mm of the contract point using time differences of arrival or TDOA calculations. TDOA is a method of positional tracking that pinpoints locations by measuring the difference between how long it took for a wave or object to reach two fixed points.

$$\sqrt{(x_t - x_1)^2 + (y_t - y_1)^2} - \sqrt{(x_t - x_2)^2 + (y_t - y_2)^2} = c(t_1 - t_2) \qquad (13)$$

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 to recreate a performance on the LUDS as a MIDI file.

Referring back to equation 13, there will need to be six variants of this equation to properly calculate the position. Each equation will find the time difference between a sensor, n, and the sensor immediately next to it going clockwise, n+1, giving a revised equation of show in figure 14.

$$S_{n,n+1} = \sqrt{(x_t - x_n)^2 + (y_t - y_n)^2} - \sqrt{(x_t - x_{n+1})^2 + (y_t - y_{n+1})^2} = c(t_n - t_{n+1}) \quad (14)$$

$$x_n = r * cos(\theta_n),\ x_{n+1} = x_n + 60^o \quad (15)$$

$$y_n = r * sin(\theta_n),\ y_{n+1} = y_n + 60^o \quad (16)$$

$$c = \frac{2\pi rf}{2.045} \quad (17)$$

This pattern will hold true until sensor six, since there is no seventh sensor, the TDOA will be calculated with sensor one. The speed of the sound wave in the drum, c, is currently an unknown factor, but there are several methods of solving for this variable. The equations for calculating the coordinates for each sensor are in equations 15 and 16. One method is to use the TDOA equation itself by striking the drum at a known origin point, such as the center or on one of the sensors. The other is to use the equation 17, where r is the radius of the drum and f is the fundamental frequency. Given that the drum is 14” that means the radius is 177.8 mm and the fundamental frequency is 170 Hz, making the speed of the vibration 92.87 m/s.

The other primary calculation that will be performed is the calculation of force that will identify the volume of each hit. To calculate the force of each impact is simple. The force of an object is just the acceleration 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 used to find acceleration and that is 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.

$$F = m * a \quad (18)$$

$$a = \frac{v - v_0}{t} \quad (19)$$

$$v = \frac{d}{t} \quad (20)$$

The steps used to do this calculation are shown in equations 18, 19, and 20 where d is the width of the drumstick's head, t is the time for which the beam is broken, v_0 is the average velocity, and m is the mass of the drumstick's head. They are simple equations compared to TDOA, but there may be holes in this data because of how the beam break sensors that collect this data are implemented. To fill in these gaps, a localized average of the hits before and after the hole will be calculated and applied to these missing points.

Besides being connected to the main PCB, the sensors may have to be connected to a second processor to generate replay data. This processor will be used if the generating the replay data with the main PCB causes too much of a time delay between a strike and flash. If PCB can be optimized to do these calculations with a noticeable delay, then an extra processor is unnecessary. If it is necessary, then a simple solution would be using something like a Raspberry Pi Pico. If this proves insufficient, then a digital signal processor, a processor specially designed to process sound could be used to handle the analog signals.

Not only can this data be used as replay data, it can add to the visual impact of the LUDS in presentation mode. Using the data, the LUDS can change how the LEDs flash, making a performance even more dynamic. Right now, the data of the force each hit will be used to change the brightness of the LEDs, with softer hits triggering a dim flash and harder hits triggering brighter flashes. The positional data can be used to allow different sections of the drum to trigger different colors. For instance, the right half of the drum could be coded to flash red, while the left half triggers a blue flash.

A tertiary feature of the LUDS could be to use the replay data to create an automated light show. This would involve taking the replay data it generated, either raw or as a MIDI file, and running it through another code that reads the data and activates the LEDs as if someone was playing the LUDS. If this program is compatible with MIDI files, the LUDS could even display light shows based on existing songs by loading the MIDI into the LUDS's removable memory.

5.6.4 Alternative Solutions

If the reflectance sensor design proves unworkable, there are other possibilities for detecting the hit of a drum. The primary back up plan is to use an intensity-based optical fiber sensor. This fiber sensor works by guiding light from a modulator through the fiber and measuring the output, with vibrations causing the output to fluctuate, allowing the sensor to detect a change. This design has the potential to be more complicated and costly to set up but it could be more stable in the long term, able to better withstand the stresses of an actual performance.

The fiber sensor can take many forms. The one that would be used in the LUDS is a microbend structure that relies on direct contact. In this design, the fiber is placed within the object it is being used to monitor causing the curvature to change when the vibrations deformed the structure, which causes the intensity to change. A diagram of how this system is shown below in figure 22. On the LUDS, the fiber would be directly affixed to the underside of the drum's skin, allowing it to bend and deform along with the skin when hit. This is the go-to back up design because of its relative simplicity.

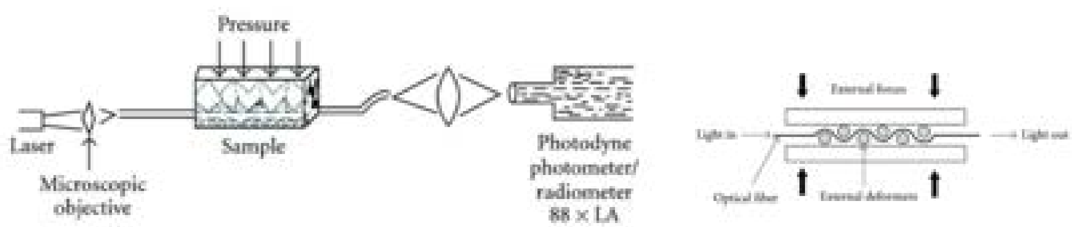


Figure 22 - Microbend intensity-based optical fiber sensor system

The microbend sensor is a good alternative because it partially maintains the simplicity of the current design. It also would be sturdier than the reflectance sensor design. The modulator and sensor could be housed outside of the actual drum head with the fiber running into the head, winding around the skin and traveling back out. The fiber itself would be quite resistant to being damaged by the vibrations since it doesn't have electrical components to mess up.

This design is considered a back-up plan because, while it is a simple solution, it is still more complex than the reflectance sensor design. Acquiring the fiber and the other necessary components to make this design work would be much more expensive than fabricating a housing for the reflectance sensors. Additionally, the light sources and fiber must maintain strong alignment in order to work properly and the system would require a reference to maintain calibration. This means that the system could be more durable, but it would need more maintenance to keep operational. The other drawback of this design is that it can be used for positional tracking. However if this design is deemed necessary, there is still a method using positional tracking with the beam break sensors. It would likely require an expansion of the beam break sensor array's design to make it very hard for the drummer to miss a beam break sensor while drumming.

5.7 Power Supply

In order for the microcontroller and other components in the L.U.D.S system to be supplied with power, the input must be rectified and regulated. This section will delve into the various components that make up the power supply as well as power related components. This includes the various voltage regulators that may be used. Different rectifiers will be discussed along with corresponding characteristics.

Other power related discussions deal with battery considerations and even power switch technologies. Reliability is one of the focal points of a good power supply. An unreliable power supply will inevitably and proportionally affect the reliability of the entire project. Therefore keeping the current supply in mind will be of the utmost importance. The power that is consumed by the L.E.D strip will be of a notable value. Consequently the voltage regulators and amplifiers must both work quite hard to ensure the microcontroller and L.E.D strip are supplied efficiently.

5.7.1 Voltage Regulators

There are three significant power supplies that are traditionally used. Those supplies include an unregulated, linear regulated and switching power supply. Unregulated power supplies exhibit unstable fast changing voltages and will lead to a proportionate discrepancy between a change in input in comparison with the output. They are relatively cheap and quite reliable however their biggest disadvantage lies with the output's inconsistent state. The first voltage regulator is responsible for transforming 12 V DC to 3.3 V DC. The second voltage regulator will however be responsible for transforming 3.3 V to -12V.

5.7.2 Linear Voltage Regulator

The linear voltage regulators overall provide a simple cheap design and low noise. They're also generally designed to output a fixed voltage even when dealing with various input voltages. Linear regulated voltage regulators are split between two different type regulators.

The first would be a shunt type regulator where the regulating element is parallel with the load. Shunt voltage regulators aren't used as much unless dealing with small currents and a range of small voltage levels. Shunt regulators draw full current even when the load is in a position where it doesn't need the full current. This characteristic of the shunt regulator makes it quite inefficient depending on the voltage levels a device is working with. Usually this particular regulator is used with devices that have a low input voltage level.

The other type of linear regulator is a series regulator that utilizes its regulating element in series with the load. A series linear regulator is more efficient than a shunt regulator because it doesn’t draw full current when it is unessential. This characteristic is almost the polar opposite of the shunt regulator.

Linear power supplies usually give a stable regulated output when dealing with varying input voltage levels. However they are not very efficient and have a propensity to generate a lot of heat. The main component that is responsible for the large amount of power dissipation would be the transistor. The overall increase in temperature will affect the majority of electrical components. This could lead to a massive thermal shutdown and possibly do permanent damage to the components. Many series linear regulators need a heat sink at the regulating component to ensure heat removal and help protect the rest of the components.

5.7.3 Switching Voltage Regulator

Switching regulators are considerably more efficient than linear regulators and have the flexibility to work with numerous applications. However the linear voltage regulator is able to compete due to its simplistic design. Switching regulator is more expensive than the linear regulator but is able to gain an efficiency over 90%. The regulator is also much better at providing low heat generation. The switching element of the regulator causes sudden changes in voltage and current. The resulting switching can lead to large amounts of noise.

We decided that the linear voltage regulator would be the best fit for the L.U.D.S. It is a cheap and reliable regulator that will give a stable regulated output. The TPS563212DRL regulator is a great fit and fulfills the specifications necessary. The regulator is able to handle 12 V DC input from the rechargeable battery. Its input range is from 4.2 V to 18 V which is well within the specifications for the regulator needed. The lowest input voltage from the MSP430 is 1.8 V. Therefore the regulator must be able to output this voltage in order to safely power the microcontroller.

TPS563212DRL voltage output has a range of 0.6 to 7 V. This also falls in accordance to the specifications so that the microcontroller can safely operate. In addition, this particular linear voltage regulator boasts a thermal resistance of 70 degrees C/W. This regulator's low heat resistance is highlighted especially because linear voltage regulators are known to have trouble with heat dissipation. The low heat resistance allows for heat to flow much easier and helps protect the surrounding components. Table 25 below shows the recommended operating conditions for the TPS56321DRL.

			MIN	MAX	UNIT
V_{IN}	Input supply voltage range		4.2	18	V
V_{OUT}	Output voltage range		0.6	7	V
	Pin voltage	SW, DC	–0.1	18	V
		SW, transient < 10 ns	–3	20	
		VIN - SW, DC	–0.1	18	
		VIN - SW, transient < 10 ns	–3	20	
		BOOT	–0.1	23.5	
		BOOT - SW	–0.1	5.5	
		EN, FB, PG/SS, MODE	–0.1	5.5	
I_{OUT}	Output current range		0	3	A
T_J	Operating junction temperature		–40	125	°C

Table 25 - TPS56321DRL Recommended operating Conditions

Below is the schematic based on the preliminary input conditions I had set for the voltage regulator. The topology for this linear regulator is more specifically called a buck converter. Buck converters serve as a step down DC to DC converter. Figure 23 provides the design schematic created through the software program Webench. Following that is Figure 24 which is Webenches recommended operating condition for the design created through its software.

