# DRUM SMART

ECE 445 Design Document — Spring 2020
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4/17/20

# 1 Introduction

## 1.1 Objective

An issue in today's society deals with the amount of opportunities each community throughout America has to offer. For instance, one area might have thousands of available options and possibilities whereas another town could have only a small fraction of the previous community's opportunities. To reduce this difference in opportunity, the Hip Hop Xpress is a bus that will travel to areas and neighborhoods throughout the US to educate people on both music and technology to demonstrate the resources that are available outside of their area [1]. We want to bring each visited community together in an educational way. By adding an interactive device that people could pick up and use, we would have these people physically working with some of the resources their environment does not currently offer. To meet this objective, we plan to design a drum capable of sounding like several other types of drums. It will look just like a marching band drum except the drum pad would consist of a layer of rubber to absorb most of the noise coming from the physical striking of the pad. We want to minimize the sound coming from the strikes because we want the created drum sounds to be outputted through a connected speaker through an AUX cable. Our electronic drum will be similar to an actual snare drum in the aspect of force-to-sound ratio; the harder the strike, the louder the sound. To select the type of drum the user desires, we will implement a control knob the user can twist to select the type of sound the drum will make when the pad is struck. We also plan to allow the user to control the pitch of every selected drum sound by flipping a switch to either raise or lower the pitch to add more variation to their sounds. To make our drum portable, all of our electrical components will be powered by a rechargeable battery.

## 1.2 Background

For many people in America today, they are immensely impacted by their surrounding environment. For example, some individuals have a lot fewer options than others purely due to their communities. Some areas do not present all the possibilities or opportunities that exist around the world. If we are able to demonstrate something that they find very cool or interesting, we have a chance at changing those individuals' futures, hopefully for the better. One way to reach many people and also get a message across is through music [1]. With the help of the Hip Hop Xpress, our idea is to show some simple yet cultivating aspects of music and technology to people that have never seen or even knew of technology like this existing. Overall, we want to spark interest in musical and technological industries hoping that one day, someone visited by the Hip Hop Xpress finds their true passion from interacting with the resources that were not previously offered to them.

The use of technology in music today is very prevalent. Besides gifting musicians with the ability to record their music, technology is also used to develop many of their skills such as rhythmic accuracy, memorization, and expression [2]. Since technology has become such a large part of music, we knew we had to find a creative way to utilize technology with an instrument to achieve our goal of teaching people about both music and technology. However, Drum Smart is not the first solution for addressing our objective. Some techniques that try to solve our issue involve incorporating engagement, utilizing music the user enjoys, and inspiring creativity [3]. We believe Drum Smart demonstrates all the previous methods in one device. Since the user is physically playing the drum, we are having the user engage with our device. The user can play any music they desire, so they have the option to play music they enjoy or not, the choice is theirs. Drum Smart inspires creativity because there is no electronic drum that allows the user to switch the sound it emits. The most similar product that resembles Drum Smart would be the Rock Band drum set. However, Drum Smart has only one pad to be struck whereas the Rock Band drum set has four separate pads along with a pedal [4]. Our device is also able to be used without having to play a video game, however, the drum set from Rock Band only functions when the game is running. This limits the user to playing only the songs on the game whereas Drum Smart allows the user to play anything they desire.

**1.3 High-Level Requirements**

- One drum sound is emitted for every strike on the drum pad. We do not want two sounds outputted when the pad is only struck once. We want our electronic drum to be as similar to a real drum as possible. Since a real drum does not make multiple sounds from one strike, our device should not either. To test that our drum sounds like a real drum, we will blindfold a drummer to listen first to our drum and then a real drum. If they are unable to tell the difference between the drums, we have reached this goal.
- The user has the choice to pick between four different types of drums. The types of drums we wish to include are snare, tenor, bass, and cymbals. These are the main instruments that makeup a marching band percussion section giving the user a variety of drums to pick from which increases the chances the user finds something they enjoy.
- All of our components in our device are powered by only one rechargeable battery that does not need to be removed from the device to be recharged. We do not want the user needing to take apart the device just to recharge the battery. The single battery is able to power everything for at least four hours when the drum is under continuous use without needing a recharge.

