Hawk Ear 2.0

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1 Introduction

Often times when trying to innovate new technologies, it is useful to look towards nature to see how similar problems have been solved through evolution, and then apply those insights into a scientific solution. This concept is particularly relevant for echolocation. Everything humans have learned about sonar has been through studying animals that use it, such as dolphins and bats. These animals produce sound waves at a particular frequency, and then use the reflections of those waves to locate and identify objects around them. Bats have perfected this technique over the years to have extremely sophisticated echolocation abilities. One interesting ability in particular is the capacity for bats to travel in extremely large, closely knit groups while using echolocation. Logic would dictate that all of the signals getting sent out in such a small space would cause significant interference and impede the bat's' ability to fly without crashing into other bats. Instead, bats are able to navigate quite well in these large groups, raising questions about how they modify their echolocation strategy to ignore the effects of interference. Knowing more about this solution would be extremely relevant for emerging technologies that use sonar, and as such the US Navy has expressed extreme interest in finding a scientific solution to this problem which has been solved by nature. This interest resulted in Professor Laura Kloepper receiving a grant from the Office of Naval Research to do research into how these bats modify their echo location signals to navigate in large groups. Since then, Professor Kloepper has been working with Professor Robert Stevenson to try and answer this question.

Studying large groups of bats can be extremely difficult. The main reason for this is that useful data must come from inside the swarm, as this data will be able to detect how the signals are changing as well as how the bats move in response to the signals. Because of this, using a drone is impractical because it does not have enough fine control to avoid running into the bats when flying at that close of a distance. So professors Klopper and Stevenson again turned to nature to solve this problem, and came up with the idea for Hawk Ear. This concept involves mounting audio recording equipment onto a trained hawk, which will easily be able to navigate through bat swarms and collect the necessary data. The first attempt at this solution was done in a senior design project last year, but we hope to build on and improve their design. Last year's project had a microphone and video recording equipment attached to the hawk's head, with all other necessary circuitry housed in a plastic container on the hawk's back, as seen in **Figure 1**. It should be noted that while the video processing equipment will be used in conjunction with the audio equipment, our project will focus solely on improving the audio recording system from last year's project.

Figure 1: Hawk Fitted with Recording Device

2 Problem Statement and Proposed Solution

Problems:

In version one of the project, Professors Kloepper and Stevenson ran into some significant problems which our group is hoping to address this year. With version 2.0 we hope to address and fix these issues while delivering on our design specifications.

The most important problem which was identified is the data storage for the system, especially in the case of power failure. In the previous version, data was written to an SD card, but in cases of power failure the file data structure was never updated so that the file could not be found on the SD card when it was transferred to the PC. This meant that if the battery died before the hawk finished its flight and the SD card was removed, all data would be lost.

The anti-aliasing, low-pass filter in the old system did not have a sharp enough cutoff at 90 kHz, which was the desired cutoff frequency. This caused issues with aliasing signals at slightly higher frequencies which distorted the data.

The gain control was difficult to modify and was overly complex. Switching from automatic gain mode to selected gain mode required opening the housing on the hawk and physically rewiring the circuitry. Additionally, there were over 20 options for selected gain, which

Professor Stevenson claims was far too many and caused confusion in the field when researchers were trying to determine which gain mode to use.

There was only one microphone mounted on the hawk's head in last year's project. This made it difficult to determine where sound was coming from relative to the hawk and made the data collected less useful than it could have been. Furthermore, the user interface of the device was inconvenient. Necessary control buttons were not easily accessible, so in order to turn on the device or begin recording the circuit housing on the back of the hawk needed to be opened, which wasted valuable time. Additionally, there was no clear indication whether the device was powered on and whether it was currently recording, which caused unnecessary confusion.

The old battery had a short life and would not last long enough to allow the hawk to make multiple passes through the bat swarm. This short life contributed to the loss of data problems as the device would die suddenly, and the system was not continuously saving the data.

There was an LED on the head of the hawk which was used to synchronize the audio and video data. The problem is that this LED was too large and bulky, which is undesirable for our client. The battery was also not securely connected to the main circuit board, but hanged on by two wires. There were concerns that this would cause unnecessary wear and may result in the battery coming disconnected.

Proposed Solutions:

Instead of an SD card we will use flash ROM to store data. As mentioned we will be incorporating a second microphone into our design, and each microphone will write 16-bit words at a rate of 200 kHz, resulting in 400 kB/s being written from each channel. Therefore, we will need to write 800 kB/s to our flash storage. The two channels can still be maintained during the current microcontroller. This will be done by connecting an external flash ROM memory component to the microcontroller, and using MPLAB to code the necessary data transfer rate. Without the use of SD cards, transferring data to a PC will be done using a USB cable. We will also code in MPLAB so that our device periodically saves data, and in case of power failure will be able to retain the data.