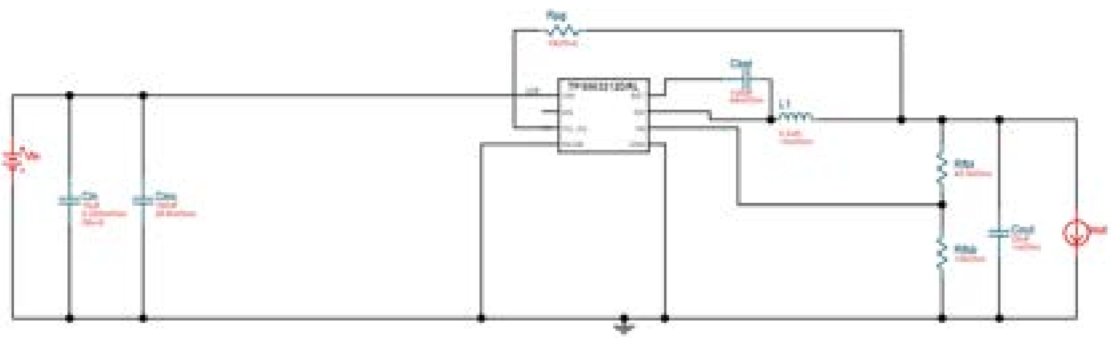


Figure 23 - TPS56321DRL Design Schematic provided through Webench

Operating Values

#	Name	Value	Category	Description
1.	Cin IRMS	907.185 mA	Capacitor	Input capacitor RMS ripple current
2.	Cin Pd	917.22 µW	Capacitor	Input capacitor power dissipation
3.	Cout IRMS	276.222 mA	Capacitor	Output capacitor RMS ripple current
4.	Cout Pd	76.299 µW	Capacitor	Output capacitor power dissipation
5.	IC Ipk	2.478 A	IC	Peak switch current in IC
6.	IC Pd	569.81 mW	IC	IC power dissipation
7.	IC Tj	69.887 degC	IC	IC junction temperature
8.	IC Tolerance	6.0 mV	IC	IC Feedback Tolerance
9.	ICThetaJA Effective	70.0 degC/W	IC	Effective IC Junction-to-Ambient Thermal Resistance
10.	Iin Avg	577.92 mA	IC	Average input current
11.	Ipp percentage	47.843 %	Inductor	Inductor ripple current percentage (with respect to average inductor current)
12.	L Ipp	956.86 mA	Inductor	Peak-to-peak inductor ripple current
13.	L Pd	52.992 mW	Inductor	Inductor power dissipation
14.	Cin Pd	917.22 µW	Power	Input capacitor power dissipation
15.	Cout Pd	76.299 µW	Power	Output capacitor power dissipation
16.	IC Pd	569.81 mW	Power	IC power dissipation
17.	L Pd	52.992 mW	Power	Inductor power dissipation
18.	Total Pd	624.009 mW	Power	Total Power Dissipation
19.	BOM Count	10	System Information	Total Design BOM count
20.	Duty Cycle	27.741 %	System Information	Duty cycle
21.	Efficiency	91.362 %	System Information	Steady state efficiency
22.	FootPrint	157.0 mm²	System Information	Total Foot Print Area of BOM components
23.	Frequency	1.192 MHz	System Information	Switching frequency
24.	Iout	2.0 A	System Information	Iout operating point
25.	Mode	CCM	System Information	Conduction Mode
26.	Pout	6.6 W	System Information	Total output power
27.	Total BOM	$1.28	System Information	Total BOM Cost
28.	Vin	12.5 V	System Information	Vin operating point
29.	Vin p-p	31.662 mV	System Information	Peak-to-peak input voltage
30.	Vout	3.3 V	System Information	Operational Output Voltage
31.	Vout Actual	3.318 V	System Information	Vout Actual calculated based on selected voltage divider resistors
32.	Vout Tolerance	2.671 %	System Information	Vout Tolerance based on IC Tolerance (no load) and voltage divider resistors if applicable
33.	Vout p-p	12.733 mV	System Information	Peak-to-peak output ripple voltage

Figure 24 - Webench Power Supply Recommended Operating Conditions

5.7.4 Battery

This section will discuss the numerous battery types that may be considered. Batteries are generally placed within two distinct categories, primary and secondary. Primary batteries can not be recharged easily after being used once. They are usually disposed of after single use. In contrast, secondary batteries are capable of being recharged and being returned to the cell's originally charged level.

There are many different chemical makeups that could serve as a primary battery. The most common would be lithium, alkaline and carbon zinc batteries. Lithium shouldn't be confused with lithium-ion, the former being non rechargeable. Although they aren't able to recharge, lithium has a higher energy density than lithium ion batteries. This allows for lithium batteries to offer more capacity. Effectively allowing the battery to do mre off one single charge even if said battery was only charged one time in its life.

Alkaline batteries are very common and can be found almost everywhere. They power the majority of toys, cameras, flashlights and other various electrical products. It is likely known as the most common household battery. Alkaline batteries are composed of zinc metal and manganese dioxide. Its unique composition allows for the battery to have the highest energy density discussed amongst the primary cells. As a consequence the shelf life associated with this battery is quite long. The average storage life for an AA battery spans 5 - 10 years.

Carbon zinc batteries have the worst shelf life and associated energy density. It will not be considered. At this point the consideration for a primary battery compared to a secondary battery is unclear. However if chosen, the alkaline battery would serve as the best primary cell battery source.

Rechargeable batteries have taken a foothold in many of the contemporary technologies used today. Ranging from mobile devices to portable speakers as well. In fact the Secondary batteries can be split between the two most prominent battery chemistries. Lithium ion and nickel metal hydride.

Nickel metal hydride for the most part replaced the old nickel cadmium battery. The nickel cadmium battery had a higher cost and its use of cadmium made it more hazardous. Cadmium is a highly toxic metal and extended exposure to it could cause adverse respiratory issues or even death. Nickel metal hydride is more energy dense than the previous battery. Each cell within a nickel metal hydride battery is capable of delivering 1.2 V of power. A Nickel metal hydride's cell will only be able to produce nominal voltage of 1.2 V similarly.

Lithium ion batteries are able to boast a much higher energy density than the nickel metal hydride battery. Each cell within a lithium ion battery is capable of outputting 3.6 V of power. The overall life cycle is about five years. Nickel metal hydride has an overall life expectancy of two to five years. Below, table 26 gives a comprehensive analysis of certain battery types discussed.

Specifications	Lead Acid	NiCd	NiMH
Cell Voltage (nominal)	2 V	1.2 V	1.2 V
Overcharge Tolerance	High	Moderate	Low
Charge Temperature	-20 to 50 ◦C	0 to 45 ◦C	0 to 45 ◦C
Cost	Low	Moderate	High
Self-discharge per month	5%	20%	30%
Internal Resistance	Very Low	Very Low	Low

Table 26 - Battery Specification Comparison

The linear voltage regulator and power amplifier each need to be able to handle an input 12 V from the rechargeable battery. The battery must also meet engineering requirements. Therefore the weight and dimensions will heavily influence the most optimal choice for the battery.

The UB1208 is a maintenance free rechargeable battery capable of outputting 12 V for 20 hours at 0.04 A. The battery also meets the dimension specification due to its relatively small size. It is concise and small enough to fit within the housing which will be a 6 inch wide, 6 inch tall, and 3 inch deep aluminum box, as specified in section 9.1. The stipulation with this battery is the 0.8 amp hour capacity that it has.

Due to UB1208 lack of battery capacity it will no longer be considered.
Another more appropriate option would be the BW 1250 rechargeable battery. The battery can supply a nominal voltage of 12 V and has a capacity of approximately 5 Amp hours. This is estimated to be about 2.3 hours of battery operated time. As a result, it would meet the specification set to have the L.U.D.S system be powered by battery power for at least 2 hours. The dimensions also coincide with the estimated space already delegated for the control box housing.

Although the BW 1250 battery is considerable, it wouldn't be the best fit for the L.U.D.S. The dimensions for the battery are less than ideal for the control box enclosure. In addition the recharging aspect wouldn't be as seamless as it would with the 18650 battery pack. The 18650 battery pack from BATTERYINT is a 6000mAh lithium ion battery with a nominal voltage of 12 V. The average current consumption enables the battery life to be about 2 hours and 47 mins. The dimensions of the battery are 57.6 mm wide , 66.4 mm tall and 38.79 mm deep. The dimensions are significantly decreased in comparison with the BW 1250 battery. In fact the battery life is slightly better with the 18650 battery pack from BATTERYINT. Therefore it will be chosen to be one of the voltage sources for this project. The dimension of the battery will be presented in Figure 25 below.

Figure 25 - 18650 Battery Pack Dimensions

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 this power supply is given in Figure 26 listed below.

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

Figure 26 - TMPS 15-112 product details

5.7.5 Power Switch

The power switch is an indispensable component that provides a connection from a voltage source to its load. In this unique case the switch will be responsible for establishing two different input voltages to a load. The power related switch will allow the user to utilize the power from the battery or the AC adapter.

The switch must be able to interrupt 12 V DC coming from the battery and AC adapter. In addition it is key that the switch has two poles and is capable of switching between three positions. Double pole switches can divert two current lines to another set of lines. This effectively allows the switching between two separate circuits. As a result each circuit or incoming voltage can be isolated safely.

The momentary toggle switch is among the three 3 position switches considered for this project. The switch is also a two pole switch capable of switching between two separate circuits. It has a rated voltage of 250 V AC and a rated current of 15 amps. The switch will easily be able to handle 12 V DC power coming from both the battery and AC adapter. Similarly the switch has such a high current rating that it will be able to safely interrupt without causing any damage to the product.

The final power switch considered for this project is a rotary switch. It is a 4 pole switch that also has 3 positions. Allowing for the switching between 4 separate circuits. The A40315RNZQ rotary switch is also rated to interrupt DC voltages up to 125 V. Therefore this switch will be able to handle the voltage source levels that are associated with the scope of this project. The distinct elongated spindle allows for an easier switch between the 3 positions for the user. In addition it also helps to denote the individual position better than a momentary 3 position toggle switch. Below Figure 28 shows the rotary switch from Digikey.

Figure 27 - A40315RNZQ Rotary Switch

5.7.6 AC Adapter

One of the main goals of the L.U.D.S system is to be powered from both the battery and from the outlet. Wall outlets provide 120 V alternating current at a frequency of 60 Hz. AC adapters or power adapters serve as the perfect component for efficiently transforming AC Voltage inputs to regulated DC voltage outputs. AC adapters are great AC to DC converters.

Older devices would have AC to DC converters already built within their system, this made them heavy and more burdensome. Contemporary technological devices are more portable by electing not to have an integrated AC adapter within their design. External AC to DC converters allow for the device to be more lightweight and mobile

In addition to the overall loss in system weight, external AC to DC converters help reduce heat dissipation. Integrated AC to DC converters share the same environment as many other temperature sensitive components that are usually found within a circuit. Converters are susceptible to running quite hot due the overall transformation in voltage. Therefore a shared environment could adversely affect other components within a relatively short time in comparison with external converters.

External converters also help to reduce the electrical noise given off by a device, overall helping to maintain and advance safety. The unique position of the converter is also great for unforeseen electrical problems. In the case of a significant voltage spike or a brownout, the rest of the hardware dedicated to the project are safe and the adapter is easily replaceable.

Once the adapter is plugged in it will rectify the 120 V AC current to a regulated DC Voltage of 12 V. The adapter must be to output at least X Watts in order to power on the L.E.D strip, microcontroller, power amplifier and other peripherals. The COOLM AC power supply would be a great fit for the scope of this system. It's able to rectify up to 240 V AC to a regulated DC voltage level of 12 V. In addition this power converter has a current rating of 4 amps, allowing the maximum output power of about 48 W. This should be more than adequate enough to ensure a reliable power for the rest of the system.

The COOLM AC adapter also comes with a female connector allowing for varying input connections to the 2 pole 3 position switch. Below figure 29 shows the discussed AC adapter along with the given connector.

Figure 28 - COOLM AC Power Converter

5.7.7 Inverting Buck Boost Converter

Similar to the previous voltage regulator topology, the second voltage regulator is a buck boost converter. However it is an inverting buck boost converter capable of inverting the input voltage. The power amplifier design requires a 12 V signal for +VCC and a - 12V signal for - VCC. Therefore 2 distinct voltage regulators are required to realize this design.

Texas Instruments provides a reference design for an inverting buck boost converter PCB. It allows an input voltage range of 3 to 4.5 V while being able to invert and boost the output voltage signal to -12 V. The output voltage correlating to the previous buck boost converter design falls perfectly in the range of voltage levels that the inverting buck boost converter is capable of handling. The 3.3 V output from the first voltage regulator will act as the input voltage for the microcontroller as well as the inverting buck boost converter design.

The voltage converter chip used in his reference design is the TPS62136. Unlike the PCB design that Texas Instruments provides called the TIDA -01323, there will be no jumpers or pin headers. The design is slightly changed to fit the parameters of the project and its connected circuits. The enable pin will connect to Vin since the scope of the project would need the -12 V signal every time the converter design receives a 3.3 V signal from the previous buck boost converter. Below the schematic for the inverting buck boost converter is shown if Figure x.

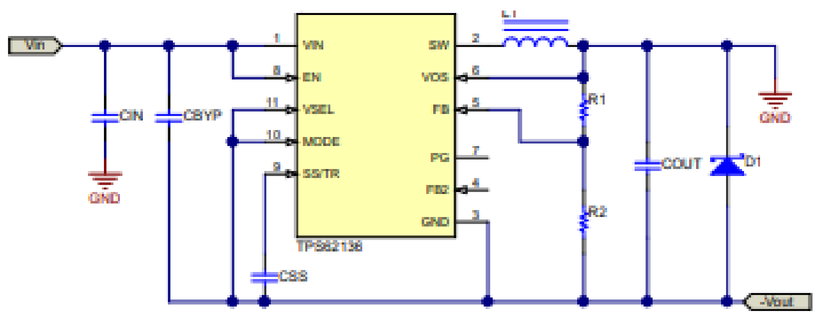


Figure 29 - Inverting Buck BoostConverter

5.8 Microcontroller (MCU)

After comparison with all the available options, the best possible fit for programming and software design, the project system will be requiring the MSP430FR6989 microcontroller. The Code Composer Studio (CCS) application will be used to program the microcontroller. In Appendix A, the image on the left represents the actual picture of the microcontroller. The MCU will be connected with the printed circuit board (PCB) along with other components used for the vibration detection and LED flashing. The image on the right in Appendix A is from the MSP Launchpad development kit’s user guide which represents some of the primary components on the microcontroller such as the 40-pin module, switches/buttons, segmented LCD display, etc.

