ECE 445
Wildlife Audio Sensing
Design Review

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Table of Contents

1 Introduction

1.1 Statement Purpose

An audio sensing and recording system that records animal sounds. Continuously operating microphone and passive filter, which is never powered off, connected to Main Control Unit which remains continuously on, mostly in an idle state, only switching to active operating state and recording sound data to SD card storage when wildlife sounds are detected by microphone. By remaining idle, the Microprocessor conserves power usage and allows for continuous monitoring, only operating and running in active state when sound is detected. The system is powered by a NiMH battery and Solar Panel to provide additional operating time, expected to last 30 days on battery alone. The Microphone with Preamp records wide range of sound frequencies 0-10 kHz, to ensure animal sounds which range up to 8 kHz can be recorded, while the Passive Low Pass Filter blocks out undesired sound frequencies above 8 kHz. The complete system consists of three modules: Sensor Module, Power Module, and Main Control Unit Module.

Wildlife monitoring systems already exist, however most of them are continuously recording even white noise, or operate in on-off periods. The benefits of the proposed system are quite valuable to wildlife research as it allows for data to be gathered over longer periods of time, without recording everything including white noise, or being forced into periodic on-off states that might miss data. By selectively recording only animal sounds it saves on memory space and power consumption.

1.2 Objectives

Benefits:

1. Long lasting power source (30 days)
2. Better storage management (MicroSD Card and Interface)
3. Continuous Monitoring of Sound (Active MCU when sound detected, else in idle state, Sensors always active)

Features:

1. Record only animal sounds (Filter blocks out undesired frequencies)
2. Solar panel for extra power source (supplement and extend power supply)
3. Continuously powered-on Main Control Unit and Sensors (Tiny Gecko Microprocessor, Microphone with Preamp, and Passive Low Pass Filter)

2 Design

2.1 Main Block Diagram

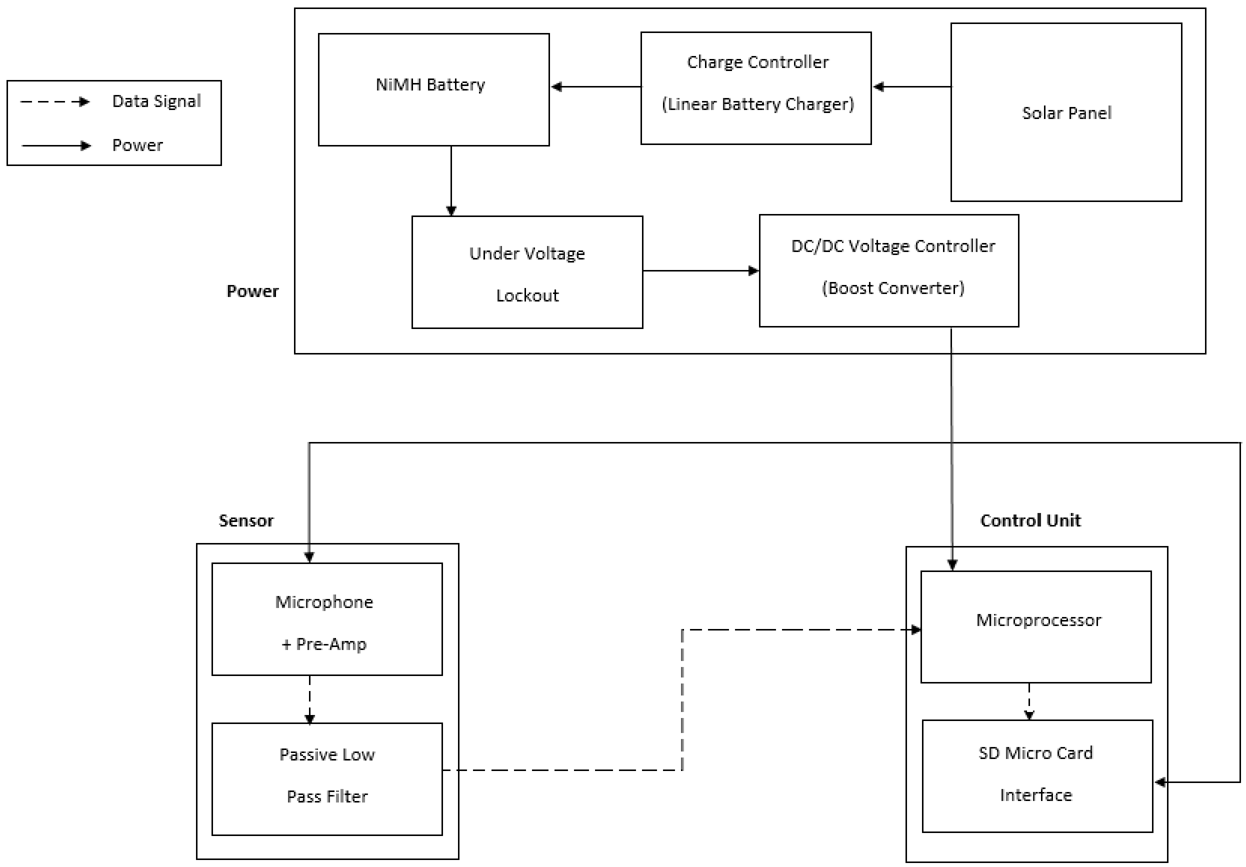

Fig 1. Block diagram

2.1.1 Block Diagram Overview

Power Supply module consists of Solar Panel which provides power to Linear Battery Charger which charges the NiMH battery. Under Voltage Lockout ensures that battery voltage does not drop below one volt, as anything below might damage the battery, i.e. while battery voltage remains above one volt, UVL allows current to flow through the system into the DC/DC Voltage Controller, i.e. the Boost Converter, which takes the input voltage of around 1.2 Volts and boosts it up to an output of 3 Volts which the Sensor and Control Unit modules run on.

The Sensor module consists of the microphone and preamp component which records sound and outputs it as an amplified signal from the preamp, going into the Passive Low Pass Filter to filter the frequency of the signal, which then continues into the Control Unit module.

The Control Unit module receives the signal from the Sensor module into the ADC port of the Microcontroller, which converts it from analog to digital, and then the program writes the sound signal data by storing it inside the MicroSD card inside SD card interface.

2.2 Block Description

2.2.1 Sensor Module

<u>Sensor Module Block Diagram</u>

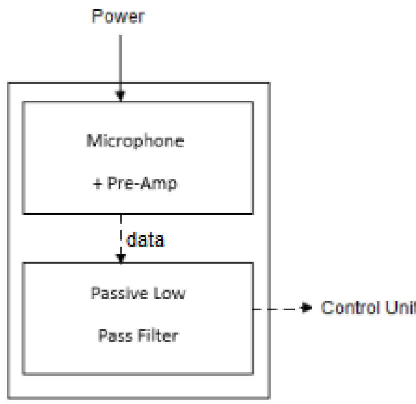

Fig 2. Sensor module block diagram

<u>Block Description of Audio Sensors</u>

- Sparkfun Electret Microphone with preamp: Cheap and easily available, 100 to 10k Hz with 60x preamplifier, can capture desired animal sounds up to 8k Hz as desired by Mentor. Captures audio and transmits as electrical signal, which is amplified by the preamp, to the passive low pass filter. Requires power supply and ground [1].