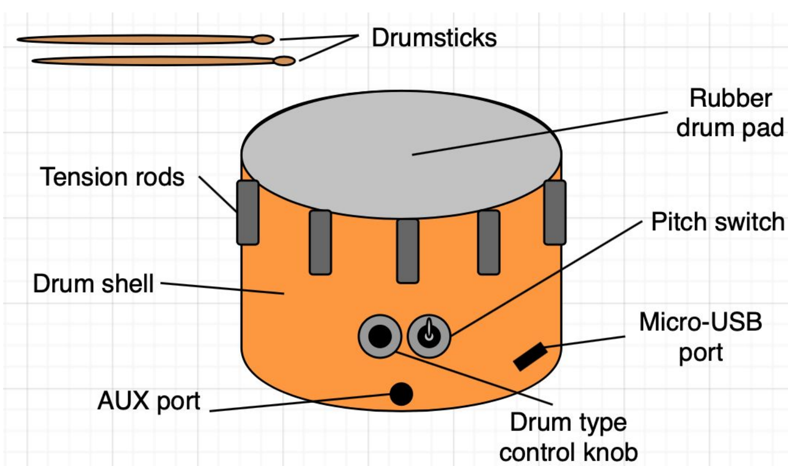


*Figure 1: Drum Smart Physical Design*

*Our drum will look similar to a marching band drum. The user will strike the drum with the drumsticks like a regular drum. There will be a layer of rubber on the drum pad. On the drum shell, there will be a control knob for drum type selection and a switch for pitch. Additionally on the shell, there will be an AUX port to connect an AUX cable to play the created sounds through a speaker and a Micro-USB port to recharge the battery.*

## 2 Design

Our plan is to design a drum capable of sounding like several other kinds of drums. Our device will look like a marching band drum with a drum pad as a layer of rubber to absorb most of the noise coming from the strikes on the pad. Underneath the rubber, an accelerometer will measure the amount of force used to strike the pad. This data will be sent to our microcontroller. Our microcontroller will use this user input data to access memory to output the desired drum sound. This sound data from memory will be sent to a sound card which will significantly improve the sound quality. These created drum sounds will be outputted through a connected speaker via AUX. We will implement a control knob the user can twist to select the type of drum sound our drum will emit when the pad is struck. We also plan to allow the user to control the pitch of every selected drum by flipping a switch to either raise or lower the sound by one octave to add more variation to their drum sounds. To make our drum portable, all our electrical components will be powered by a rechargeable battery.