From the image of the microcontroller overview, the 40 pin module will be used to connect with the external LCD display, switch for mode change, infrared sensors, BPM rotatable knob, LED strip lights, light flash or fade switch, and LED color controller. The other parts in the microcontroller such as the buttons, user LEDs, segmented LCD display may not be used entirely because the external parts have similar functionalities with much better features.

In this microcontroller, the programmed data is sent and stored via the micro-b USB port which is located as shown in the image below. This microcontroller is divided into two parts with the debug MCU on the top while the bottom MCU is the target device. Although, the entire device works and performs uniformly since all the functions are related in some form which is shown with arrows in the image below. This image is obtained from the microcontroller datasheet for the reference of connections.

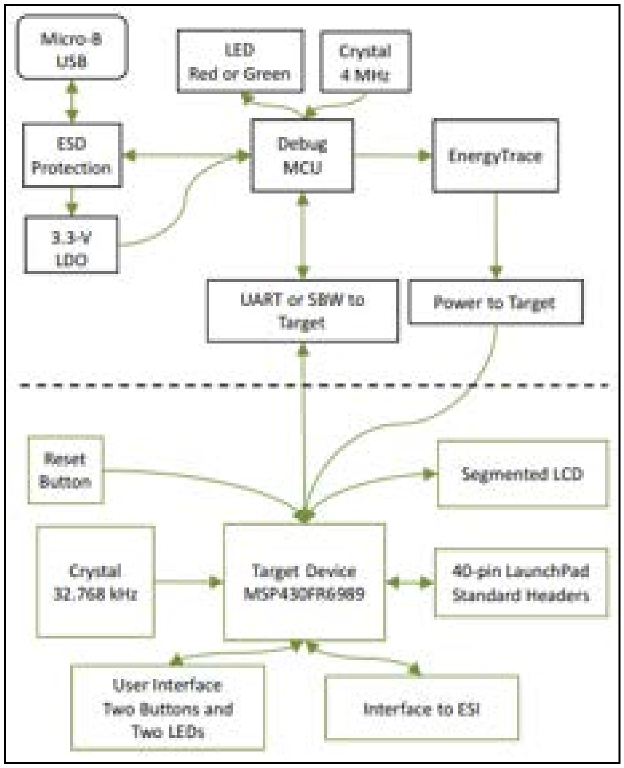


Figure 30 - Microcontroller components

As shown in the image, the 40-pin module is primarily connected with the target device and does not completely interact with the top part of the MCU. Along with this info, the microcontroller has physical timer crystals and digitally controlled oscillators to perform timer based functions. The user chooses the type of clock during the software design based on the specific project requirements.

5.8.1 Timers and Clocks

The MSP430 devices contain a few types of timers, which includes the Watchdog timer, basic timer1 (LCD controller), real-time clock, timer_A, and timer_B. For this project, the Watchdog timer will be disabled all the time. From the five clocks, timer_A will be used for this project because it is more versatile and has three channels in the microcontroller. This timer can handle external inputs and outputs, which is highly preferred in this case to receive data from the infrared sensor, switches, and knobs.

Along with the timer_A, the real-time clock might be used as well to save the data in terms of time from the infrared sensor for each drum beat detected. The real-time clock can measure seconds, minutes, hours, and up to a century. All the other available clocks will not be used since it is not required for any other parts in the software design. Even though the timer_A is used for the counter of measurement, it requires a clock to relate with the real time. Basically, that would depend on the frequency of the clock chosen for the timer_A. There are two primary internal clocks which are the SMCLK and ACLK. Also, there are two external clocks which are TACLK and INCLK. but the external clocks will not be used anywhere in this project. The clock is chosen using the TASSELx bits in the timer initialization function.

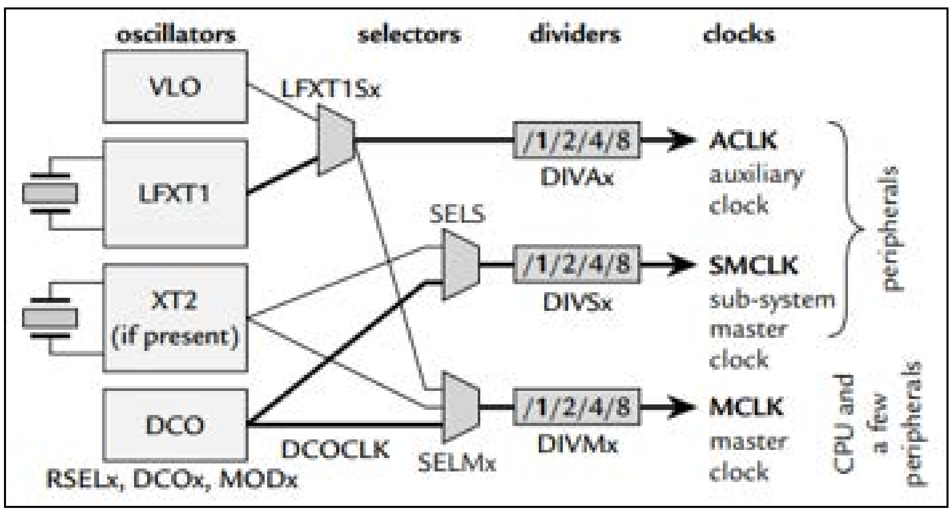


Figure 31 - Timer Module for Primary Clocks

5.8.2 Interrupts, Resets and LPMs

In the MSP430 architecture, there are few interrupt basics that are used to understand and implement interrupt events in this project. To begin with the “Global Interrupt Enable (GIE)” is the switch to on/off all the interrupts in a program and this bit is located in the Status Register (SR). This project will be using interrupts for the detection by the infrared sensors. In the C language, using the line “_enable_interrupts()” will set the function and using the line “_disable_interrupts()” will clear the function. The GIE should be used as the last line in the timer initialization function.

Along with the GIE, there are other bits such as the interrupt enable bit, interrupt flag bit, and interrupt service routine. These bits have their own individual functions that allow them to control specific events but the GIE bit should be enabled to use these bits. The interrupt Enable bit (xIE) will be used for each interrupt event to be enabled or disabled. The x term is replaced with the event such as timer_A (TAIE) and

The interrupt flag bit (xIFG) raises a flag by the hardware when an interrupt event has occurred. This bit also puts an interrupt only when both the xIE and GIE bits are enabled. The interrupts service routine (ISR) is a special function and each interrupt event has a ISR function specifically for it. Also, the hardware finds the ISR using the specific interrupt value.

The MSP430FR6989 supports many low-power modes which includes the LPM0, LPM1, LPM2, LPM3, LPM3.5, LPM4, and LPM4.5. Although the microcontroller offers about seven low-power modes, only three of them are the most popular and will be used frequently in this project. Conversation of the power is very important for this project system because it is running on battery power rather than supply from an electronic device or wall outlet. The three primary LPMs are LPM0, LPM3, and LPM4 which have their own specific function corresponding to the type of clock and shown in the table below.

Modes	ACLK	SMCLK	MCLK
Active Mode	ON	ON	ON
LPM0	ON	ON	OFF
LPM3	ON	OFF	OFF
LPM4	OFF	OFF	OFF

Table 27 - Primary Low Power Modes Functions

5.8.3 Universal Asynchronous Receiver and Transmitter (UART)

The UART is an interface in the MCU that allows transmitting information between the microcontroller and the PC. The receiver and the transmitter have their own clock so it is considered to be asynchronous. The UART does not have a major role in the overall project design but it is the only to send data to the PC so that the information can be stored in a USB drive for later user access. As seen in the previous section of low-power modes, the UART also has some popular parameters similar to the popular kinds of LPMs. The table with the parameters and the configurations are shown below. This is the same configuration that will be used to transmit data to the PC for the project.

Parameter	Configuration
Baud Rate (transmission speed)	9600
Data size	8-bit
First Bit	LSB
Parity bits to detect errors	N/A
Stop Bit	1-bit
Flow Control	N/A

Table 28 - Popular UART Configurations

The UART communication will be performed via the enhanced universal serial communication interface (eUSCI). In MSP430, there are two channels for the eUSCI module and the microcontroller may also have multiple eUSCI modules. The channel A will be used in this case because it supports the UART along with SPI as well, but the latter part will be discussed in a later section. Another channel B supports the SPI too along with I2C, which will also be discussed in a later section.

There are many other baud rates available such as the popular 32,768 Hz crystal but it might not be good enough for this required design. Also, the UART needs few definitions along with default assignments. These include the flags, receive flags, transmit flags, receive buffer, and transmit buffer. The programming for this part is explained in more detail in the software design section.

5.8.4 Inter-Integrated Circuit (I2C)

The Inter-Integrated Circuit communication is the most important part of the microcontroller for this project. The I2C module is basically used to communicate with the infrared sensor and collect the data from it. This module has two bidirectional wires which are the serial data (SDA) and serial clock (SCL). Any type of sensor should have register values for the I2C module to be able to communicate and collect data. As previously explained in the earlier section, the eUSCI channel B should be used with the I2C module.

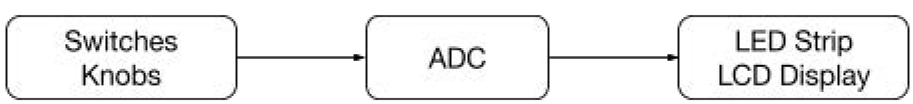
There are five modes that the I2C supports for the maximum clock frequency. In this case, the standard mode should be perfect because most infrared sensors support it as well as the microcontroller. This mode basically has the maximum frequency of 100 KHz while most infrared sensors might just require approximately a similar maximum value.

5.8.5 Analog to Digital Converter (ADC)

The ADC will be used to read the values from the switches and the knobs. The flip switches and the rotatable knobs in the design provide analog values as input which will be converted to binary numbers (digital data) by the ADC. Then, the digital values will be used to do the specified tasks to the LED strip and the LCD display. All of the functions of the LED and LCD are specified in their corresponding sections.

There are three types of the modules for the ADC, which are the comparator, successive-approximation, and sigma-delta. For the scope of this project, the software will only be using the successive-approximation (ADC SAR-type) module to perform all conversions. Within this type, there are two versions which are the ADC10 and ADC12. These versions just mean that the outputs of the digital data will be 10 bits and 12 bits, respectively.

Since the ADC is being used for the project, there are some issues that need to be taken into consideration. Since the value is being converted from analog to digital, there will always be errors in terms of accuracy, noise, and timing. These issues are sometimes very basic and do not affect the digital values too much.



5.8.6 Serial Peripheral Interface (SPI)

The SPI will be used to send information that should be displayed on the external LCD display and flash the entire LED light strip. The serial peripheral interface is the simplest communication protocol for general programming. This protocol is full duplex and uses four wires which are serial data out, serial data in, serial clock, and chip select. Along with the UART module, the SPI protocol will also be used to send data to the USB drive since this can transfer large amounts of data. Since the UART and SPI are required together to send data to the USB drive, the connections of the transmit buffer and receiver buffer with the USCI_B0 module in SPI mode is required. The block diagram for this process is shown in the image below.

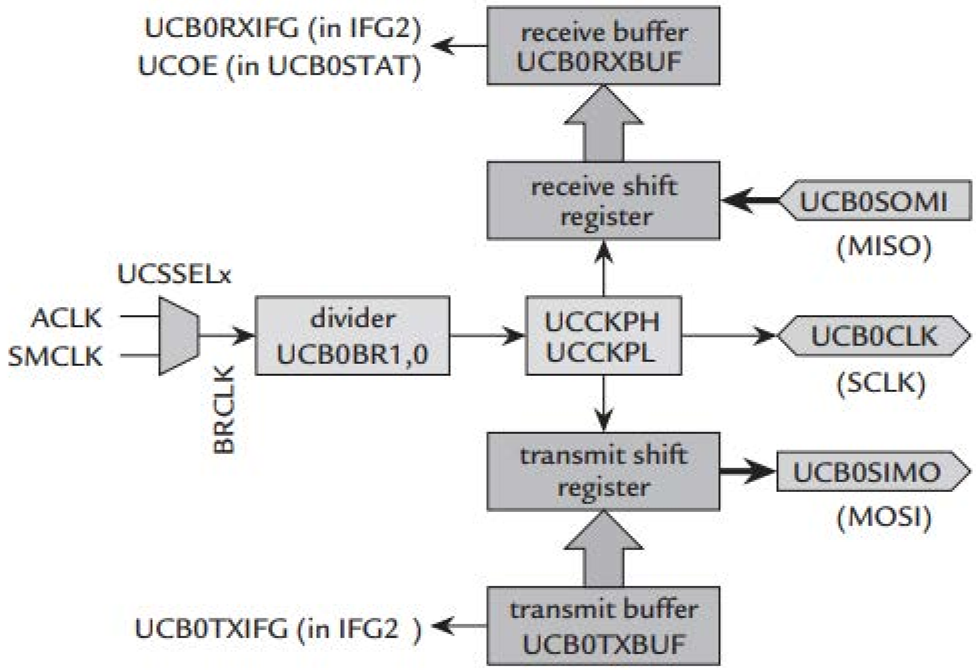


Figure 32 - USCI_B0 in SPI Mode

The SPI can be used with both the USCI_A and USCI_B because both modules support SPI functionalities. And they both work the exact same way, except the registers are shared with one channel of USCI. Also, the USCI activates the SMCLK which is preferred in this case, because SMCLK is used for the timers in this project.