We will solve the poor alias filtering problem by designing and building a dedicated aliasing filter. Last year there was aliasing built into the amplification stage by including a capacitor in the feedback loop of the op-amp. Instead, we will design a low pass filter which will have a sharp cutoff at 90 kHz and will be able to sample at frequencies up to 200 kHz, since those are the frequencies the bats emit.This filter will be a first order active low pass filter, in order to reduce weight as much as possible. Therefore the only components we will need are a capacitor and resistor, whose values will be calculated later.

We will install a manual gain selector comprising of 3 dip switches. Each dip switch will correspond to a single digit on a 3-digit binary number, allowing us to include 8 different gain options. This will reduce complexity, and it is sufficient for what we are aiming to accomplish. We will also eliminate the automatic gain mode as Professor Stevenson noted this mode is non-essential.

In order to solve the sound localization problem we will include a second microphone on the hawk’s head. The microphones will be placed as far apart as possible to allow the best possible sound localization. Analyzing minute differences in the two signals will allow us to determine where in space the sound source was relative to the hawk, which will yield more valuable information. This analyzation will be done using MPLAB.

We will make a separate user-interface board in Eagle which will have a power-on button, a record button, two LEDs to indicate the status of each of these buttons, and the 3 dip switches mentioned. Having this circuit board separate from the rest of the device will allow us to put it in a more convenient place. One option would be to put the buttons, switches, and LEDs on the outside of the circuit casing so that it would not have to be opened to make routine adjustments. Considerations for this would be getting dust into the circuit casing through this interface.

We need to scale our battery to last approximately 45 minutes to an hour, while still being as small and light as possible. To do this we will need to measure the current draw of our completed circuit, and use this information to calculate an appropriate size for our battery. We will also work in every step of our design process to minimize power consumption so that we can make our battery as small and light as possible.

We will order a smaller and lighter LED which is still bright enough to be picked up by the video camera and used to synchronize audio and video data. Determining the minimum amount of power needed for this task can be accomplished by trial and error using a few potential LEDs and seeing how small they can get before they stop being recognized by the video camera. We will also use a battery which is designed to be soldered to circuit boards.

3 System Requirements

Our system must fit a variety of requirements in order to be successfully used in the fields of New Mexico. Our system must be able to sample the entire range of frequencies that the bats are emitting without aliasing. These frequencies are between 10 and 100 kHz. Our battery must have a minimum life of 45 minutes. It does not have to be more than this due to the falcon only being able to fly twice, at 15 minutes a piece for each flight. Should the battery die though, the data that has been taken will have been saved to the flash memory. Since the field is very remote, instead of having to reprogram the board to switch gains well will implement a user interface with switches that will allow easy access to gain changes. The falcon can also only support so much weight, so the design must be less than 50 grams in order to allow the falcon to fly for the desired time. The microchip will support two channels for the two microphones, and will save data from both synchronously.

4 System Block Diagram

4.1 Overall System:

A block diagram showing the overall flow of information from the microphones to the flash memory is shown in **Figure 2**.