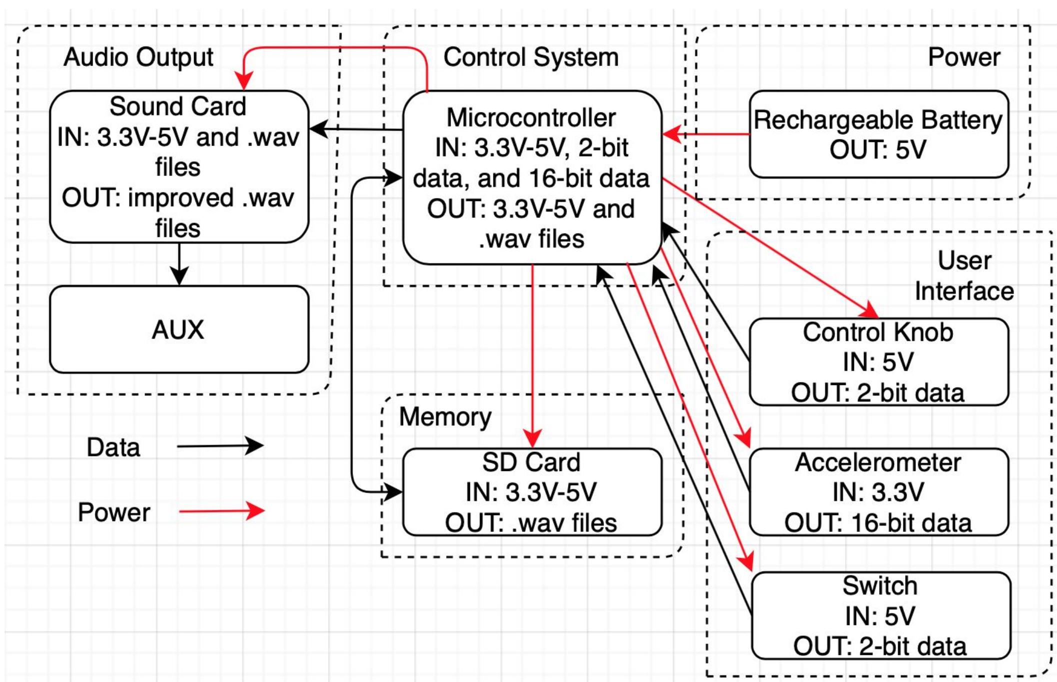


*Figure 2: Drum Smart Block Diagram*

*A rechargeable battery will power our device. The user will be able to control volume by the accelerometer, type of drum by a control knob, and pitch level by a switch. The data collected by the accelerometer, knob, and switch will be sent to the microcontroller. Our microcontroller will access memory on the SD card based on the user input data to pull the correct sound from memory. The microcontroller will send this data from memory to the sound card to improve the sound quality. This improved sound is lastly outputted through AUX.*

### 2.1 Power

The power supply will ensure all our components in Drum Smart remain functional. We wanted our device to be portable, so we decided to use rechargeable batteries as our power source instead of using a plug-in which is a big limit where the user can take the device.

| Requirements | Verifications |
|---|---|
| 1. Must output a minimum 5V. | 1a. Probe the battery with an oscilloscope to ensure the battery is outputting our desired minimum voltage. |

*Table 1: Rechargeable Battery Requirements and Verifications*

**2.1.1 Rechargeable Battery**
IN: Recharges from Micro-USB
OUT: 5V
DESCRIPTION: Our device utilizes a rechargeable battery that outputs 3.3V-5V capable of powering all of our components. This battery can be recharged using a USB to Micro-USB cable. This hat is attached to our microcontroller, the Raspberry Pi, by four screws. Our device can even function while charging. The rechargeable battery allows for portability of the device. This battery can function off of a full charge for about 4-6 hours under constant use [5].
PART: PiJuice HAT (includes 1820 mAh Lithium-Ion battery and battery HAT)

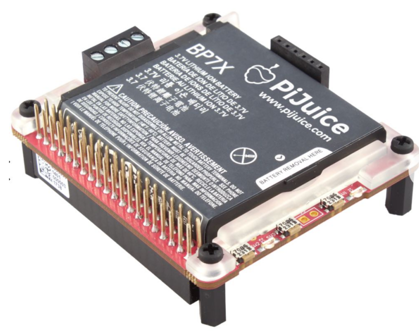


*Figure 3: PiJuice HAT Physical Design*

*Requirement: Stored below 60℃. Output 5V.*

**2.2 Memory**
Drum Smart must store .wav samples that can be played when needed. The memory system must allow for quick access so that the drum hit to sound output delay is not noticeable.

**2.2.1 SD Card**
IN: 3.3V-5V (powered by Raspberry Pi when placed in Micro SD Card slot)
OUT: .wav files
DESCRIPTION: The .wav files of audio samples are stored onto an SD Card. Using an SD Card, we can store higher quality samples without worrying about limitations of memory. Up to 8 samples can be played at one time. The data from the SD Card is sent to the sound card, then to the output.
PART: SanDisk 32GB Ultra microSDHC Card Class 10 (SDSDQUA-032G-A11A)


*Figure 4: SanDisk 32GB Ultra microSDHC Card Physical Design*

*Requirement: Can be read at 250 KB/sec.*

**2.3 Control System**
The control system of the unit must take data inputs from the accelerometer and control knobs and then send the correct .wav file to the soundcard for output.

| Requirements | Verifications |
|---|---|
| 1. Operates within range of 5V +/- 5%. | 1a. While running the microcontroller, probe input and output voltage with DMM/ oscilloscope to confirm the difference between Vin and Vout is within 4.75V-5.25V. |

*Table 2: Control System Requirements and Verifications*

**2.3.1 Microcontroller**
DESCRIPTION: Raspberry Pi will be able to take input data from the accelerometer, control knob, and switch. Using this data, the microcontroller decides what audio file from the SD Card to drive to the sound card and at which volume the audio will be outputted.
PART: Raspberry Pi Model 3 A+