5.9 Software Design and Coding

For the overall functioning of the system, the programming of the microcontroller is the most important task in the entire project. This includes the functions of taking inputs from the infrared sensor, flashing the LED strip lights, and displaying the user interface on the LCD. While these are primary functions of the microcontroller, there are more purposes such as the user inputs of the system mode, beats per minute, light colors, etc. Along with these functions, another major task is to store the velocity/vibration detections in a USB for later access to the user.

To begin with, all pin connections are required to be connected to the microcontroller. For the design, one MCU with the 40-pin module should be enough. So the software design will only be focused on one microcontroller programming. The primary functions include the timer initialization, timer interrupt, LCD initialization, LCD reset, and main function. The display also requires a few more functions to display characters and numbers. Also, for the data to be sent to the display, two more functions are required for both the characters and the unsigned characters.

Along with the primary functions and LCD functions, the light flashes require some functions as well since the microcontroller takes input from the switches and the rotatable knobs. There are four switches in the entire system but only three will be taken for inputs by the microcontroller since the fourth switch is just for the power supply. Also, there are three rotatable knobs for user inputs as well. Along with the initial interrupt function for the infrared sensor detection, another timer interrupt function will be used to detect the switches and the knobs when the user operates.

The mode switch (metronome or sensing) requires a function to change the LED flash rhythm with bpm or based on drum beat. Basically, in the metronome mode, the interrupt looks for a detection in the bpm knob and the time signature knob. Then, a function sends these inputs to the LED strip based on the values set in the knobs. Then, in the sensing mode, many tasks have to occur simultaneously. To begin with, the interrupt looks for a detection in the second switch which sets the LED strip to be turned on dimly all the time or entirely off. Then, after the detection, another function will send data to the LED strip. Next, the third switch will be used to set if the LED should just flash or fade slowly for each drum beat. This also will be detected by the interrupt function and sends the data to the LED strip. Along with this switch, the third knob is also checked for the time of flash or fade before the LED strip returns back to normal. All of the above mentioned switches and knobs along with their functions are represented in the block diagram below.

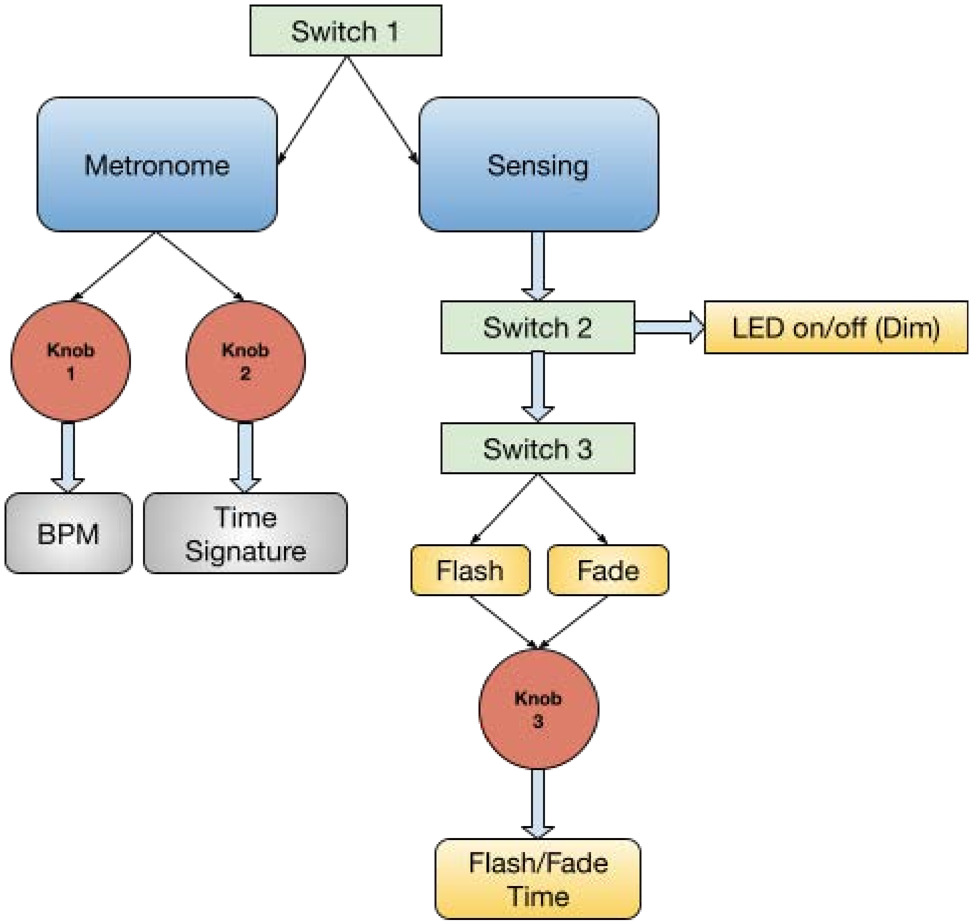


Figure 33 - Functions of Switches and Knobs to Interact with MCU

For the advanced goal, another function will be required to store the data collected by the infrared sensor. The data will be stored in a text formatted file (.txt) in a USB drive for later access to the user. This function will take the inputs, convert them to text, and include the units along with the value. It will also name each of the data with the date and time of the drum beat detected. This process will be programmed after all the primary functions are completed and tested to work properly.

Even though each function has its own tasks and properties, they all will be called from the main function or other primary functions but they will not be returning any values. The interrupt functions will be always active in real-time to check for the switches, knob, and vibration detection. Each of the functions will be declared as void because return values are not required.

5.9.1 Libraries, Definitions, and Global Registers

The primary registers that will be used throughout code will be found in the MSP library itself. For using the registers from this library, the code line “#include <msp430fr6989.h>” will be used to declare many of the important registers such as the GPIO pins, output/input pins, etc. Other libraries will also be used since this default MSP library does not contain all the register functions that will be used in this program. Other libraries that will be used in this code are “stdlib.h”, “string.h”, and “stdio.h”. All of these will be included along with the default library and extra libraries may be added if required for certain outputs such as the text file storage in the USB drive.

After all the libraries are declared initially, the microcontroller (uC) GPIO ports and peripheral pins need to be assigned. For the liquid crystal display, most of the pins need to be connected with the microcontroller. The LCD EN will be defined to be set as BIT2 and the LCD RS will be defined to be set as BIT3. The LCD DATA needs to be defined to be set to all the bits that have some functionality. The D4, D5, D6, D7 will have to be connected and these will be set as BIT4, BIT5, BIT6, and BIT7, respectively. Then, another register should be defined to be set with the three of the registers above which are the LCD EN, LCD RS, and LCD DATA. Similar to the defined registers for the LCD display, the IR TRIG should be set to BIT4 which will be used to take inputs from the infrared sensors.

After defining all of the port and pin assignments, few global registers are required to be declared based on the software design requirements for this project. These registers include the bpm, counter to measure the vibration in microseconds, and velocity in meters per second. Initially, these are only global registers that will be coded in the program, while more may be added if required to change the algorithm of the design.

5.9.2 Main Function

This function is responsible for initializing the rest of the other functions to perform each of its own operations to detect vibration and flash LEDs and as well as declaring the input/output pins, timers, etc. The timer will also be programmed within its own function rather than in the main function so that it can be initialized in the main function only when it is required rather than running the timer continuously. This is one of the methods used to save the battery consumption since the entire setup is powered via a battery source.

In this code, the main function will always contain the lines to disable the watchdog timer and to enable the GPIO pins. This will be at the beginning of the function and will never be changed or removed because it can make the microcontroller unstable. For instance, the watchdog timer is always enabled by default, which can restart the microcontroller very often and it could cause issues with the program when running. Also, the GPIO pins is disabled by default and it needs to be enabled so that it allows timers, interrupts, communications, pins, and other functions from this register to be able to operate.

After the initial two operations, the primary coding design for this project can be started with initialization of registers, output pins, and input pins. To begin with, the output pins for the LCD display and infrared sensor need to be set. Secondly, the input from the infrared sensor can be set along with registering the conditions for the sensor triggering such as the timer. After the initialization of the basic input and output pins, the LCD display function is called, then the timer function. With both of these initialized, the characters such as the lines, variable names, and units are called to their appropriate functions.

In the final part of the main function, the infinite loop needs to be used to display any numerical values on the LCD and flash the LEDs based on the vibration. This loop needs to be infinite such as “while (1)” or “for (;;)” because the program should be constantly running forever. This loop makes sure that the code doesn’t get terminated or stopped in any case. Inside the loop, multiple things happen that include the measurement of the numerical values to be displayed on the LCD and sending the output to the display by calling the individual functions. Along with that, the controlling of the LED strip flashes around the drum set is also set to happen within the infinite loop.

5.9.3 Timer Interrupt Functions

There are three internal clocks in this microcontroller which are MCLK, SMCLK, and ACLK. For this timer interrupt, the SMCLK will be used at the default configuration of 1 MHz to measure for the vibration continuously. Even though the most accurate clock being the ACLK with 32.768 KHz crystal for the MSP, the SMCLK seems to be a better option for this program. Another option is the MCLK, which might also not be as much as superior than the SMCLK in this case.

Clock Type	Actual Name	Frequency	Oscillator
ACLK	Auxiliary Clock	32 KHz	Low Frequency Crystal
SMCLK	Subsystem Master Clock	1 MHz	Digitally Controlled

MCLK	Master Clock	1 MHz	Digitally Controlled

Table 29 - Available clock frequency representations

The pragma vector for the clock that will be used is Timer_A0_VECTOR which is a timer peripheral in the microcontroller. This interrupt vector will be coded as a void function so it doesn't return anything which it is called from the main function. Inside the interrupt function, multiple ways can be used to constantly check for the vibration in terms of the force. The timer needs to counter the values of the force, BPM, and the time signature. For which an if-else statement will be used to counter each of the values using certain equations. The first if statement will check during the raising edge of the clock while the else statement checks during the falling edge of the clock. Then, the interrupt flag will be cleared outside the if-else statement.

Input clock		Timer clock		Range of timer	
Source	Frequency	Divider	Resolution	Frequency	Period
SMCLK	16 MHz	1	$\frac{1}{16}$ µs	240 Hz	4 ms
SMCLK	1 MHz	1	1 µs	15 Hz	66 ms
SMCLK	1 MHz	8	8 µs	2 Hz	0.5 s
ACLK	32 KHz	1	31 µs	$\frac{1}{2}$ Hz	2 s
ACLK	32 KHz	8	240 µs	$\frac{1}{16}$ Hz	16 s

Table 30 - Clock Frequency Comparisons in Continuous Mode

5.9.4 Timer Initialization

The SCMLK needs to be initialized with specific conditions and in-fact, the default clock is the ACLK, and therefore the clock needs to be changed to the SMCLK. This whole procedure can be coded within the main function itself but using a separate function makes it more user friendly to understand the concept. In the first part of this function, the TACCTL0 register needs to be set to read the vibration with the capture registers. These registers are used with their own conditions such as the edges, inputs, modes, etc. Along with it, the capture compare interrupt enable register is also set with the TA0CCTL0 register.

Next part of the code requires configuring the Timer A with the clock type, mode, and divider. The mode will be the SMCLK as stated earlier, while the mode and divider will be figured out later during the coding process. Also finally in this function, the global interrupt bit should be enabled so the timer can be used within the interrupt function.

5.9.5 Switches and Knobs Related Functions

The ADC module will be used to convert the analog data from the switches and knobs to digital (binary) numbers. The SAR ADC creates the x number of bit results by making multiple comparisons in terms of the voltage. The ADC module that is built in the microcontroller to produce the results in 10 bits or 12 bits based on the specified coding. In this project design, the ADC12 will be used because it has a higher number of bits. There is a computation required for the sample and hold time for the ADC module. This value is based on the cycle number which has specified values as 4, 8, 16, 31, 64, 96, 128, 192, 256, 384, and 512. So after the computation is calculated, the number of cycles should be the next value of the calculated value. For example the value calculated is 250, then the number of cycles should be 256, and therefore the program should be programmed with that sample and hold time.

5.9.6 LCD Related Functions

The SPI module will be used to send data to the LCD display. To display information about the system mode and the beats per minute, multiple functions for the LCD specifically will be required to achieve each task. To begin with, the LED first displays the characters “BPM” and “time signature” for which two separate functions are required. These functions will be called from the main function before displaying the numerical values to let users know which is the BPM and time signature. After the numerical values, the units of these two variables need to be displayed, so another two separate character functions are required. Along with these functions, two integer functions will be used to display the BPM and time signature.