- Passive Low Pass Filter: Passes through frequencies up to 8k Hz, and filters out anything above desired frequency of animal sounds as specified by Mentor. Since it is a passive filter, it does not require a power supply, only ground, and is very reliable [2]. Receives electrical signal from microphone and preamp, then passes through to the ADC located inside Microprocessor.

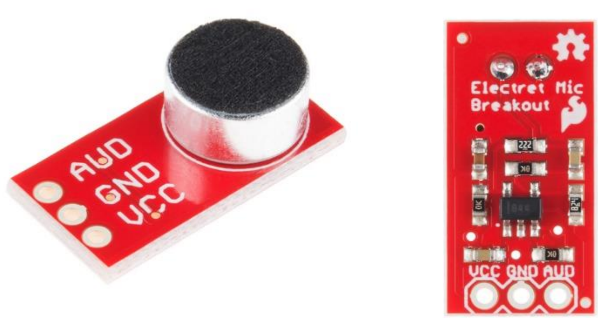

Fig 3. Sparkfun Electret Microphone with preamp [1].

Design And Schematics

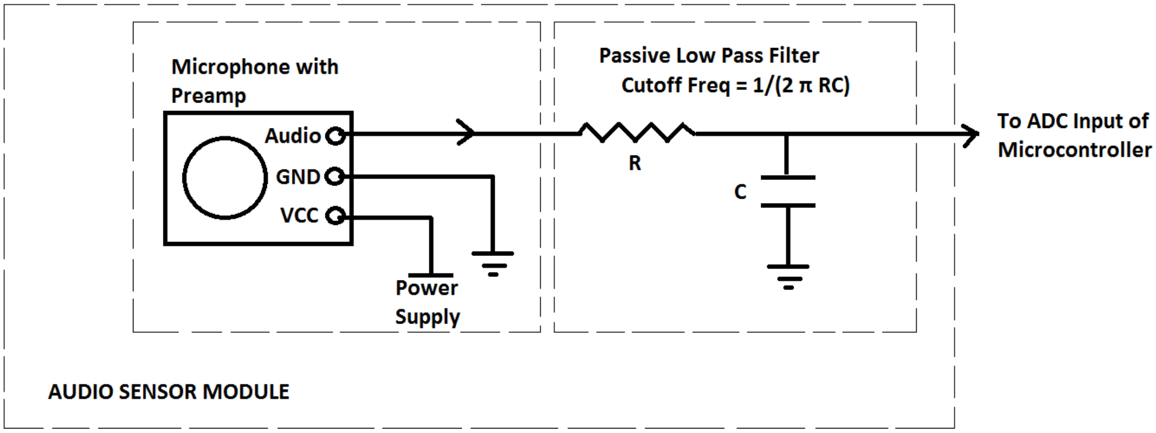

Fig 4. Sensor module (with passive low filter [3]) design and schematics

Calculations

To determine the resistor needed for the low pass filter, the following steps show how to get the appropriate R values.

Cutoff frequency, f_C [3]:

$$f_c = \frac{1}{2\pi RC}$$

Since the desired f_c is 8 kHz, and using 0.1 µF capacitor, then the resistor value that will be needed is:

$$R = \frac{1}{2\pi fC}$$

$$R = \frac{1}{2\pi(8000)(0.1 * 10^{-6})} = 198.9\,\Omega$$

Simulations

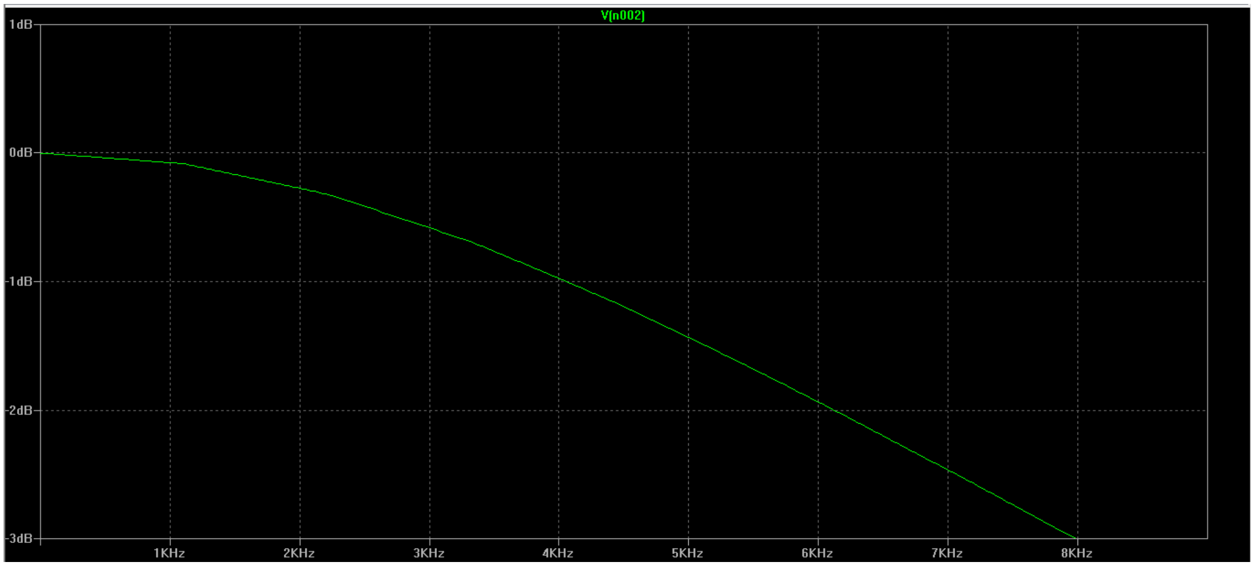

Fig 5. Low pass filter simulation graph

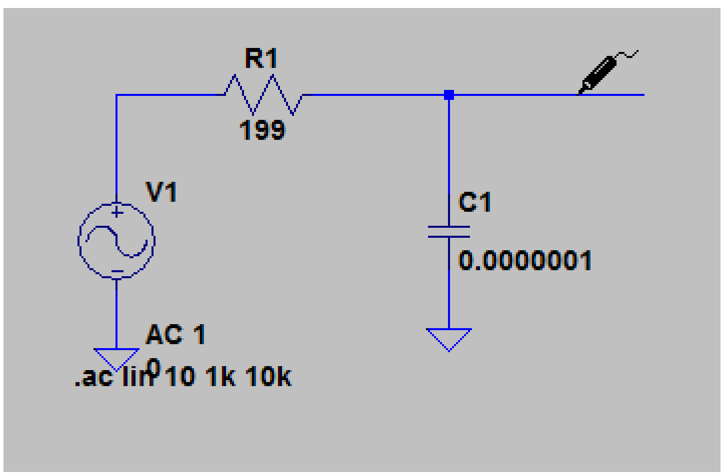

Fig 6. Low pass filter simulation design

2.2.2 Main Control Unit Module

MCU Block Diagram

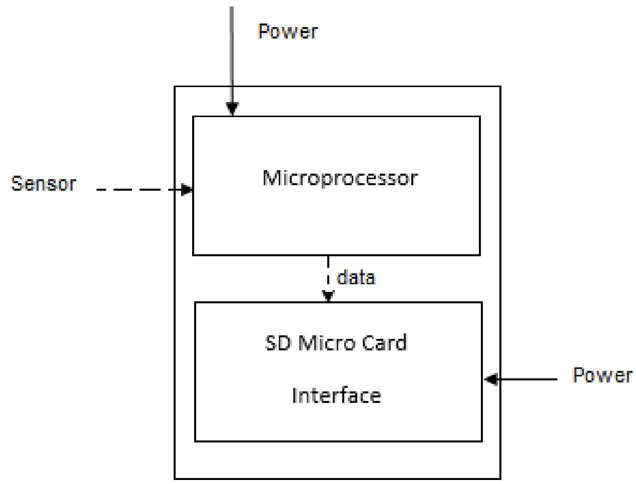

Fig 7. MCU block diagram

Block Description of Main Control Unit

- Microprocessor (Tiny Gecko) receives filtered analog sound signal from Sensor Module, which is input through the ADC (Analog to Digital Convertor) located on the Microprocessor chip. The signal is converted from analog to digital signal by the ADC, and is read by the Tiny Gecko Microprocessor. The Microprocessor is programed to record and store the sound data, which it sends to the MicroSD Card Interface to save onto MicroSD Card memory. The Microprocessor operates in three states: Idle when no sound data is sent from the Sensor Module, Active Read when it receives sound data and running program to save data, and Active Write when it is running the program and store the data into the MicroSD card. The Idle state consumes the least current and therefore least power, while Active Write consumes most current and power. The Microprocessor requires a power supply to function, which it receives from Power Supply Module, and therefore it has a Vcc and Ground connection [4].

- MicroSD Card interface receives data signal from Microprocessor to write onto MicroSD Card. Requires power supply to write data, which it receives from Power Supply Module. Only purpose is to write and save sound data to be retrieved at a later point by Wildlife researcher to gain access to sound recordings.

Design And Schematics

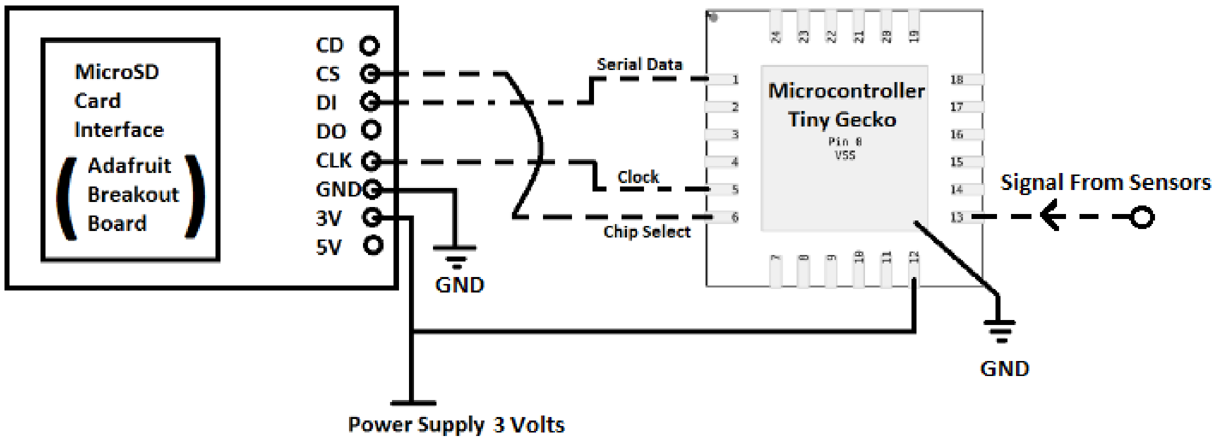

Fig 8. MCU (Tiny Gecko [4] and microSD interface [5]) schematics

Table 1. Tiny Gecko Pin Assignment [4]

Microcontroller Pin	Pin Function
0	Ground
1	Serial Data Input/Output
5	Clock
6	Chip Select
12	Vcc Power Supply
13	ADC Data Input

Table 2. SD Card Interface Inputs [5]

SD Card Interface Inputs	Function
CS	Chip Select
DI	Data Input
CLK	Clock
GND	Ground
3V	Vcc Power Supply

Calculations

For this project, 2GB micro SD card will be used. Below show the steps to figure out whether 2 GB has enough capacity to record the animal sounds for a month. Animal sound frequency ranges from 0 to 8 kHz. Average animal call period is 1.5 seconds, and a maximum size of recording is 2 bytes [6].

Nyquist frequency, f_N [6]:

$$f_N = 2 \cdot f_{max}$$
$$f_N = 2 \cdot 8000\,Hz = 16\,kHz$$

And the size of call formula, S_C [6]:

$$S_C = f_N \cdot T_{length\,of\,call} \cdot S_{recording\,byte}$$

Hence, the required size to record animal call is:

$$S_C = 16\,kHz \cdot 1.5\,s \cdot 2\,bytes = 48\,KB$$

Number of calls, N_C [6]:

$$N_C = \frac{S_{SD\,Card}}{S_C}$$
$$N_C = \frac{2\,GB}{48\,KB} = 416,667$$

And calls per minute, C/M:

$$\frac{C}{M} = \frac{N_C}{30\,days}$$

$$\frac{C}{M} = \frac{416,667}{30d \cdot 24h \cdot 60m} = 9.65\,\frac{calls}{min}$$

According to Long, the calls per minute over a month is usually 2 calls / min on average [6]. Hence, the calculations show that 2GB SD card is more than adequate to record animal sounds for 30 days since it is capable to have 9.65 calls / min over a month.