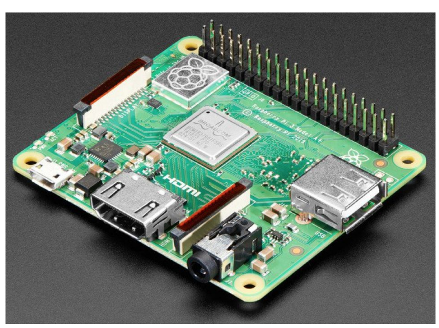

*Figure 5: Raspberry Pi* Model 3 A+ *Physical Design*

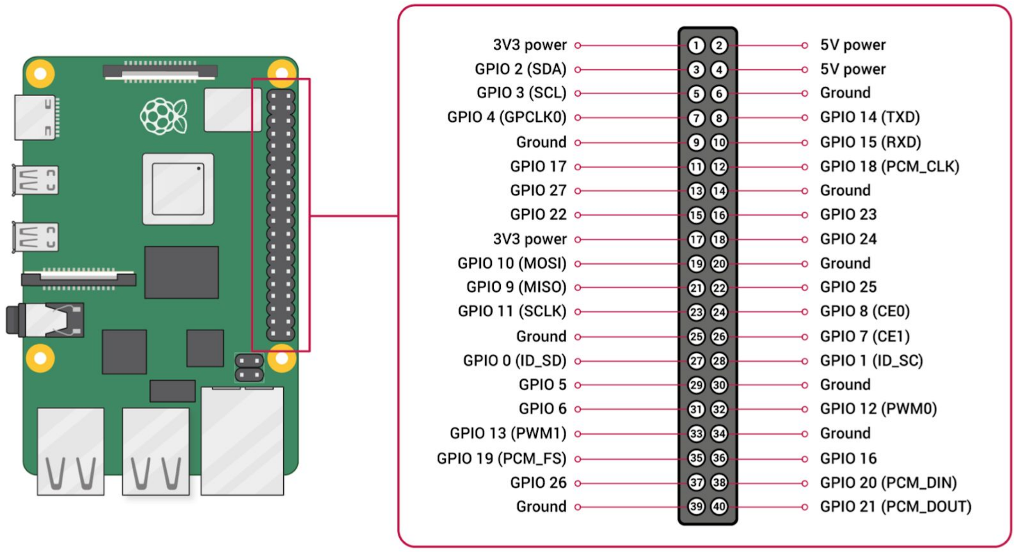


*Figure 6: Raspberry Pi Model 3 A+ Pin Configuration*

*Requirement: Function at 3.3V-5V from battery.*

**2.4 User Interface**

Our desire is to make Drum Smart as similar in use to an average drum while including parameters that a user can change.

| Requirements | Verifications |
|---|---|
| 1. Accelerometer, knob, and switch must have a maximum latency of 0.2 seconds. | 1a. Use an oscilloscope to measure response time after an individual pad strike. We will do this by probing the signal from the accelerometer and compare that time to the signal time sent by the microcontroller due to the action. The difference between signal times must be at most 0.2 seconds. |

*Table 3: User Interface Requirements and Verifications*

**2.4.1 Accelerometer**

IN: Changes in acceleration of the drum pad
OUT: 16-bit digital output
The accelerometer converts the force and acceleration of the drum head into three digital outputs for the X, Y, and Z axis measurements. We chose to use the ADXL375 accelerometer because it has a wide force detection range (±200g) which corresponds to ±1,960m/s^2. This piece reads the amount of force which allows for change of volume of sound output. This component has a 16-bit digital output which means no additional ADC is needed to make coding feasible [6].
PART: ADXL375 - Accelerometer, 3 Axis Sensor Evaluation Board