These functions will have to print the values on the LCD display continuously so a “while statement” is required to display these character sentences. The characters will be used as pointers so that it can be simpler to call from the main function. Overall, the display will have two lines, in which the first line will display the BPM and the second line displays the time signature. Also, all of the functions used to display on the LCD will be void functions so it shouldn’t need to return any values or characters.

Another important task by the microcontroller is to reset the LCD display every time before it displays a new value for BPM and time signature. This can be programmed by using the Pout registers for each digit along with the delay cycles.

5.9.7 LED Strip Related Functions

Similar to the functions for the LCD display, the SPI module will also be used to send any flash related information to the LED strip attached to the drum circumference. Basically, the functions provided by the switches and knobs are the flash on/off dimly, flash or fade, and the time to flash or fade. There are two switch related functions and one knob related function.

5.10 Full Drum Kit Integration

Drum kits are usually made up of 8 pieces: a 14” diameter snare drum; 22” bass drum; 16” floor tom; 12” and 13” mounted toms; and ride, hi-hat, and crash symbols. If the project moves far ahead of schedule, the LUDS could hypothetically be integrated into a full drunk kit like in figure 34. The LUDS will be initially implemented into a snare drum. Snare drum is played the most often as a standalone instrument, such in marching bands and other musical arrangements, making it a logical starting point.

Figure 34 - Label picture of a complete drum kit

5.10.1 Toms and Bass Drum Integration

Each drum beyond the snare would require a slight modification to the design of the sensor array. For the reflectance sensors, the bigger the drum is the more sensors it would require and smaller drums require less. For the base drum there would probably have to be ten sensors and eight for the floor tom. The mounted toms could possibly use as few as four, but five would be more accurate.

The beam break sensors are a bit different in that the smaller toms would not have less than six sensors. This is because of how the beams need to cover as much surface as possible, so using less sensors severely would hurt the LUDS. The floor tom would need eight to ten sensors, but the sensors would also have to be more powerful to accommodate the larger size. The bass drum is interesting because of how it uses a foot pedal, meaning that the only one sensors is need, but it would likely have to be the expensive WF225-B4150 to full cross the width of the drum

5.10.2 Symbol Integration

Due to the nature of the symbols, it is unlikely that the safe type of design could be used for the sensors or the LED arrays. The LED stripes could be mounted on the edge of the underside of the symboles. In the care of the hi-hat, they would have to be placed carefully because of how the hi-hat collides with another symbol below it.

The reflectance and beam break sensors would have varying levels of success with the symbols. The beam break sensors would be totally ineffective. The reflectance sensor could be used, but it would not be the best solution. The sensor would have to be mounted in the open under the symbols, which is both aesthetically unappealing and leaves the sensors vulnerable to both general interference and being hit by the symbols themselves.

A better solution would be to use the optical fiber solution proposed as an alternative to the reflectance sensors in 5.6.4. The fiber could be attached to the underside of the symbol with the vibration from the symbol disrupting the path of the light in the fiber. The transceiver unit sending light would detect a difference in the light being received and that would count as a hit. How much the light changes from the expected signal could also be used to potentially calculate the force of the impact.

5.10.3 Interaction with Microcontroller

The MCU would all have to be upgraded to handle multiple sets of inputs and keep them separate. It wouldn't just have to keep up with more inputs from the different drums and symbols, there would also have to be more knobs as switches to control each drum. The MCU would have to have a larger housing with multiple screens or a very large LCD screen to keep track of all the information.

Alternatively, if the project reaches this point, an app could be developed to control all the different features. With the LUDS being put into a single drum and no computer engineer on the team, it would be too much effort to design an app user interface. However, a design as complicated as a full drum kit integrated with LUDS would justify the investment of making the user interface physical instead of digital as it would greatly streamline things.

6. Project Prototype Construction and Coding

6.1 LED Array Assembly

To assemble the LED array for the prototype the LED strip, the dimming module, the amplifier circuit, the MCU, a 2.1mm pigtail plug, a 2.1mm connecting cable, and a 4-pin RGB connecting cable are required. The assembly will start by connecting the LED strip to the 4-pin RGB connecting cable. Then the other end of the connecting cable will be plugged into the output on the dimming module. Next, the input of the dimming module will be plugged into the 2.1mm connecting cable which will be plugged into the 2.1mm pigtail connector. Finally the 2 loose copper wires from the pigtail connector will be soldered to the output of the voltage amplifier which is wired to the MCU.

6.2 Infrared Sensor Array Assembly

The early prototypes will be done on a smaller drum and will be used to calibrate basic aspects like optimizing the position of the sensors and ensuring that they function with the MCU. Then the full set of sensors will be applied to a full sized snare drum. This will be when the tracking aspects are calibrated to allow the LUDS to collect replay data as accurately as possible.

6.2.1 Reflectance Sensor Prototyping

The first phase of prototyping the reflectance sensors is just to make sure that it works. This task is easier said than done because the IR beam is invisible to the naked eye. Using tools like IR cards can see the beam, but it's hard to make adjustments and use these tools at the same time. It might be frustrating, but it should take too long with the right set up. Then they can be used in a prototype, which will establish the optimal distance from the head of the drum that the sensors will permanently rest at in the final product.

6.2.2 Beam Brake Sensor Prototyping

Prototyping a design for the beam break sensors should be much simpler, since there is no deformation to worry about and the beam travels in a straight line and doesn’t reflect off anything. The main query to test is what detection should be the end point velocity timer. The distance between the sensor and the drum will be fixed, but there might not be enough room for the beam to become unblocked by the drumstick. This would mess up the timer, so the detection of a vibration from the reflectance sensor could be used to end the timer instead.

6.3 PCB Vendor and Assembly

EAGLE CAD software will be used to create the digital schematic and design for the PCB board. Footprints from different parts will be found on the websites from which those parts were found. If the website/vendor does not have those footprints, a footprint will be manually created in EAGLE CAD. Below is a list of potential vendors to be used for PCB manufacturing. Each vendor will be evaluated during Senior Design 2 in order to make sure the vendor suits the needs of the project. Some needs consist of timeframe, manufacturing cost, and reliability.

Potential Vendors
1. Advanced Circuitry International (ACI)
2. Rush PCB Inc
3. Custom Circuit Boards
4. Journey Circuits Inc
5. TechnoTronix

6.3.1 PCB Assembly

The PCB consists of the majority of the circuits that are correlated with the L.U.D.S project. The main circuits include voltage regulators, power amplifier, encoder, switches and IR sensors. Below in Figure 35 the top view of the PCB can be seen. The upper right portion of the PCB is the section of pin headers that correlate with the switch circuit design. To the left of that section would be 7 groups of 3 pin headers that are used for the sensor circuits. The top left of the PCB has the headers that will connect to the LCD display. The secluded 5 pin headers towards the bottom of the PCB will be used to program the microcontroller.Majority of the different circuit designs that have been assembled are on the top of the PCB. However the power op-amp design circuit was assembled and designed to be on the bottom. The placement of this design was because of the complications of routing various airwires in the EAGLE CAD software. The vendor used to create the printed circuit board for the L.U.D.S project was PCB International.

Figure 35 - PCB Top View

6.4 Power Supply Assembly

The power supply assembly consists of many different components. It includes a battery, a power transformer, a power switch and the voltage regulator with its corresponding circuit. There are three main objectives in which the power supply is responsible. First would be the safe transformation of high AC voltage to a regulated DC voltage that most devices can take. The AC adapter is a power transformer capable of supplying a regulated DC voltage that is within the scope of our rated conditions.

The system must be able to receive power from both the battery and the power from an outlet. Consequently, the second objective deals with the switching component. A power switch rated to interrupt the amount of voltage incoming from the two DC voltages will be used. The switch will have two poles to ensure the safe switch between two separate electrical circuits. In addition the switch will feature 3 separate positions.

The final objective involves designing a voltage regulator capable of stepping down the DC voltage to the desired level. There are different voltage regulators that were considered but the buck step down converter was chosen. Webench Power Designer is a software used to design the most efficient power regulator needed for the scope of this project.

6.5 Final Coding Plan

To begin with the software planning, the infrared sensor detection is the initial task to be accomplished. The inter-integrated circuit (I2C) connection from the infrared sensor to the microcontroller should be programmed initially. There are three functions specifically to this process. First, the I2C protocol should be initialized in master mode with the eUSCI module. The clock, divider, mode, and other related operations should be declared or set within this function. Next, the I2C should read values and write values. The function to read values makes sure the values are measured and received each time. The function to write values is just to detect the correct sensor based on the configuration value. After the I2C programming is completed, the next task is to use a similar approach for the switches and knobs. This process is very simple using the ADC module to convert the analog values from the switches and knobs to a digital value.

Unlike the I2C protocol, the ADC module just requires one function which contains all parts of the code to convert the values. The initialization function for ADC will do the conversion and the values can be requested from the main function by calling the ADC initialization. After the ADC is programmed, the SPI module is programmed using similar approaches to send the information to the LED strip and LCD display. This would be the basic plan for coding the prototype but the overall software design will be improved dramatically during the process.

7.0 Project Prototype Testing Plan

Before a full prototype is assembled, it is important to test each individual hardware component and feature before they are combined into one cohesive device. Broadly speaking, the main individual hardware components that need to be tested include, the power supply, beat detection, LED array, LCD display, switches, and knobs. Similarly, it is important to test individual software features before putting them together in a final prototype. The main individual software features that need testing include the LCD display of each feature,the LED activation, the metronome functionality, the idle glow, flash, and fade features, the data collection of beat detection, the LED playback of collected beat data, and the activation of features via the knobs and switches. Each of these components have more specific features that shall be explained in the section corresponding to each component. The hardware and software testing will need to be done in parallel because some hardware components require the software to test and vice versa. These tests will likely take place in the UCF TI innovation laboratory and/or the CREOL photonics laboratory. The tests will use the equipment available at each laboratory unless unavailable. In the case that the laboratory doesn't have the testing equipment needed, the equipment will be rented or purchased to be used in the laboratories. The individual testing components and models used in each test will be recorded during data collection. After each component is tested, the hardware and software components will all be combined to create the first full prototype which will undergo a second round of testing to ensure the device meets the standards, constraints, and specifications given at the beginning of this report.

7.1 Power Supply Testing Plan

Verifying the performance and design of the power supply is essential when ensuring a quality product. The power supply serves as the basis of any electrical device. Under normal operating conditions the power supply may operate effectively. However if conditions start to lean outside of the typical rated conditions, many unforeseen consequences may result.

Understanding the amount of time it takes for the power supply to output a regulated voltage is greatly important. Using an oscilloscope, the input connection along with the output connection should be probed. Their respective voltage profiles should be analyzed over time. More specifically the time it takes for the output voltage signal to reach 97% of its estimated final voltage.

Another key aspect to test and analyze would be the overshoot. Before an output voltage reaches its determined voltage there may be time where the voltage is higher than what is nominally set. An oscilloscope should connect to the input and output connections and considerable note should be taken of the peak output voltages.

7.2 IR Sensor Array Testing Plan

Testing the IR sensors will be tough due to the nature of IR light, which is invisible to the naked eye. This will make testing tougher than working with visible light because what is going wrong cannot be immediately pinpoint. There are a number of ways around this problem though, such as using optical power meters to measure the output and IR cards to visualize the beam.

7.2.1 October 25th Demonstration

The first major test of the IR sensor array came on October 25th, which was a mandatory demonstration for CREOL senior design students. During this demo, the students had to present an early prototype for the optical design. The demo was set to be based on a single reflectance sensor detecting a drum beat and activating a single LED. This demonstration would consist of a sensor temporarily affixed to the side of a smaller drum, and connected through a circuit to a Raspberry Pi running a program to detect the output of the sensor, which would activate a LED when the sensor is triggered.

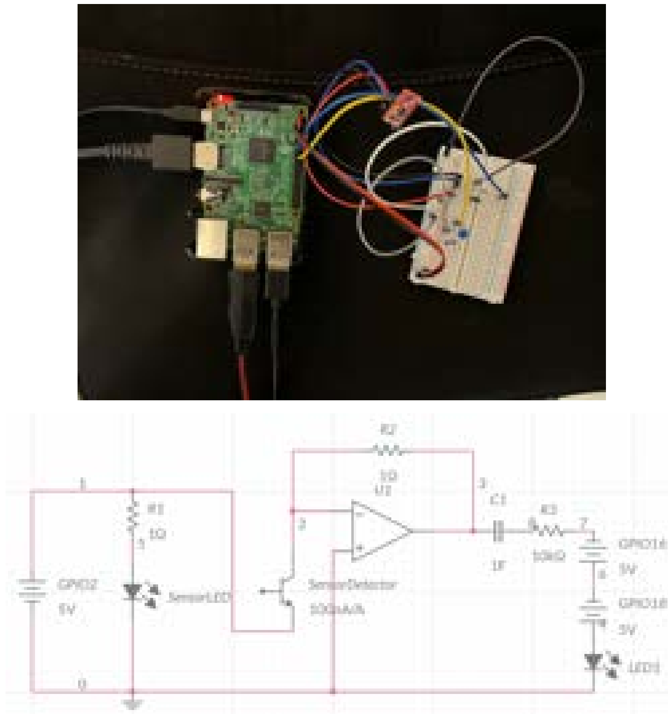


Figure 36 - Circuit design used in the October 25th demo. Breadboard and Raspberry Pi not representative of final design

With the sensor as a pre-built unit, the circuitry for the demonstration was very simple. The input power from general-purpose input/output (GPIO) pin 2 of the Raspberry Pi leads into the sensor, which is connected to GPIO pins 6 (ground) and 16. Pin 18 then goes into the LED, which is also grounded. Later a 10kΩ resistor was added to pin 16 to better control the digital input.