Code/Program Flowchart

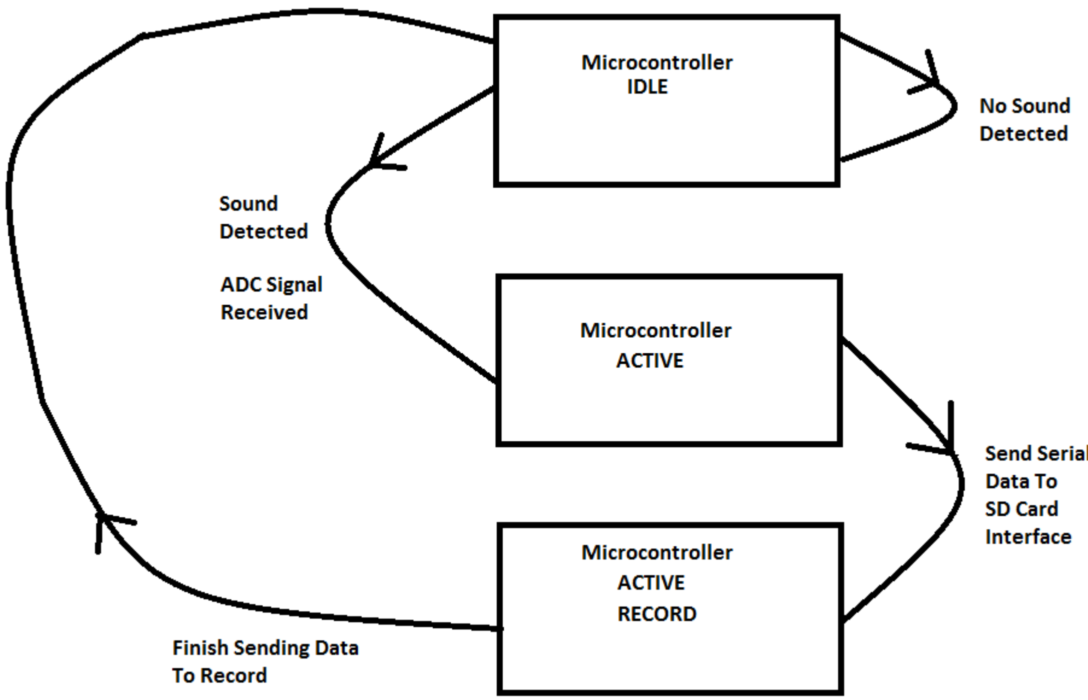

Fig 9. MCU flowchart

2.2.3 Power Supply Module

Power Supply Block Diagram

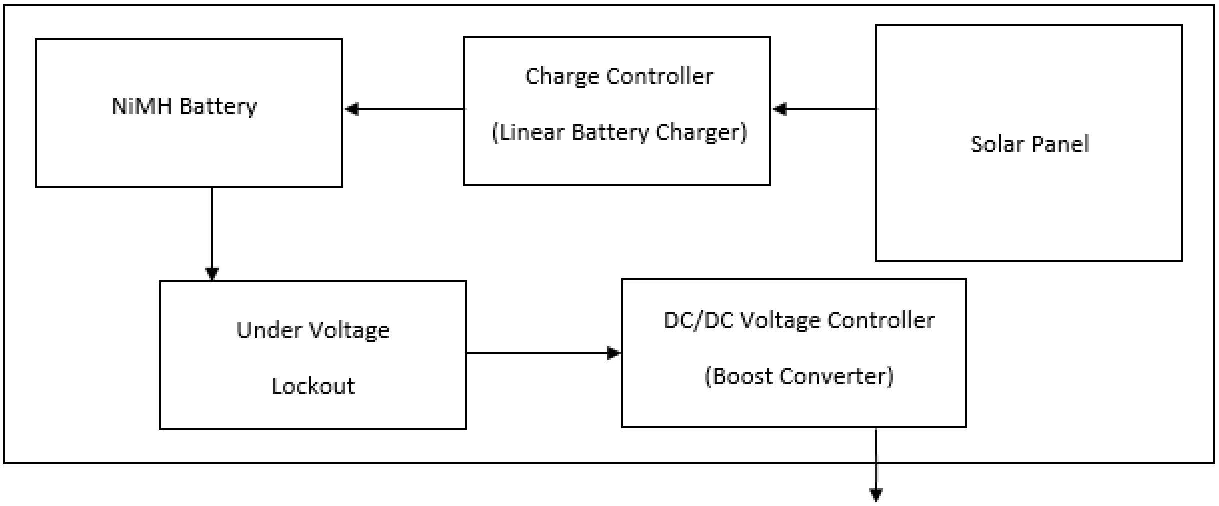

Fig 10. Power supply block diagram

Block Description of Power Supply

- Solar Panel receives sunlight onto photovoltaic cells which convert it into energy as current and voltage. The panels operate at 5 volts and 178 mA when connected to a load at PMPP [7]. The solar panel is connected to the Linear Battery Charger, supplying it with power.

- The Charge Controller, i.e. Linear Battery Charger receives power from the Solar Panel at around 5 volts and uses it to charge the NiMH battery. It ensures that the battery is not overcharged or charged improperly, acting as a safety precaution to prevent damage to the battery and overall system, prevents battery fire from occurring [8].

- NiMH D-cell battery is charged by the Linear Battery Charger, receiving power from it to replenish lost energy. It is the main supply of power to the system, and can power the system without additional power from solar panel if needed.

- Under Voltage Lockout receives power from battery and sends it to the DC/DC Boost Converter. It acts as a precautionary method to prevent battery damage by cutting off the battery from discharging energy when the battery voltage falls below one volt, as this may cause damage such as decreasing overall battery capacity [8].

- DC/DC Voltage Controller, i.e. the boost converter, receives power from the battery and power supply at around 1.2 volts and boosts it to 3 volts at which the Sensor and MCU modules operate at [8].