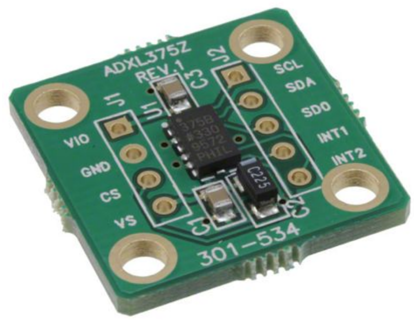


*Figure 7: ADXL375 Accelerometer Physical Design*

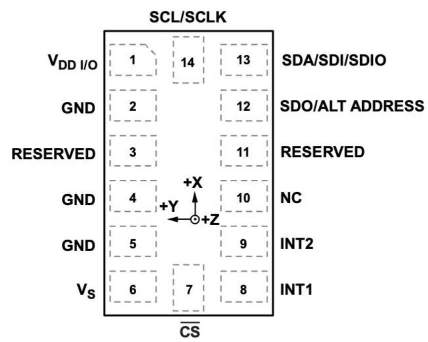


*Figure 8: ADXL375 Accelerometer Pin Configuration*

| Pin No. | Mnemonic | Description |
|---|---|---|
| 1 | $V_{DD\ I/O}$ | Digital Interface Supply Voltage. |
| 2 | GND | Ground. This pin must be connected to ground. |
| 3 | RESERVED | Reserved. This pin must be connected to $V_S$ or left open. |
| 4 | GND | Ground. This pin must be connected to ground. |
| 5 | GND | Ground. This pin must be connected to ground. |
| 6 | $V_S$ | Supply Voltage. |
| 7 | $\overline{CS}$ | Chip Select. |
| 8 | INT1 | Interrupt 1 Output. |
| 9 | INT2 | Interrupt 2 Output. |
| 10 | NC | Not Internally Connected. |
| 11 | RESERVED | Reserved. This pin must be connected to ground or left open. |
| 12 | SDO/ALT ADDRESS | SPI 4-Wire Serial Data Output (SDO)/$I^2C$ Alternate Address Select (ALT ADDRESS). |
| 13 | SDA/SDI/SDIO | $I^2C$ Serial Data (SDA)/SPI 4-Wire Serial Data Input (SDI)/SPI 3-Wire Serial Data Input and Output (SDIO). |
| 14 | SCL/SCLK | $I^2C$ Serial Communications Clock (SCL)/SPI Serial Communications Clock (SCLK). |

*Table 4: ADXL375 Accelerometer Pin Functions*

| Power Mode | $V_S$ | $V_{DD\ I/O}$ | Description |
|---|---|---|---|
| Power Off | Off | Off | The device is completely off, but it is still possible for the device to create a conflict on the communication bus. |
| Bus Disabled | On | Off | The device is on in standby mode, but communication is unavailable and the device can create a conflict on the communication bus. Minimize the duration of the bus disabled state during power-up to prevent a conflict on the communication bus. |
| Bus Enabled | Off | On | No functions are available, but the device does not create a conflict on the communication bus. |
| Standby or Measurement | On | On | At power-up, the device is in standby mode, awaiting a command to enter measurement mode, and all sensor functions are off. After the device is instructed to enter measurement mode, all sensor functions are available. |

*Table 5: ADXL375 Accelerometer Power Modes*

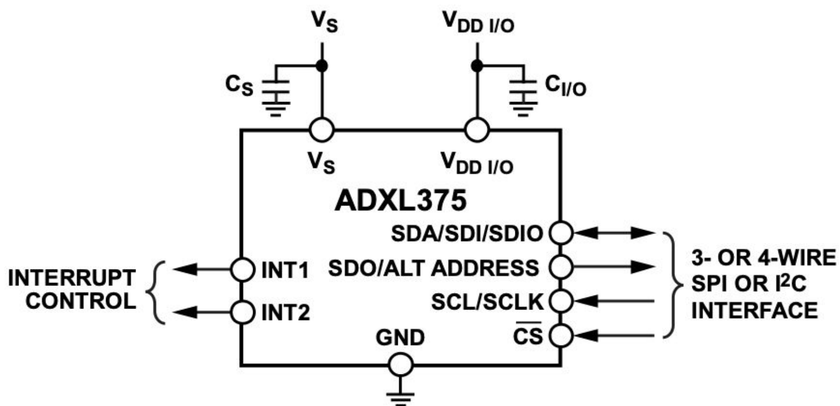


*Figure 9: ADXL375 Accelerometer Application Diagram. CS = 1 microF and CI/O = 0.1 microF*

*Requirement: Voltage range is 1.8-3.6V. Device typically draws 300 µA.*

### 2.4.2 Control Knob

IN: Drum type selection
OUT: 2-bit digital output
DESCRIPTION: We want to give the user the choice to pick among four different drum types. We decided that turning dials, or control knobs, to select the desired drum was the easiest method for any user to understand. For the drum type control knob, we will be using a rotary encoder. This encoder operates at 5V [7]. The SW pin will not be connected because it changes the switch function which is not needed [8].
PART: KY-040 Rotary Encoder Brick Sensor Module Development