It should be noted that in the diagram in figure 36, The VCC power source icons represent GPIO pins, not power sources. Also in all following diagrams, R1, R2, and C1 are not actually 1 ohm or farad respectively, but they represent components built into the sensor along with the LED, phototransistor, and amplifier.

As shown in appendix B, the script for the demo was coded in python. It is a simple code that reads an input from the sensor at one GPIO, then activates the LED with another pin. “import RPi.GPIO as GPIO” and “import time” are preconditions that allow the program to recognize the PI’s GPIO pins and internal clock respectively. The next lines of code tell the program that the sensor is on pin 16 and the LED is on pin 18, followed by code that allows it to recognize the sensor as an input and the LED as an output.

Once the code is run, the code beginning with “GPIO.output(light,False)” dictates the starting parameters of the program, in this case having the LED start out off, as well as printing a phrase to let the user know it is active and the LED set to off. The following while loop that comes next in the code is what truly allows the code to function. This loop allows the program to continually check if the input the Pi is receiving from the sensor is on or off. If the sensor detects light, the if statement is triggered and the LED is activated for 0.2 seconds and the word “Hit!” is printed. If the sensor is dark, no input is given and the loop repeats without change.

With the circuit and code set up, the first major issue had presented itself. The sensors that had been ordered for this demo were digital, not analog. This was not an insurmountable problem in and of itself, as the design simply could be modified to account for this; however, the drum head did not deform enough to allow for digital sensors to be used. This was the point when the decision to use analog sensors was finalized. The decision was made to not use the drum in this demo and only demonstrate the use of the reflectance sensor in general.

The next problem arose when the circuit was connected to the Raspberry Pi. The problem being that the sensor did not turn the LED on. Troubleshooting was approached from multiple different angles. Running simpler code to test if the pins were properly set on. Using an IR card to test if the LED in the sensor was on. The sensor was tested in multiple lighting conditions and with multiple types of objects. A pull-down resistor was added to the sensor to correct for any digital biasing. While all of these testing techniques independently showed positive results, none of them actually allowed the sensor to operate correctly. In the end, this problem proved insurmountable for this timeframe and the demonstration was ultimately unsuccessful, though it did yield useful information for the long term planning of the LUDS.

7.2.2 December 1st Demonstration

After the October demonstration, the next deadline was another demo on December 1st. The time between demonstrations has been used to try to figure out why the first demo didn’t work, thus the goal for this demo is to present a working version of the originally planned. The process of fixing the initial demo has so far unfolded in two phases of testing, with a third happening soon.

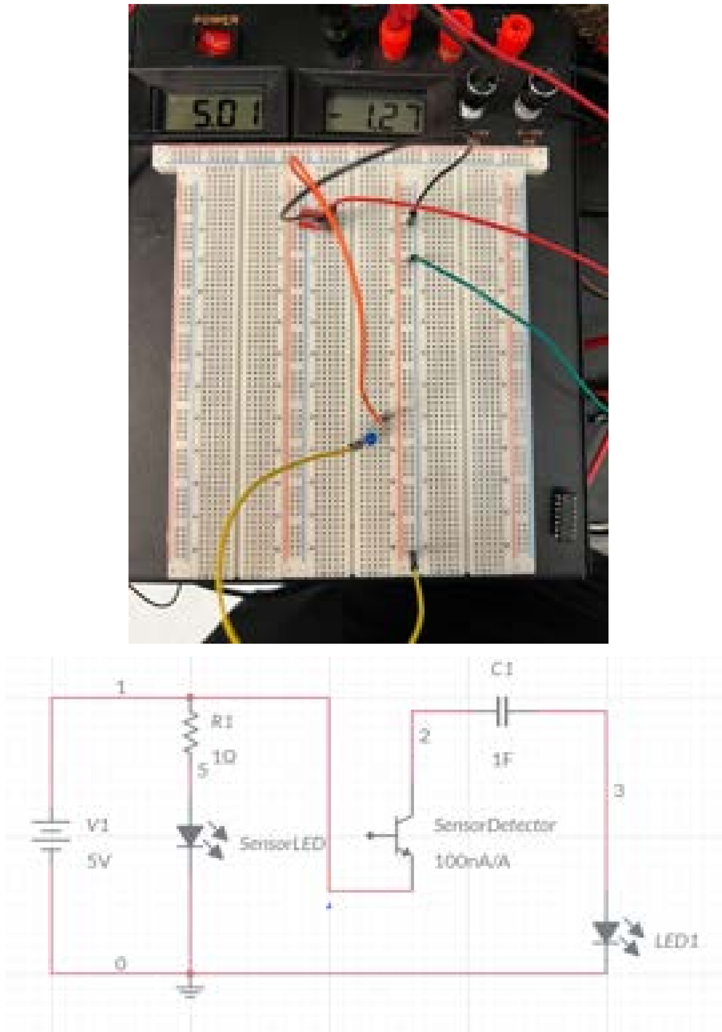


Figure 37 - Simplified Circuit design from early November with just the sensor and the LED. Breadboard not representative of final design

The initial idea to fix the problems from the first demo was to strip the design back to an even simpler variation, which is shown in figure 37. By removing the Raspberry Pi entirely, any potential issues created by the code are eliminated, allowing for the sensor to be tested more directly. In the new design the sensor's output is connected to the LED, so that photocurrent flows directly into the light source. Note that in the diagrams of figures 23 and 24, VCC and ground represent a DC power supply built into the breadboard.

With the sensor and LED directly connected, the LED still did not light up. Applying a digital multimeter to the circuit showed that barely any voltage was being sent to the LED, with only small fluctuation. This would make sense since the output of the phototransistor is only 100 nanoamps. It was believed that there was an amplifier built into the sensor, this appears not to be true.

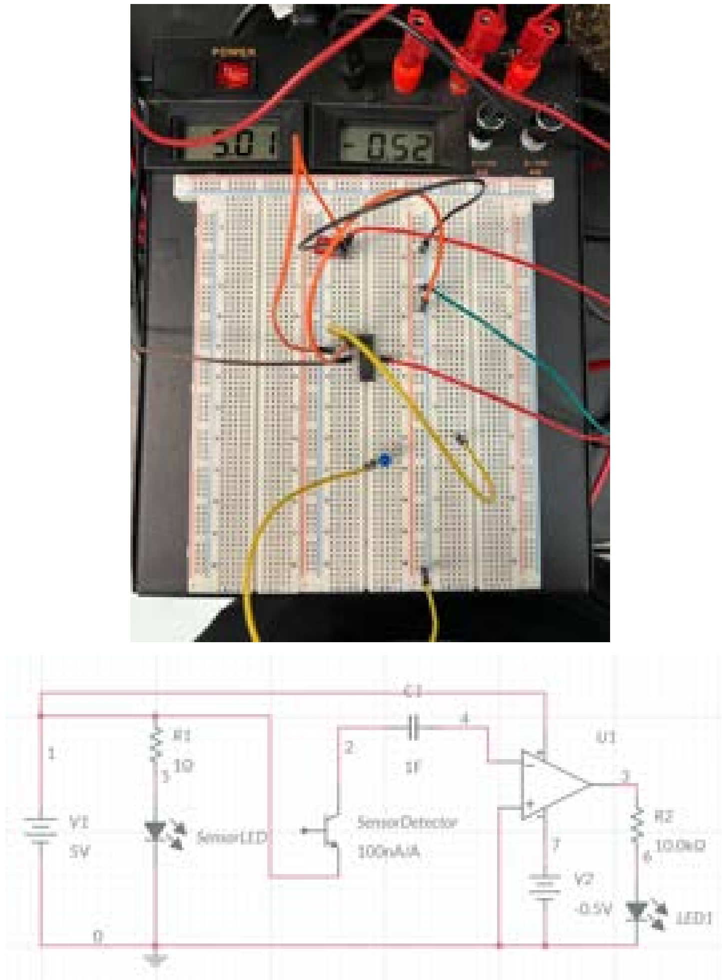


Figure 38 - Circuit Design from November 15th with added opamp (U1). Breadboard not representative of final design

Next logical step was to add an opamp, which is an electrical component that can amplify an input based on the difference between two voltages. This addition gave the circuit shown in figure 38 a larger output, but this proved to not be the entirely correct solution. The circuit now had the opposite problem where the LED was always on. 1 and 10 kilo ohm resistors were put between the opamp and the LED, but only served to dim the LED, not turn it off.

The next step for this design is to try adding a potentiometer to manually adjust how much voltage is entering the circuit. This may not be a practical solution for the final design, but will be able to inform that design. There is also the possibility of re-introducing the Raspberry Pi before December 1 and getting the sensor to work with some kind of code.

There is also a chance that this sensor design may have to be more severely rethought. While it is possible to make this concept work with these sensors, as shown by Sokolovskis and McPherson, their method may be beyond the means of this project. This scenario is unlikely to take place, but it's a possibility. If this does prove.

There is also the matter of switching over the analog sensors. Whether this is done in time for the demo is a matter of logistics. The analog parts have been ordered, but they may not get to the team in time to be incorporated into the demo. If the demo does not include the analog sensors, they will be the first addition to the design after the demo since they are fundamental to the setup of the reflectance sensors.

Note that due to an injury on the part of the LUDS's optical engineer, the team did not participate in the December 1st demonstration.

7.2.3 Future Testing Plan

Many aspects of the IR sensor array have yet to be tested. Once the reflectance sensors can reliably turn on a single LED and have been switched to analog, the next step is designing the arrangement of the reflectance sensors. The optimal positioning of this set of sensors would be the next major hurdle to clear. This aspect of the design may have to be quite precise to have peak functionality from both the sensors and the actual drum. It will also have to be stress tested to ensure the parts keeping the sensors in the head do not fall apart. Not only could that compromise the ability for the LUDS to light up, even non-critically breakage could create debris that affect the sound of drums.

The next phase after getting the sensors to respond is installing a sensor into a small drum. This should allow us to find the best distance between the drum and the sensor. The effective range of the sensors is 3 mm, but depending on how much the drum deforms when vibrating, the best positioning of the sensor will change. Of course to do this, we'll have to measure how much the drum deforms, which can be found with the equation shown in equation 21.

$$\frac{\partial^2 u}{\partial t^2} = c^2\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) = c^2\left(\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r}\right) \quad (21)$$

Where u is the shape of the drum head head while at rest as a function or position (x and y or r) and time t. c is the speed of the wave, which was earlier calculated to be 92.87 m/s for a drum with a 177.8 mm radius.

After optimizing the distance from the drum, the next phase is to begin building the sensors into the main drum to coordinate the TDOA calculations. This will require making sure the code for the TDOA works to the specified accuracy will take a lot of troubleshooting. It will require mapping a coordinate plane onto the drum with an arbitrary x and y-axes chosen to act as a reference, then the team needs to ensure the code can calculate the right equations in the right order to get the desired results.

There is also a whole other half of the sensor array to test with the beam break sensors. With the lessons learned from the reflectance sensors and the larger scale those sensors are operating on, that should be much simpler. The biggest challenge with these sensors should be finding the ideal way to mount them on the outside of the drum while making sure the sensors are safe and secure from the wear and tear of playing a drum as well as hopefully maintaining the drums aesthetic appeal. The design may also have to be expanded if the array is found to not reliably detect the speed of the drumming. Right now six is the target number of sensors, but more may be necessary. Too many sensors also could become inefficient.

For the beam break sensors we'll have to find the average velocity of the drumsticks hitting the head. This is important for calculating the force of individual strikes, since force is a product of acceleration and acceleration needs a change in velocity to be calculated. To find the average velocity the team will have a drummer play a mid-intensity song on the drum, tracking the velocity of each hit, then averaging those data points together. When the LUDS is in performance mode, hits with equal velocity have 0 acceleration and create a moderate flash or light, hits with less velocity will have negative acceleration and create a dim flash, and hits with more will have positive acceleration and generate a brighter flash.

Once the average velocity is found, the calculations for the force should be very straightforward, hopefully meaning there won't need to be a lot of trial and error in testing the code. Given that the beam break sensor does not have a given value on the data sheet, it is possible that the response time could be sluggish for the beam brake sensors, which would require programming around.

In addition to the physical design of the sensor array, making sure the code can track the hits of the drum accurately will likely take a lot of trial and error. The actual calculation should be simple, but making sure the LUDS doesn't drop inputs and properly stores them will be the failure point to really look out for. This could be a time consuming process where fixing one mistake causes another, but this is the last aspect of the sensor array that can be tested since it requires the physical array to be complete before any test could be considered reliable. The debugging process will have to be done efficiently to bring the code up to a working standard in time.