Design And Schematics

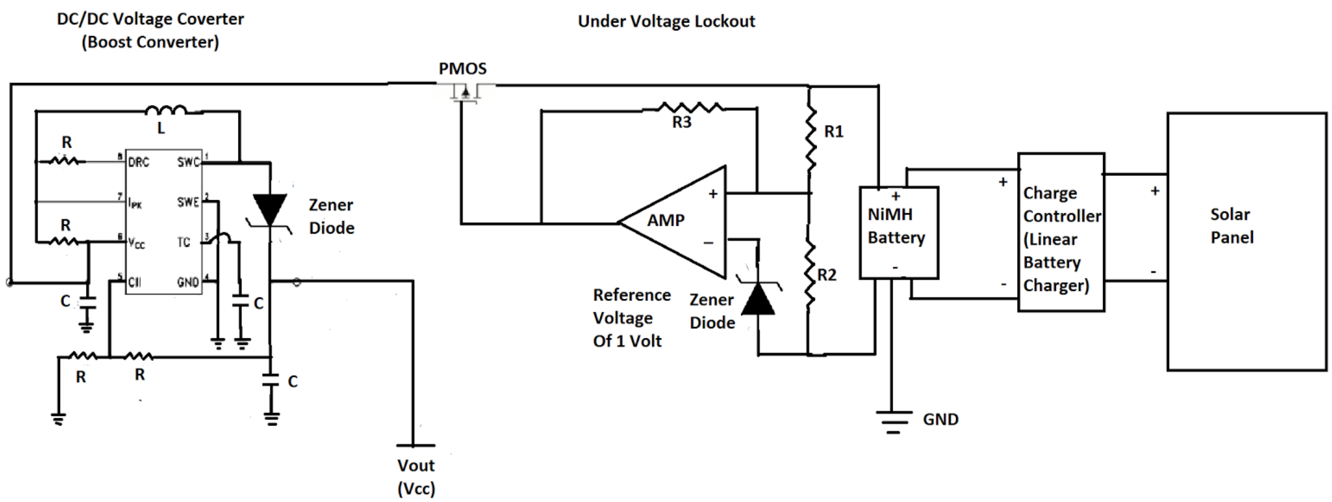

Fig 11. Power supply (boost converter [9], UVLO [10]) schematics

Charge Controller Circuit Sub Schematics, as Suggested from Component DataSheet

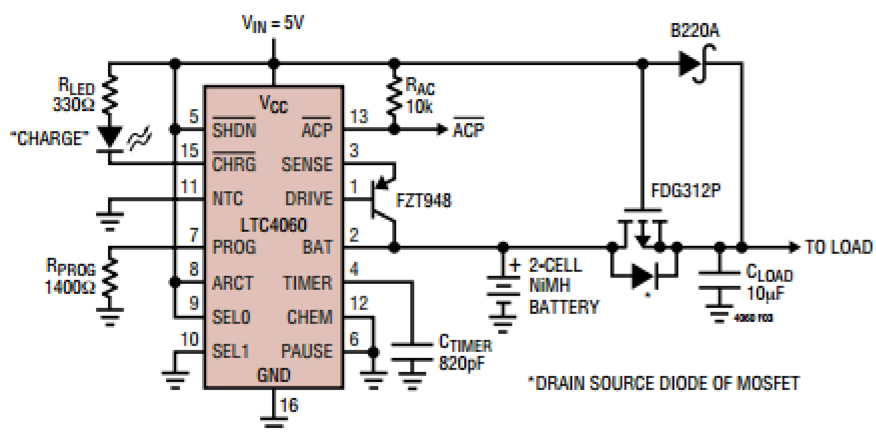

Fig 12. Charge controller circuit schematic [11]

Boost Converter Circuit Schematics as Suggested by Component Datasheet

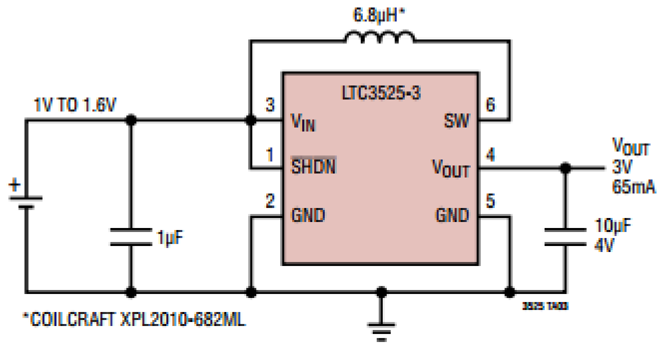

Figure 13: Boost Converter Circuit Schematic [9]

Calculations

Below is the list of activities that draw power [12].

Table 3. Power consumption list

Parts	Symbol	Note	Power Consumption
audio processing			
MIC			0.2 - 0.5 mA
OPA344(Preamp)			0.3 mA
12-bit ADC(on Microprocessor)			0.5 mA
Total	A		~1.0 mA
uC module			
TG (tiny gecko - active)	R	150 uA/MHz, max 32 MHz	4.8 mA
TG (idle)	I		0.12 mA
other			
Writing to SD card	W		40 mA

In order to figure whether the battery will last for a month, below is the calculations to figure this out.

The NiMH battery has 10,000 mAH capacity. In 1 month, the average mA that will be available is [12]:

$$EnergyBudget = \frac{10,000mAH}{720Hours} = 13.89mA$$

Processing algorithms can be organized into three subtasks [12]:

- event detection
- event tracking
- logging / transmitting of audio events

Event detection (T is period):

T1 (W+R+A) + T2 (R+A) + T3 (I+A)
0.1(40+4.8+1) + 0.8(4.8+1) + 0.1(0.12+1) = 9.332 mA

Event tracking:

T1 (R+A) + T2 (I+A)
0.8(4.8+1) + 0.2(0.12+1) = 4.864 mA

Logging / transmitting of audio events

T1(R+A) + T2 (I+A)
0.6(4.8+1) + 0.4(0.12+1) = 3.928 mA

The average possibilities of these 3 subtasks [12]:

Event detection	10%
Event tracking	5%
Logging / transmitting of audio events	85%

So, the estimated average power consumption is:

10% (9.322 mA) + 5% (4.864 mA) + 85% (3.928 mA) = 4.5152 mA

Which is less than the available power per month, or in other word, the battery will last for about:

$$\frac{10,000\,mAH}{4.5152\,mA} = 2214.74\,H \approx 92\,days$$

The worst scenario is where the event detection happens with probability of 100%. The power consumption would be around 9.322 mA for 1 month. Hence, the battery will last for:

$$\frac{10,000mAH}{9.332mA} = 1071.58Hours = 44.65Days$$

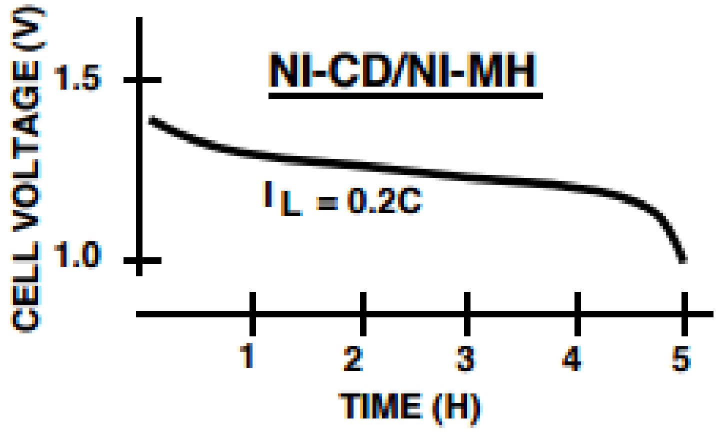

Fig 14. Characteristics of Rechargeable Batteries [13]

Table 4. Rates of discharge [13]

CELL TYPE	NI-MH	NI-CD	LI-ION
SELF-DISCHARGE @ 20°C (%/MONTH)	20-30	15-20	5-10

Assuming scenario of 30% battery charge loss over month, still have 7,000mAH of energy.

$$\frac{7,000\,mAH}{9.332\,mA} = 750\,Hours \approx 31\,Days$$

Simulations

UVLO Simulation:

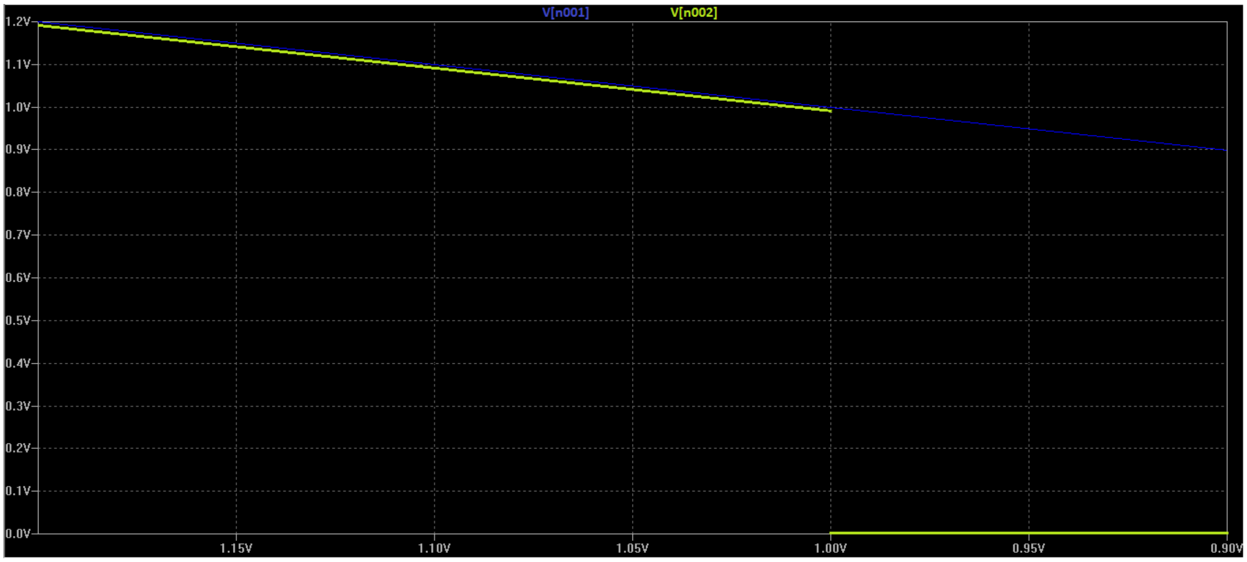

Fig 15. UVLO simulation graph

Desired UVLO Behavior, Yellow Output Voltage, Blue Input Voltage

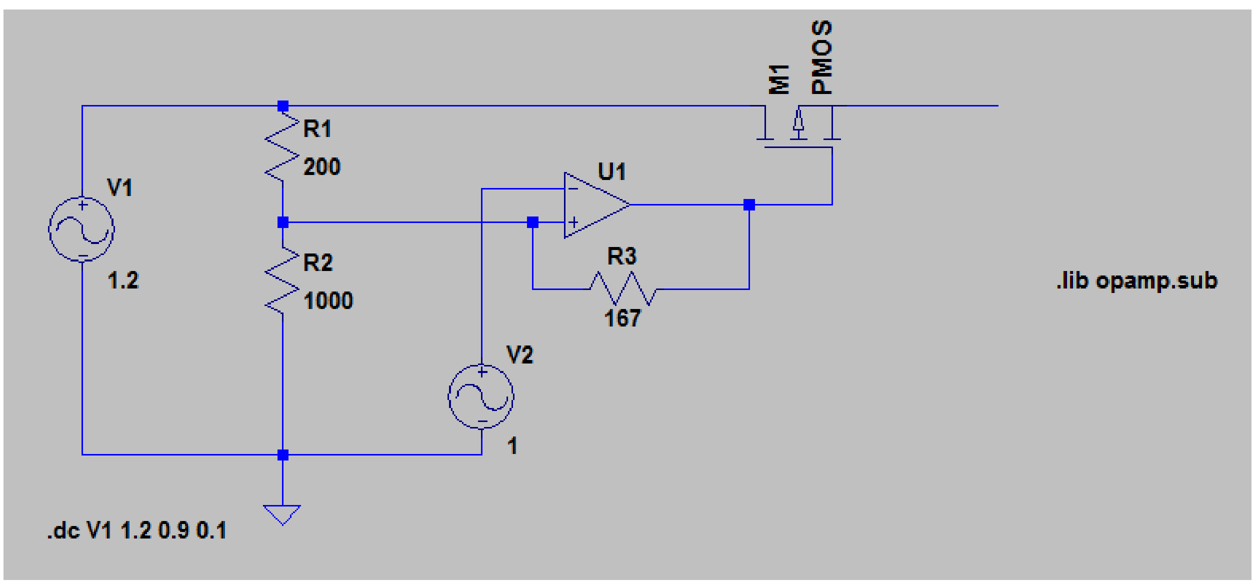

Fig 16. UVLO design

Boost Converter Simulation:

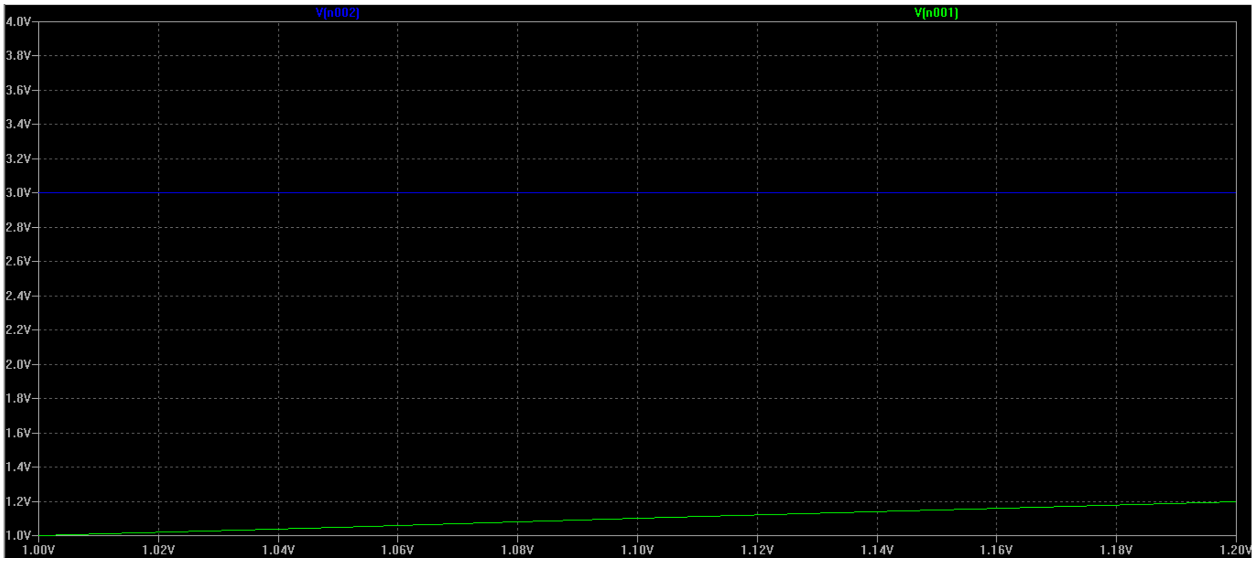

Figure 17: Boost Converter Simulation Graph

Mechanical Component Design

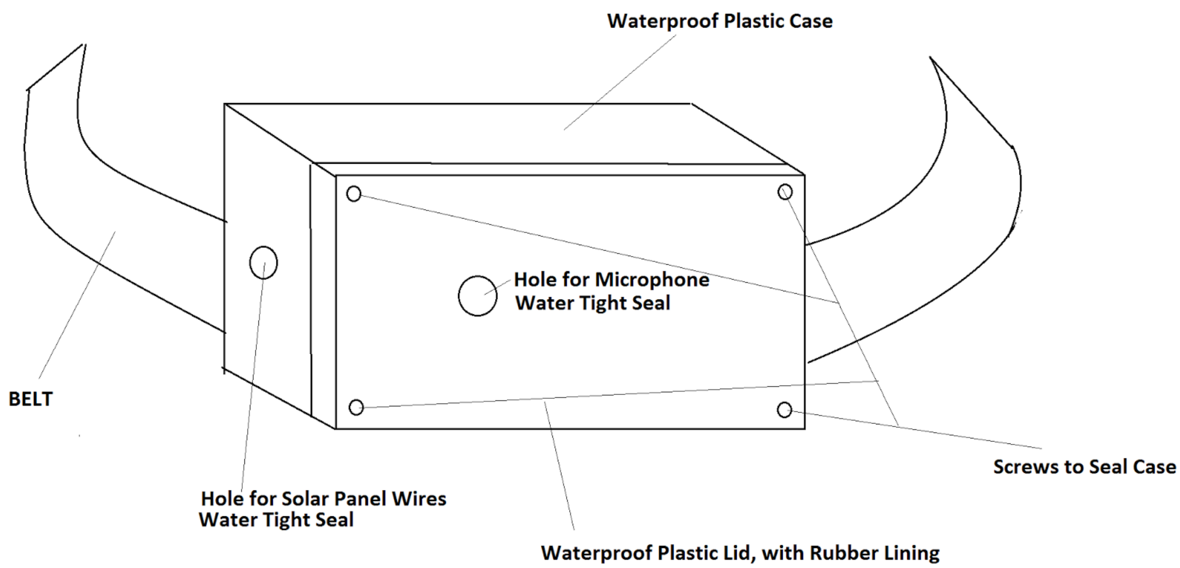

Fig 16. Mechanical design

System will be stored inside waterproof case, with holes for microphone to be outside to record, and for Solar Panel wire so Solar Panels can be outside case to provide power. Belt is used to attach system case around tree or other object so recordings of animals can be made in outside environment. System can be accessed by unscrewing lid, then can replace battery and retrieve sound recording data on SD card.

3 Tolerance Analysis

The required resistor for the low pass filter to have 8kHZ cutoff frequency is 198.9 Ω. With tolerance value of ±1%, then the expected cutoff frequency becomes:

$$f_c = \frac{1}{2\pi RC}$$

$$f_{c\,low} = \frac{1}{2\pi(198.9\Omega \cdot 1.01)(0.1 \cdot 10^{-6} F)} = 7922.5\,Hz$$

$$f_{c\,high} = \frac{1}{2\pi(198.9\Omega \cdot 0.99)(0.1 \cdot 10^{-6} F)} = 8082.6\,Hz$$

Using resistors ranged from 197 Ω to 218.8 Ω will give cutoff frequency ranged from 7922.5 to 8082.6 Hz.

$$\%\,error = \frac{8082.6 - 8000}{8000} \cdot 100\% = 1.03\%$$

1.03% error is an acceptable number and will not affect the system significantly.

Assuming the capacitor also has tolerance value of ±1%, the worst scenario would be:

$$f_C = \frac{1}{2\pi(198.9\Omega \cdot 0.99)(0.1 \cdot 10^{-6} \cdot 0.99)} = 8164.2\,Hz$$

$$\%\,error = \frac{8164.2 - 8000}{8000} \cdot 100\% = 2.05\%$$

2.05% error is still an acceptable number that will not affect the system functionality.

4 Requirements and Verification

4. 1 Sensor Module RVA

Requirements	Verification	Points 15
Microphone • Must record frequencies 0 to 8k Hz to capture animal sounds which range in frequency up to 8k Hz as stated by Mentor.	1. Connect microphone to computer. 2. Emit different sound frequencies from device such as cellphone using an app. 3. Test by playing sounds into microphone 10 times for each frequency range: 0-2k, 2k-4k,4k-6k, 6k-8k Hz. 4. Record and display results on computer to check the frequencies recorded. 5. Graph results, and make sure at least 90% of attempts from each range were recorded. Perform more trials for each range if necessary.	5 Points if all four ranges record 90+% of time ---------Partial---------- • 4 pts if 3 of 4 ranges 90+% • 2 pts if 2 of 4 ranges 90+% • 1 pts if 1 of 4 ranges 90+%
Passive Low Pass Filter • Must block out frequencies greater than 8k Hz, +/- 100 Hz, as this is outside the frequency range of animal sounds as stated by Mentor. Mentor suggests this is optional, not critical as not many frequencies above 8k Hz will be encountered.	1. Connect Passive Low Pass Filter to computer, input will receive various signals, and output will send filtered signal to computer. 2. Pass signals from computer at various frequencies. 3. Test by sending input frequencies 10 times for each range, 0-2k, 2k-4k, 4k-6k, 6k-8k, 8k-9k, 9k-10k Hz. 4. Record and display results on computer to see which frequencies were passed, and which were blocked. 5. Graph results, and make sure filter passes 90+% of frequencies up to 8k, and make sure filter blocks 8k+ Hz 90% of time.	10 points if only passes 0-8k Hz 90+% of time --------Partial----------------- • 9 pts if passes up to 9k Hz 90+% of time • 8 pts if only 0-6k Hz pass 90+% of time • 5 pts if only 0-4k Hz pass 90+% of time

4.2 MCU Module RVA

Requirements	Verification	Points 20
Microcontroller • ADC input must convert analog signal to digital signal/data. • Serial Data Output must send out data correctly. -------------------------------------- - • Clock Output must generate square wave signal.	1. Connect clock output to oscilloscope and record result waveform. 2. Run 10 trials on clock output --- 3. Connect Microphone to ADC. 4. Connect Serial Data output to computer. 5. Play sound or speak into microphone. 6. Record the data output on computer as a sound file. 7. Play sound file and confirm correct sound recorded. 8. Perform 10 trials for sound and data.	15 points total ------------------------------------ 1. 5 pts if Clock outputs correct waveform all 10 trials ------Partial------- • 3 pts if clock outputs correct waveform only 5/10+ times ------------------------------------ 2. 10 pts if ADC converts sound correctly and Serial Data Output sends correct data 9/10+ times -----Partial------- • 5 pts if only 5/10+ times
SD Interface • Must write 95% + data received to be effective and useful for wildlife research.	1. Connect Interface inputs: Data In, Chip Select, and Clock to computer. 2. Connect 3 volt power supply and Ground to interface. 3. Insert SD card into interface. 4. Run clock input from computer. 5. Send 100 sets of data into interface Data In input to be recorded onto SD card. 6. Remove SD card and check on computer number of sets of data recorded. 7. Ensure 95%+ is recorded, graph the results. 8. Perform 10 trials of this.	5 points if all 10 trials record 95%+ -------Partial------------- • 4 points if 8 trials 95%+ • 3 points if 7 trials 95%+ • 2 points if 6 trials 95%+