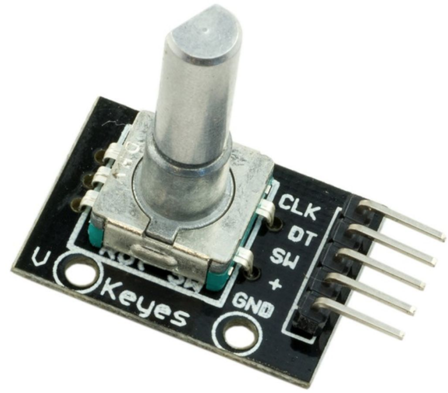


*Figure 10: Rotary Encoder Physical Design*

*Requirement: Operates at 5V.*

**2.4.3 Switch**
IN: Octave level selection
OUT: 2-bit digital output
DESCRIPTION: The SPDT ON-OFF-ON Switch is a switch the user can move to three different positions [9]. When the switch is flipped up, our drum will make sounds one octave higher. When the switch is flipped down, the drum will make sounds one octave lower. When the switch is in the center, our drum will make normal drum sounds at regular octave.
PART: Toggle Switches 3-6A 125-250VAC SPDT ON-OFF-ON SLDR IP68

*Figure 11: SPDT ON-OFF-ON Switch Physical Design*

| POLES & CIRCUITS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Toggle Position ( ) = Momentary | | | Connected Terminals | | | Throw & Schematics |
| Pole | Model | Up | Center | Down | Up | Center | Down | Note: Terminal numbers are not actually on the switch. |
| SP | M2012<br>M2013<br>M2018 | ON<br>ON<br>(ON) | NONE<br>OFF<br>OFF | ON<br>ON<br>(ON) | 2-3 | OPEN | 2-1 | SPDT 2 (COM) 3 1 |

*Table 6: SPDT ON-OFF-ON Switch Positions and Terminal Connections*

*Requirement: Needs to have three different positions.*

### 2.5 Audio Output

After the drum has been activated and a hit has been detected, our device plays the desired sound using the output of a sound card. The audio must be high quality and have negligible delay from hit to sound output.

| Requirements | Verifications |
|---|---|
| 1. Audio is outputted with a signal to noise ratio of at least 25dB. | 1a. Using an oscilloscope measure the fourier transform of the audio output signal and observe the output.<br>1b. Calculate the SNR from the frequency spectrum to ensure it is at least 25dB. |

*Table 7: Audio Output Requirements and Verifications*

To create drums that sound realistic, the same exact .wav file should not be played over and over again. To counter this, we will sample each unique drum sound multiple times, with random changes in velocity and EQ values. The velocity values range from 1-127, but in our implementation we randomly adjust the value in each sample to values ranging from 60-80. The EQ changes are subtle but add some differences in each drum hit, such as taking off part of the low-end or high-end. All together, each drum hit will be slightly different than the last. This is especially important during a drumroll. During a drumroll, the user repeatedly hits the drum. In our previous design, the same .wav file would play over and over, creating a non-realistic effect. Our new randomized hit sample allows for realistic sounding drums. The volume of each sample is decided by the force of each hit. Each drum sample can be pitched up or down an octave depending on what the user selects.

#### 2.5.1 Sound Card

IN: USB on Raspberry Pi
OUT: AUX on Sound Card
DESCRIPTION: Using a Sound Card will significantly increase output sound quality but increase latency; however, the difference in latency is minimal. The Sound Card plugs into the USB input of the Raspberry Pi and outputs the improved sound quality through its AUX port [10].
PART: UGREEN USB External Stereo Sound Card Audio Adapter with 3.5mm Aux and 2RCA Converter


*Figure 12: Sound Card Physical Design*

*Requirement: Needs to improve sound quality.*

**2.6 Tolerance Analysis**

The sensitivity range of our accelerometer was a very crucial aspect to our drum. Since we wanted our drum to be similar to a real drum, we wanted the force-to-sound ratio to be similar as well. This means the harder the strike on the drum pad, the louder the sound that is created. To make this feature a reality, we needed to implement an accelerometer that would be able to withstand the maximum amount of force our drum pad would feel [11]. Most accelerometer data sheets provided ranges of acceleration each component could handle. We knew we had to do some calculations and research to find the best accelerometer for our project.