7.3 LED Testing Plan

After purchasing and acquiring the “Non-Waterproof IP20 LED Flex Strip”, the first step to testing the LED strip is to plug it into a standard 12V power supply to ensure the strip functions properly. After supplying the power, the LED strip will be checked to make sure each of the lights are lighting up at a similar luminosity. This can be checked with the eyes of the tester but a light meter may be used to ensure the correct luminosity as advertised in the product details. The strip is rated to have 1080 lumens per meter according to the product details sheet. A tolerance of 100 lumens will be acceptable as a successful test.

7.3.1 LED Dimming Module test

After it is confirmed that the purchased LED strip is functioning properly, then the DIMMER-3CH dimming module and remote must be tested. The dimming module will be placed between the 12V power supply and the LED strip. To test the dimming module, the dimming module's IR remote will be used to switch between all sixteen color combinations to ensure that each of the colors work properly. Next, the custom color programming option will be tested. To test this, five different unique color combinations will be programmed and tested using the IR remote of the module. These five different color combinations will each be from a different part of the visible light spectrum to ensure a wide range of programmability will work on the LED strip and dimming module. The dimming module has additional features that are not integral to the function of the L.U.D.S. but need to be tested regardless to ensure the dimming module works 100% and has no broken functions. These additional features include flash, strobe, fade, and smooth functions. The IR remote will be set to each of these features and tested with three different colors, red, blue and green.

7.3.2 Variable voltage and dynamic luminosity test

A very important function of the L.U.D.S. is the dynamic luminosity of the LED strips. To test this dynamic luminosity, the strips will be supplied by a variable voltage source so the voltage can be varied from 0 to 12V. This test will ensure that the LED’s will produce a linear luminosity with a linearly changed voltage range. This function of the LEDs is required for the dynamic output based on velocity of drum strikes and the fade feature of the L.U.D. system. This test will be done by supplying zero volts of power and incrementing the voltage by one volt and then measuring the luminosity of the LED strip. The data will be collected and then graphed using Microsoft Excel to observe the relationship between voltage and luminosity. According to the RGB 5050 LED data sheet, the luminosity should change linearly with voltage. But in the case that it does not, the graph created using Excel can be observed to help program the MCU to "tune" the output voltage to create a luminous response that appears linear. For example, if the voltage-luminosity graph is exponential, the output voltage based on the velocity of the drum strike might be run through a logarithmic function to offset the exponential behavior of the LEDs.

7.3.3 LED voltage amplifier test

Since the MCU voltage output ranges from 0V to 3.6V DC and the LED strips require 0V to 12V DC, there must be a voltage amplifier between the two components. While this amplifier circuit will be part of the PCB board, it is important to recreate the circuit with a breadboard to verify the design works correctly. To test the design of the circuit, the components of the circuit will be compiled at the testing station along with the appropriate testing equipment. The circuit components required are the TL084CN operational amplifier, one 1KΩ resister (R2) (part number RC0402JR-071KL), one 2.33KΩ resister (R1) (part number RQ73C1J2K32BTD), the Non-Waterproof IP20 LED Flex Strip, a 2.1mm DC pigtail plug wire, the DIMMER-3CH dimmer module, and an assortment of breadboard jumper wires. The testing equipment required consist of a DC voltage generator, a function generator, an oscilloscope, a multimeter, and the appropriate leads for supplying the voltage and probing the circuit (the specific types of leads are subject to what kinds of leads are available in the testing environment. Before the circuit is assembled, the resisters will be tested to ensure they have the appropriate resistance. To accomplish this, the multimeter will be set to measure resistance and the leads placed on either side of the resistor. The resistor will be considered properly functioning if it has a resistance within 1% of the proposed resistance. The TL084CN will be placed on the breadboard with positive and negative leads running from the voltage generator to the breadboard nodes corresponding to pins 4 and 11 respectively on the TL084CN amplifier (see pin configuration in figure 28 below). Next, the breadboard node connected to pin 2 of the amplifier will be wired to the 1KΩ R2 resister. All breadboard wiring will be done via breadboard jumper wires unless specified as a lead from the voltage generator or oscilloscope. The other side of the R2 resistor will be wired to a ground node connected to VCC- which is pin 11 on the amplifier. Then, the 2.33KΩ R1 resistor will be wired between pin 2 and pin 1 of the amplifier. Once the non-inverting operational amplifier circuit is created, it is time to wire the input and outputs. The input will be the oscilloscope which will be wired to pin 3 on the amplifier. The output will be an open circuit for the first test and once the design is verified the LED strip and dimming module will be used as the output for a second test.

Test 1: No Load

Once everything is wired for the first test, the voltage generator will be set to supply 12V DC to node 4 for VCC and 0V to node 11 for VCC-, which is also GND. Next, the positive and negative output leads will be wired from the function generator to pins 3 and 11 respectively. Finally, the oscilloscope leads will run from the oscilloscope to pins 1 and 11 of the amplifier. To conduct the first test, the voltage generator will be activated to supply the power, the function generator will be set to 0V DC, and the oscilloscope will be dialed into the scope of 0 to 15V DC. The voltage of the function generator and the oscilloscope will then be recorded as the function generator is incremented by 0.36V up to 3.6V. The test will be considered a success if the oscilloscope reads values equal to 3.33 ± 0.1 times the voltage supplied by the generator.

Test 2: LED Strip and Dimmer Load

Once it has been confirmed that the circuit works with no load, a similar test will be implemented except with the inputs and outputs changed. The input of the circuit will be replaced by a wire leading from an output pin of the MSP430FR6989 MCU to the pin 3 of the amplifier. Then the 2.1mm pigtail connector will be wired to the output of the circuit with the black wire connected to pin 1 and the red wire connected to pin 11 of the amplifier. Then the plug side will be plugged into the dimming module and the output of the simming module will be connected to the 4-pin RGB input of the LED strip. Next, software will be flashed to the microcontroller allowing it to output 0 to 3.6V DC with increments of 0.36V. The oscilloscope will still be connected to the pin 1 of the amplifier to measure the new output voltage. A light meter will be used to measure the luminosity of the LED strip. The input and output data will be recorded for each incremented voltage level of the microcontroller. The test will be considered a success if the luminosity of the strip increases linearly with the voltage output of the microcontroller. If the test is not a success, then the design on the amplifier may be changed to increase or decrease the gain in order to create a successful test. If it is determined that the design in itself cannot produce the power required for the LED strip, the voltage amplifier may be replaced with a power amplifier circuit to supply the correct amount of power.

7.4 LCD Display Testing Plan

The objective here is to check if the LCD is able to display the two variables that are planned in the design. The first line needs to display “Mode: Metronome” or “Mode: Sensing” which is basically tested by switching the flip switch on/off. The second line should display the beats per minute value along with its units “bpm” and the bpm value can be up to three digits. The test plan is to just rotate the knob for the bpm in the metronome mode to check if the value displayed on the LCD is accurate. Overall, for the prototype, these are the basic requirements that need to be met to achieve the core objectives.

7.5 Switch Testing Plan

To test the switch design, the switch circuit in figure 13 will be assembled on a breadboard and connected to the MCU. Before assembling the circuit, the resisters used will be tested using a multimeter to ensure they are functioning properly. Once the circuit is assembled, the MCU will be programmed to display the text “left” or the text “right” on the LCD whenever the switch is changed from left to right respectively. Then the switch will be switched left and right a total of 50 times and each time the text of the LCD display will be recorded. The test will be considered a success if the MCU correctly recognizes the change of the switch at least 98% of the time. This process will be repeated for each switch bought for the project to ensure each switch works properly. If the MCU frequently changes between displaying the text “left” and “right” without the toggling of the switch, then the switch is in a HI-Z state. To fix this, the design of the pull-down resistor circuit must be revised to ensure the only states for the switch are on and off.

7.6 Rotary Encoder Testing Plan

To test the functionality of the rotary encoder design, the circuit in figure 16 will be assembled and connected to the MCU. Before assembling the circuit, all components will be measured using a multimeter to ensure they all have the correct values required. The MCU will be programmed to display BPM on the LCD display so when the knobs are being tested, it can be assured that the MCU is reading whether the knob is rotating left or right. The BPM will increase as the encoder is rotated clockwise and decrease as the encoder is rotated counter-clockwise. Once everything is set up and configured correctly, the knob will be rotated each way and the BPM displayed by the LCD will be recorded. Once it is tested that the knob is read by the MCU correctly, then the knobs will be rotated so the LCD displays 40, 60, 80, 90, and 100 BPM. This is to ensure that the knobs are sensitive enough to easily select the desired BPM without having to very carefully dial in the knobs. If it is tedious to dial in the correct BPM, the knob sensitivity will be tuned in the MCU programming to ensure a smooth user experience. This process will be repeated for each of the knobs purchased for the prototype.

7.7 Metronome Testing Plan

To test the metronome, the prototype needs to have at least the LED strip, the power supply, and the MCU working properly. The first step to testing the metronome is to configure the L.U.D.S. prototype into metronome and input a BPM of 40. Next, the leads of an oscilloscope will be placed on the power cable connecting the voltage amplifier of the LED strip to the dimming module. The oscilloscope will then measure the voltage going into the LEDs for a total of 10 seconds. After the measuring is stopped, the time between each blink of the LED will be calculated by subtracting the time difference between the start of each blink. This gives the measured flash rate. This process will be repeated six more times, each time increasing the BPM by 10 until a BPM of 100 is tested. Once the data is collected, the expected beat flash rate will be calculated using the equation below. Finally, the metronome percent error will be calculated. The test will be considered a success if the percent error is less than 2% for each of the different BPMs tested.

$$Beat\ Flash\ Rate\ =\ \frac{BPM}{60sec} \tag{22}$$

$$Metronome\ Percent\ Error\ =\ \left|\frac{Expected\ Flash\ Rate - Measured\ Flash\ Rate}{Expected\ Flash\ Rate} * 100\%\right| \tag{23}$$

These equations are the calculations needed to test the accuracy of the metronome feature. The beat flash rate is calculated by using the input BPM. Then the metronome percent error is calculated using the expected flash rate and the measured flash rate from the tests. The result of the calculation will show by what percent, the actual metronome flash timing is offset from the expected metronome flash timing.

7.8 Unexpected Test Results

Apon first testing the non-inverting amplifier circuit, it appeared to work as planned, but once the voltage supplied to the input was taken away, the amplifier would still output 12V. This became a problem because the amplifier needs to be able to output close to zero volts when the device’s LED strips need to be off. This issue was caused by the amplifier outputting rail-to-rail since the original design had +12V at the positive rail and 0V going to the negative rail. To amend this, a voltage inverter circuit was added to the design in order to supply -12V to the negative rail.

7.9 Sensor Implementation

While it took some time to find a circuit design that worked for the reflectance sensors, the final circuit ended up being even simpler than anticipated, as shown in figure 39. We found that the problem was that the resistance values we initially used were off. We determined that the input resistance going to the IR LED needs to be at most 100 Ω, but not only that, we noticed that we could adjust the sensitivity of the sensor by adjusting this value. Ultimately we landed on 33 Ω as the value for this resistance. R2 had a value of 10k Ω and once we had completely designed and test the circuits, we found that the optimal distance from the skin to the sensors was approximately 0.5mm.

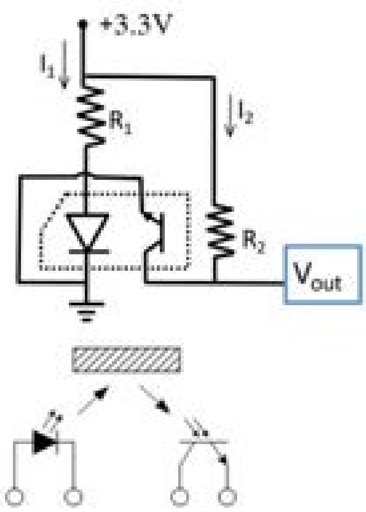


Figure 39 - Update circuit for the IR sensors

This circuit design would have also supported the beam break sensors, but unfortunately the beam break sensors could not be implemented. This was because the process of mounting the sensors to the drum in such a way that they were perfectly aligned would have taken too long by the time we had started to mount the sensors. Because the reflectance sensors were analog, with some time we still could have implemented the full motion tracking feature, there was not time to redesign this system. While testing the sensors with the LED strip, we discovered a new feature that would improve performance mode: the LEDs would produce different colors based on how hard the drum was struck. This feature looks quite striking, though we have not gotten full control of it.

8. Administrative Content

8.1 Milestone Discussion

For the completion of the project by the correct dates, the initial plan drafted during the first few weeks is shown in the tables below for both semesters. The overall plan for the first semester (fall 2022) is to complete the planning of the entire project design along with the one hundred and twenty originally authored pages with four group members. In the second semester (spring 2023), all members in the team will be working on the hardware and software design together. This part includes the overall build construction and programming of the microcontroller to achieve all the goals and objectives represented in the project documentation report in the first semester.