4.3 Power Supply Module RVA

Requirements	Verification	Points 15
Boost Converter Circuit • Must boost input voltage of 1.2 Volts to output Voltage of 3 Volts • Output at least 45.8 mA to power MCU and Sensor Modules	1. Connect Input to DC power supply 2. Measure Output Voltage with multimeter 3. Turn DC power to 1.2 Volts 4. Check to that output is 3 volts on multimeter 5. Measure output current on multimeter when attached to load 6. Check that current is at least 45.8 mA 7. Run 10 trials for each test	5 Pts total -------------------------------- 1. 3 points if 8/10+ times boost to output of 3 volts -- -----Partial------- • 2 pt if only 5/10 times -------------------------------- 2. 2 points if 8/10+ times outputs 45.8 mA current -------Partial--------- • 1 pt if only 5/10 times
UVLO Circuit • Must cutoff voltage output when input voltage(Battery Voltage) falls below 1 Volt	1. Connect input to DC power Supply 2. Measure Output Voltage with Voltmeter 3. Sweep input voltage from 1.2 to 0.9 Volts 4. Record output voltages for the input range of voltages 5. Check that voltage output is cutoff at 1 volt input and below, i.e. output voltage = 0 6. Run 10 trials	5 Pts total if 9/10+ times cuts off output voltage at 1 volt ----------Partial-------------- • 4 pts if only 8/10 times • 3 pts if only 7/10 times • 2 pts if only 5/10 times
Charger Circuit • Must output at least 10mA to battery when receive 5 Volt input to ensure charge battery given worst case scenario of average 9 mA current drain from system	1. Connect 5 Volt Supply to Charger Input 2. Connect charger to battery 3. Measure current going into battery on multimeter 4. Check that min current of 10mA is met 5. Record results 6. Run 10 trials	5 pts if 9/10+ trials at least 10mA output ----------Partial------------- • 4 pts if only 8/10 times • 3 pts if only 7/10 times • 2 pts if only 5/10 times

5 Safety

This project poses some hazard due to the nature of NiMH batteries and charging them. NiMH batteries can contain chemicals that may be toxic to nature, and since this system purpose is used to monitor wildlife in the forest or some other location outside, it is important to ensure that the battery does not leak or catch fire, as this may cause a forest fire at the worst case, or a toxic leak. The potential safety issue comes from the rechargeable battery. Extreme elevated temperatures may be experienced if a cell is excessively overcharged. This may threat a fire hazard, which can be dangerous as may cause fire and leak chemicals. To solve the issue, a linear battery charger will be used to limit how much the battery can charge so it won't overcharge. By implementing this component into the design, the threat or hazard of a fire occurring are greatly diminished. To ensure that a chemical leak does not occur, the entire system will be contained inside a watertight plastic box as shown in figure 16, which will prevent leaks from occurring such as water getting in or chemicals leaking out.

6 Ethic

Our wild life audio sensing project follows IEEE codes of ethics, with the two stated below being the most critical to our project.

1. to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;
2. to avoid injuring others, their property, reputation, or employment by false or malicious action;

These two statements are most critical as our system has the potential to cause a fire or chemical leak which is hazardous to nature and the public. To ensure that the above stated codes of ethics are followed, safety measures have been implemented, and the potential hazard have been disclosed as stated in the safety section. By following these guidelines and having implemented appropriate measures in our design, we are complying with the most important ethics that deal with safety, and thus minimizing any potential hazards from occurring.

7 Cost

Parts

1x (Silicon Labs) Tiny gecko EFM32TG Microcontroller	= $30
1x (IXYS) SLMD481H10L Solar Panel	= $36.41
2x (EBL) NiMH 10,000mAH D Cell Batteries	= $16
1x (SanDisk) 2gb micro Sd Card	= $8
1x (Adafruit) MicroSD card breakout board	= $7.50
2x (SparkFun) Electret Microphone Breakout	= $11.90
1x (Linear Technology) LTC4060 - Standalone Linear NiMH Fast Battery Charger	=$4.40
1x (Linear Technology) LTC3525ESC6-3#TRMPBFCT-ND DC/DC Boost Convertor	= $4.16
Parts Total	= $118.37

Labor:

Design Filter	- 5 hrs
Build Filter	- 5 hrs
Write code	- 50 hrs
Connect SD Interface to MCU	- 2 hrs
Connect Sensors to MCU	- 5 hrs
Design Boost Converter	- 10 hrs
Build Boost Converter	- 5 hrs
Design UVLO	- 10 hrs
Assemble UVLO	- 5 hrs
Assemble Linear Charger Circuit	- 10 srs
Wire Power Supply	- 5 hrs
Wire up system	- 5 hrs
Test Power Supply	- 10 hrs
Test MUC	- 10 hrs
Test Sensors	- 5 hrs
Test battery life	- 5 hrs
Assemble product	- 5 hrs
Total Labor Hours	- 152 hrs x $30 per hour X 2.5

Labor Cost =	$11,400
Total Cost of Parts + Labor =	$11,518.4

8 Schedule

9/12	Prepare Proposal, Consult Mentor	Piotr Lukasiewicz & Daniel Gunawan
9/19	Order parts, Basic Design -- Start convert Mentor code Java -> C	Piotr Lukasiewicz --------------------------- Daniel Gunawan
9/26	Test batteries	Piotr Lukasiewicz & Daniel Gunawan
10/3	Design and Test Low Pass Filter -- Test Microphone	Piotr Lukasiewicz --------------------------- Daniel Gunawan
10/10	Test Low Pass Filter -- Test Solar Panels	Piotr Lukasiewicz --------------------------- Daniel Gunawan
10/17	Design and Build UVLO Test UVLO	Piotr Lukasiewicz & Daniel Gunawan
10/24	Build Boost Converter and Linear Charger Circuits Test Converter and Charger Circuits -- Test recording to SD card	Piotr Lukasiewicz --------------------------- Daniel Gunawan
10/31	Assemble Power Module Test Power Module	Piotr Lukasiewicz & Daniel Gunawan
11/7	Assemble Sensor and MCU Modules Test Sensor and MCU modules	Piotr Lukasiewicz & Daniel Gunawan
11/14	Assemble Complete System Test System and Debug Code	Piotr Lukasiewicz & Daniel Gunawan
11/28	Final presentation & Demo	Piotr Lukasiewicz & Daniel Gunawan
12/5	Final presentation & Demo	Piotr Lukasiewicz & Daniel Gunawan

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