$$F = ma \qquad \text{Equation 1}$$

We started with the equation, $F = ma$, to find the maximum acceleration our component would be put under [12]. In the equation, the variable, $m$, will be the mass of one drumstick. Since our drum will look like a marching band drum and used by a variety of different users, we wanted our drumsticks to be the marching band type and very durable to withstand the style of every user. We found some durable drumsticks each having a mass of 0.080kg [13]. Next, we had to find some data on the amount of force, $F$, on the drum pad. One study found that raising the drumstick 0.6m resulted in a force of about -140N on the drum pad [14]. This was the maximum force that was recorded, so we will use this to calculate our maximum acceleration, $a$. Now, plugging in m = 0.080kg and F = -140N, we calculate a = -1,750m/s^2. This is the maximum amount of acceleration our drum will be experiencing, so we need to find an accelerometer that has a range larger than the calculated acceleration value. The ADXL375 Accelerometer can measure accelerations up to -1,960m/s^2. Since this accelerometer can measure accelerations a little larger than our calculated maximum, it seems like a good component for the project.

## 3 Project Differences

### 3.1 Overview

Our previous idea, Beat Starter, was a simple DJ drum board capable of being used by children, teens, and adults. The board offered a variety of sounds to select from and combine in a loop to create personal beats. To receive user input, the face of the board would have buttons and control knobs. The buttons were for the different instrument sounds, power, and clear function. The turn knobs would adjust volume and BPM. The user's created beats would run in a loop in memory. Beat Starter would also have a simple LCD display panel to indicate the current settings provided by the microcontroller. These settings include volume level and beats per minute (BPM) count. Our new idea, Drum Smart, is not a board at all but a marching band drum. Instead of a variety of different instrument sounds, our drum would provide different types of drums and their sounds. Instead of pressing buttons to create sounds, the user strikes the drum pad to create the sound. Instead of a knob to control volume, we are now having the volume controlled by the amount of force the user strikes the drum pad. Beat Starter needed a display for the user to see the volume level and BPM. Now, we no longer have a need for a display because we will not be using BPM and will not need to show the volume level of each strike. Beat Starter also kept the created beats repeatedly playing in a loop. Our new device will not play any beats in a loop but rather emit that certain sound once per strike.

### 3.2 Analysis

Beat Starter and Drum Smart accomplish the same goal of providing a new, easy to use instrument to all people, but the way each device accomplishes this goal is much different. Both systems require memory storage and usage, but Beat Starter utilized the RAM that was located on the Raspberry Pi. The RAM has a fast latency time and was chosen to provide an easier route for repetitive memory access during the performance loop of Beat Starter. Compare this to Drum Smart which uses an external SD Card to store musical samples. We found the read latency from an SD Card is around 1.4ms. Drum Smart does not write to memory and will have less calls to memory due to the lack of looping. If we had used an SD Card in Beat Starter, a large amount of CPU would have been eaten up by the system because of the continuous loop. Since we have no looping system, we decided to use the SD Card instead.

Beat Starter and Drum Smart have different power systems that allow for proper usage of each respected system. Beat Starter was a larger system, encouraged to be used by more than one person. Drum Smart is a personalized device that should be portable and easy to handle. Because of these differences in use, Beat Starter had to make use of a voltage regulator because the most common power supply would be from a generator or power outlet. On the other hand, Drum Smart is powered by a rechargeable battery system that connects with the Raspberry Pi. The rechargeable battery allows for portability but does make the device less reliable since the user must charge the battery properly before use.

The most significant difference between the two devices is the input/output system. Beat Starter and Drum Smart both use a sound card for sound output, but this is where the similarities end. Beat Starter also included an LED display output to help the user follow beat and provide a BPM guide. One of Drum Smart's goals is to appear less digital and more musically themed. Because of this, we decided against using an LED display for any assistance. The inputs of each system are greatly different. Drum Smart's main input is through an accelerometer, the ADXL375. The accelerometer detects drum hits and allows for a realistic drum-hitting experience. Beat Starter's main input system consisted of buttons and knobs. The knobs were used to control pitch and volume on Beat Starter whereas Drum Smart features only a single knob, the drum sound select knob, and a switch for changing pitch. The buttons served as the drum-hit input. Pressing buttons, as compared to physically striking a drum with a drumstick, is a major difference in the two systems when taking into account how the user feels and behaves during each action.