8.1.1 Fall 2022 - Senior Design I

For Senior Design I, the overall goal is to complete the project design documentation based on the topic chosen along with the construction and testing of a prototype. Initially, a group of four members is formed during the first week with a group number specific for each professor. Then, a topic is chosen that is related to the field of the team members' major which should be able to be completed in two semesters.

As a group, preparations are required to review and research on the projects from previous semesters to get familiar with the concepts of design development. Then, more research is required to be completed on the materials and components needed to constant the hardware design. Using the initial researched topics, the divide and conquer 1.0 documentation needed to be completed before the due date stated in the table. Next, the group needs to set up a meeting with the professors to fix the errors on the documentation. After the discussion, the document needs to be updated to divide and conquer 2.0 and submitted before the date stated in the table.

Then, the document needs to be updated to 60-page draft report initially then to 100-page draft report, and finally polish and finalize the overall 120-page report documentation. Before the initial draft, there is also a mid-term demonstration of the prototype construction. And after the draft submissions, there is an end-term demonstration before the due date of the final report. Altogether, these are the major objectives for the senior design I semester and the anticipated completion dates for each goal is specified in the table below.

Planned Milestones	Anticipated Completion Date
Form a group of four based on the initial project topics and ideas	During the first week of the semester
Review existing projects from previous semesters and understand the basic requirements	By the end of third week
Research for project related products, technologies, parts, components	Throughout the semester
Start preparing for initial design ideas, budget specifications and management along with team member roles for individual concepts	Throughout the semester
Complete divide and conquer 1.0 based on the preparations and research about the topic	September 16, 2022
Update and complete divide and conquer 2.0 with more additional information and details	October 7, 2022
Mid-term Demonstration on the vibration detection via infrared sensor for photonics	October 25, 2022
Update and complete the 60-page draft report documentation with more details on the major topics such as the hardware/software design	November 4, 2022
Update and complete the 100-page draft report documentation	November 18, 2022
End-term demonstration on the LED activation via vibration detection for photonics	December 1, 2022
Finish the 120-page final report documentation along with printing and bounding with non-paper cover	December 6, 2022

Table 30 - Fall 2022 Milestones

8.1.2 Spring 2023 - Senior Design II

For Senior Design II, the conclusive goal is to construct the hardware design and the software design planned in the Senior Design I documentation. The hardware part consists of the parts ordering before the beginning of the semester, then building the PCB with all the components required to set up the entire product. The software part is coding the microcontroller to take inputs from the twelve installed infrared sensors and provide the outputs to the LED strip lights and the LCD display.

Basically, the overall hardware design should be completed by the end of february which includes the entire build construction along with the PCB. The initial steps begin with the installation of the drum setup with six infrared sensors on the top and six infrared sensors below the drum skin. Then, the LED strip light should be connected around the circumference of the drum. After the basic procedures, the PCB connections should be made to the microcontroller, along with the two switches, a rotatable knob, and the light color box. The software design and coding of the microcontroller should be completed in the following month until the week of the project demonstration.

Planned Milestones	Anticipated Completion Date
Start ordering parts that are required primarily for the printed circuit board initially	First week or earlier
Perform some PCB researches based on the planned design ideas and required components	Early January
Construct and complete the overall hardware construction and setup of the planned design	Early February
Complete the overall software design and coding of the infrared sensor to output the values to the LCD	Late February
Complete the coding for LEDs flashes and colors 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	Late March
Test hardware specific and software specific	Late March
Complete the overall planned tasks and designs along with testing for the reliability and safety	Early April
Final project demonstration	Finals week

Table 31 - Spring 2023 Milestones

8.2 Budget and Finance Discussion

This section covers all things related to the budget. 8.2.1. Covers the estimated budget and how it was created. 8.2.2. Covers how the potential sponsors were found. 8.2.3 is a list of potential sponsors and their contact information.

8.2.1 Estimated Budget

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. Table 32 below shows the breakdown of the estimated budget. After completion the project cost around $730. The budget deficit came from expedited shipping and PCB lead time in order to meet deadlines.

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 32 - Preliminary Budget Estimate

8.2.2 Sponsors

In order to fund this five hundred dollar project, potential sponsors will be contacted and asked for financial support. Because this project will be a “proof of concept” device, the potential sponsors are companies that would be interested in specific parts of the design of the project. This includes stage lighting companies that might be interested in the vibration sensitive LED lighting aspect of the project, electric drum kit companies that might be interested in the infra-red beat time, location, and velocity detection, and music equipment retailers that might be interested in selling similar devices. Section 5.1 will show the contact information for specific employees at each company that would be in charge of philanthropic decisions. If such a position is not found, basic company contact information is shown. The companies/employees will be contacted via phone and/or email to inform them about this opportunity for sponsorship. Any relevant documentation and/or correspondence with the sponsors will be available in the appendix of this report.

8.2.3 Potential Sponsors

The Roland Corporation, despite its European name, is a Japanese based company with a branch based in California. They are an important manufacturer of electronic instruments such as synthesizers and drum machines. One of their largest claims to fame is their substantial role in the development of the MIDI files, a process that the LUDS hopes to implement if the time and resources can be allotted.

Company: Roland Corporation U.S.
Address: 5100 S. Eastern Ave.
Los Angeles,
CA 90040-2938
Products: Electronic Instruments and Music Equipment
Phone Number: 323-890-3700

Ef-Note is a relatively new company that produces fully electronic drum kits. Being that their kits are already fully electronic the LUDS could mesh well with their existing technology and they could provide useful guidance. Being new and smaller compared to a large and established company like Roland could also make them easier to contact and work with.

Company: Ef-Note Inc.
Products: Electronic Instruments and Music Equipment
Contact: Instagram
Instagram Page: https://www.instagram.com/efnote/

RS Sound and Lights LLC. is a local company based right here in Orland that specializes in audiovisual shows. The LUDS is an audio and visual piece, so having a company that deals with both could be an extremely useful resource. As well, having the company be based in the same area as the LUDS is being built would make communication very smooth and painless.

Company: **R S Sound & Lights LLC.**
Address: 9424 Cobalt Park Dr,
Orlando, FL
32832
Products: Audiovisual Solutions
Contact: Roberto Sanchez
Position: President
Phone Number: 407-580-8868
Email Address: rsanchez@rssoundlights.com

SweetWater Sound is a large online distributor of musical and audio equipment. Being a distributor they would have access to a large variety of equipment that the team could potentially access. They could help us select the best possible drum from the LUDS to be designed around.

Company: **SweetWater Sound**
Address: 5501 US-30 West,
Fort Wayne, IN
46818
Products: Music Equipment Retail
Contact: Heather Herron
Position: Vice President of Corporate Communications
Phone Number: (260) 432-8176 x1030
Email Address: heather_herron@sweetwater.com

8.2.4 Bill of Material

Below is the bill of materials covering each component and part required to build the L.U.D.S. prototype. It lists the purpose, description, quantity and part number for each component along with whether or not it has been acquired. The bill of materials is broken down into three sections, circuit components, battery components, and miscellaneous components each shown in figures 32, 33, and 34 respectively.

Battery Components

The bill of materials for the battery related components are listed below in Table 33. The battery related components include a power switch, AC adapter, battery and a voltage regulator. No parts from this battery related set of components have been acquired as of yet. However the potential need for a bulk purchase of these parts is assured due to prior availability research.

Description	Purpose	Quantity	Part Number	Acquired
Power Switch	Switches power from battery and outlet	1	Walfront	No
AC adapter	Rectifies AC signal to DC	1	COOLM	No
Battery	Provides power	1	BW 1250	No
Voltage Regulator	Synchronous Buck Converter	1	TPS563212DRLR	No

Table 33 - Battery Components BOM

Circuit Components

Below Table 34 lists the bill of materials for the circuit related components and features a complete number of circuit components that will be needed for this project. Components include the amplifier necessary for power amplification and the associated power resistors. In addition to the amplifier listed is the 10 K potentiometer that is responsible for changing the contrast of the LCD display. The connectors from the dimming module to the amplifier and from the dimming module to the LED strip are also shown. The connection from the dimming module to LED strip is established through the 4- pin RGB jumper cable

Description	Purpose	Quantity	Part Number	Acquired
Amplifier	Amplifying signal to LED strip	1	TL084CN	Yes
Amplifier Resistor R1	voltage amplifier for LED power	1	RC0402JR-071KL	No
Amplifier Resistor R2	voltage amplifier for LED power	1	RQ73C1J2K32BTD	No
2.1mm Pigtail Cable	Connecting voltage amplifier to dimming module	1	21M-PC-WIRE	No
2.1mm Jumper Cable	Connecting voltage amplifier to dimming module	1	LO-SC-JMP-1M	No
4-pin RGB Jumper Cable	Connecting dimming module to LED strip	1	LO-RGB-JMP-1M	No
SPDT Toggle Switch	Switches for control box	3	3-1825136-7	No
Switch Pull-down Resistors	Pull-down resistors for toggle switch circuit	6	RC0402FR-0735KL	No
Rotary Encoder	Knobs for control box	3	PEC11R	No
Rotary Encoder Resistors	Pull-down / filter resistors for rotary encoder circuit	12	RC0402FR-07300RL	No
Rotary Encoder Capacitors	Capacitors for rotary encoder filter circuit	6	CL05B103KB5NFNC	No
USB Pull-Down Resistors	USB port pull-down resistor	2	PNM0402E3502BST1	No
10K Potentiometer	To change the LCD contrast level	1	wh148kit10K2	Yes

Table 34 - Circuit Components BOM

Miscellaneous Components

The miscellaneous components consist of different parts that may not be battery or circuit related, but are very major to the system. Below Table 35 lists the bill of materials for the miscellaneous related components. Some of the components include the various sensors necessary for the L.U.D. system to be able to detect a hit on the drum. The sensors used include the beam break sensor and the reflectance sensor.

Description	Purpose	Quantity	Part Number	Acquired
Control Box	Houding all non-peripheral components	1	N/A	No
LED Strip	LED strip for drum head	1	R6060-IP20-RGB-06	No
Dimming Module	RGB control of LED strip	1	DIMMER-3CH	No
USB Receptacle	USB receptacle for control box	1	USB1046-GF-0190-L-B-A	No
LCD Display	To display the mode and BPM	1	03-01-1945	Yes
MSP430FR6989	To perform all software design and functions	1	N/A	Yes
Reflectance Sensors	Detecting drum vibrations	10	QRE1113	Yes
Beam Break Sensors	Detecting drumstick velocity	10	OPB856Z	Yes
Small Drums	Prototyping designs	5	N/A	Yes
14" Snare Drum	Building final design	1	N/A	Yes

Table 35 - Miscellaneous Components BOM

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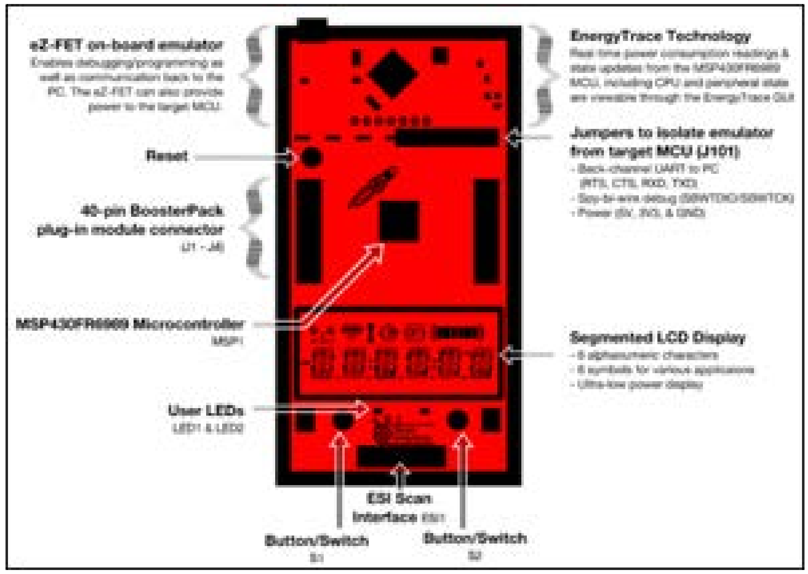
Appendix A


eZ-FET on-board emulator
EnergyTrace Technology
Jumpers to isolate emulator from target MCU (J101)
Reset
40-pin BoosterPack plug-in module connector
MSP430FR6989 Microcontroller
Segmented LCD Display
User LEDs
ESI Scan Interface
Button/Switch
Button/Switch

Appendix B

```
import RPi.GPIO as GPIO
import time

sensor = 16
buzzer = 18

GPIO.setmode(GPIO.BOARD)
GPIO.setup(sensor,GPIO.IN)
GPIO.setup(light,GPIO.OUT)

GPIO.output(light,False)
print "1! 2! 1, 2, 3, 4!"
print " "

try:
   while True:
      if GPIO.input(sensor):
          GPIO.output(light,True)
          print "Hit!"
          while GPIO.input(sensor):
              time.sleep(0.2)
      else:
          GPIO.output(light,False)


except KeyboardInterrupt:
    GPIO.cleanup()
```