## 4 Cost and Schedule

### 4.1 Cost Analysis

| Labor | | |
|---|---|---|
| Hourly Rate | Hours to Complete | Number of Partners |
| $50.00 | 125 hours | 3 |
| TOTAL LABOR COST | | $18,750.00 |

*Table 8: Labor Cost*

| Parts | | | | |
|---|---|---|---|---|
| Description | Manufacturer | Part Number | Quantity | Cost |
| PiJuice HAT | Pi Supply | PIS-0212 | 1 | $59.98 |
| SanDisk 32GB Ultra microSDHC Card Class 10 | SanDisk | SDSDQUA-032G-A11A | 1 | $8.00 |
| Raspberry Pi Model 3 A+ | Premier Farnell | RPI3-MODAP | 1 | $25.00 |
| ADXL375 - Accelerometer, 3 Axis Sensor Evaluation Board | Analog Devices Inc. | EVAL-ADXL375Z | 1 | $30.00 |

| | | | | |
|---|---|---|---|---|
| KY-040 Rotary Encoder Brick Sensor Module Development | Frentaly | B07VKF9S3W | 1 | $8.60 |
| Toggle Switches 3-6A 125-250VAC SPDT ON-OFF-ON SLDR IP68 | NKK Switches | M2013WBW01 | 1 | $12.92 |
| UGREEN USB External Stereo Sound Card Audio Adapter with 3.5mm Aux and 2RCA Converter | Ugreen Group Limited | 30521 | 1 | $16.59 |
| TOTAL PARTS COST | | | | $161.09 |

*Table 9: Parts Cost*

| Grand Total | |
|---|---|
| Section | Total Cost |
| Labor | $18,750.00 |
| Parts | $161.09 |
| GRAND TOTAL COST | $18,911.09 |

*Table 10: Grand Total Cost*

**4.2 Schedule**

| Schedule | | |
|---|---|---|
| Week | Responsibility | Task |
| 4/20/20 | Collin | Presentation slides |
| | Kevin | Schematic diagram |
| | John | Presentation division and speech |
| | All | Mock demo (4/21),<br>Project Design Review Presentation (4/23), and Design Review Peer Review (4/22-4/24) |

| | | |
|---|---|---|
| 4/27/20 | Collin | Confirm parts - operation voltages and distributors |
| | Kevin | Confirm wiring - how each component is wired together (pins) |
| | John | Write the code |
| | All | Start working on Final Paper |
| 5/4/20 | Collin | Work on Final Paper |
| | Kevin | Work on Final Paper |
| | John | Work on Final Paper |
| | All | Final Paper (5/6) |

*Table 11: Weekly Schedule*

**5 Discussion of Ethics and Safety**

Our project, Drum Smart, adheres to the specific ethic and safety guidelines put forth by IEEE and ACM. It is important to practice safety throughout development and use of Drum Smart. We plan on accomplishing this by limiting dangers and electrical hazards. Code 1 of the IEEE Code of Ethics states "to hold paramount the safety, health, and welfare of the public" [15]. The safety of the public is our number one priority. Drum Smart is used recreationally and part of a good experience in ensuring the correct connections of electrical current and creating a reliable device.

An aspect of our device that we were worried could cause hazards is the rechargeable battery. The battery we have selected is an 1820 mAh Lithium-Ion battery. We will place a warning upon the battery warning the user to not store the device above 60℃, the temperature at which the battery could become hazardous. Adhering to Code 9 of the IEEE Code of Ethics, we will "avoid injuring others" by offering a proper warning of what could cause our system to malfunction, and in turn, harm the user [9].

Drum Smart is a device that can be used by any able-bodied individual that would like to use the product. According to the ACM Code of Ethics, 1.4 emphasizes the value of equality and fairness [16]. Our device encourages use by people of any age or background. Our product specifically targets lower income communities in which Hip-Hop and music has become a focal point of the culture.

According to the CDC, damage to the hearing can be caused by prolonged exposure to sounds over 80dB [17]. Following the advice of the CDC, we want to limit the danger of hearing loss, while allowing for the possibility of loud audio output. In order to be safe and still produce loud audio, we will set very hard drum pad strikes to have a maximum sound output of 80dB.

**References**

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