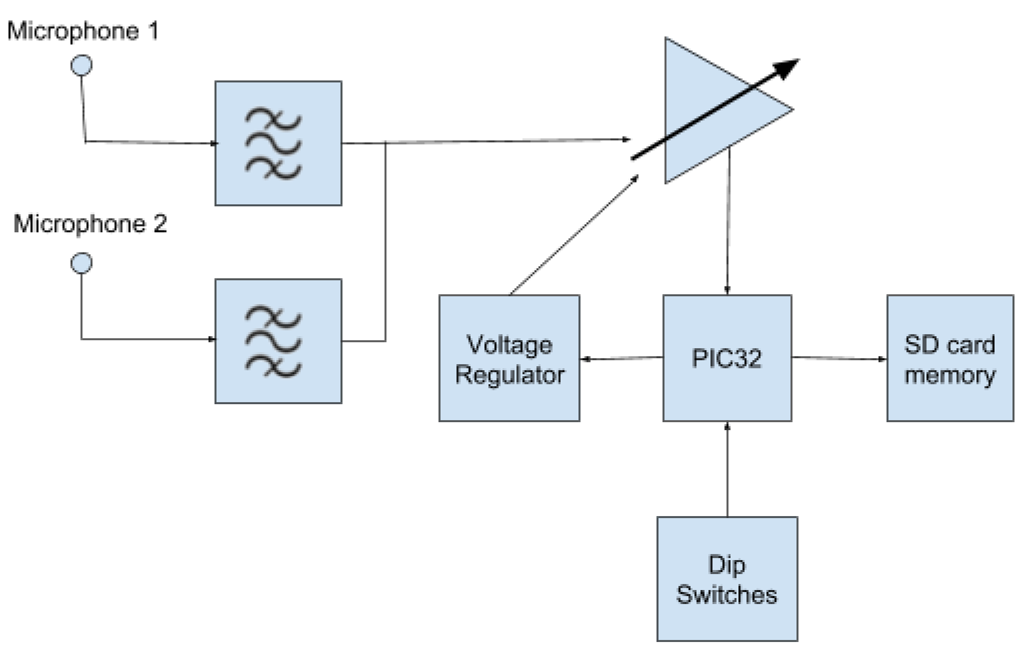

Figure 2: System Block Diagram

Our project consists of one system that has two beginning channels. Two separate microphones record signals from bats, these are passed through band pass filters to avoid aliasing. We will then amplify these signals, with the gain being adjustable through a user interface, where changing dip switches changes the gain. There will be three dip switches with eight total gain options. The amplified signal is read by the pic32 which converts the signal from analog to digital. The pic32 then writes the data onto a flash memory chip.

4.2 Subsystem and Interface Requirements:

Bandpass Filter: Our bandpass filter will be an active filter, so it must be introduced before amplification. Our pass band will be 20 kHz - 80 kHz with a sharp cutoff at 90 kHz.

Microcontroller: After completing calculations involving the size of data that we are measuring, we determined that we require an ADC rate of 0.8 Mb/s, and also must be able to write to flash at that same speed. Additionally we must be able to sample data at a rate of 200 kHz.

Flash Memory: Our flash memory must be able to be written to at at least 0.8 Mb/s, and have at least 2 GB of storage.

Data Storage Software: Our PIC32 must be able to periodically save memory to our flash storage so that in the case of a loss of power shutdown data is preserved.

4.3 Future Enhancement Requirements

Future enhancements of the project include the ability to eliminate the falcon completely. We will not be killing the falcon but making it obsolete. In order to obtain the same data without a falcon we will have a large quantity of microphone surrounding the bat cave. When the bats emerge from the cave all of the microphone will be recording them simultaneously. In order to make this data readable all of the microphones must be synchronized, and that is where version 3 will begin.

5 High Level Design Decisions

Microphone: The MEMS SPU0410LR5H-QB sensor runs on low current and has a flat frequency response at our desired band.

Filter: We will be building an active bandpass filter using op-amps, resistors and capacitors. We will use a filter calculator to determine appropriate capacitor and resistor values to achieve the necessary filter requirements.

Amplifier: Last year's project used an automatic gain amplifier. It was too complicated, and Dr. Stevenson only needs 8 gain settings. So this year we will control the amplifier with three dip switches.

Microcontroller: The Pic32 microcontroller fulfills all of our necessary requirements.

Flash Memory: We will write the data to a flash memory chip soldered onto our board rather than writing it to and external SD card. The SanDisk Ultra Compact Flash Memory Card has 8 GB of storage which should be suitable for our memory storage needs. This flash chip can write at 50 MB/s which is far greater than we need. Additionally, the chip is 9.07 grams which may be a little heavy but is feasible.

Camera: Dr. Kloepper and Dr. Stevenson are providing the camera for us.

Battery: Last year's group used a 150 mAh battery that weighed 8 grams. I found a Lithium ion battery that provides 400 mAh and weighs 9 grams. This battery if we choose to buy it, could power the device for 60% longer at the cost of only 1 extra gram out of a budget of 50 grams. (PRT-13851 ROHS)

6 Open Questions

The problem of data storage for the system during power failure is the aspect of this project that we are the most unsure how to approach. We will need to become familiar with the software code from last year's project before finding a method that updates the file data structure in a more timely periodic fashion so that the data is not lost when the power fails. This will require further research into the particulars of suitable SPI communication methods used by microcontrollers to interact with the memory chip .

Finding a stronger battery that can last the desired 45 minutes will require us to look into the power specifications of our modified board and possibly look at power saving methods. The battery specifications are entirely dependent on the supply voltages for the different components we will be powering, the current draw they need, and the length of time we will be powering them for. In addition, finding a stronger battery will need to find one that fits our weight limit of 50 grams, which poses a problem as more powerful batteries tend to weigh more. In addition, these unknowns momentarily prevent us from designing a more secure arrangement for the battery as we don't know exactly which model to use yet. We currently are looking into the PRT-13851 ROHS lithium battery, which can last longer than last year's battery at essentially the same weight, but further research will need to be done before making a final decision.

7 Major Component Costs

Major component costs can be seen in **Table 1**. One area we may look at to decrease cost if necessary would be reducing the number of printed circuit boards ordered as these make up the bulk of our cost.

Name	Description	Quantity	Cost
MEMS SPU0410LR5H-QB	Microphone	2	$1.88
SanDisk 8 GB Ultra Compact Flash Memory Card	Flash Storage Component	1	$19.96
Printed Circuit Board	Circuit boards for both the data processing system and a user interface board. Ordering 4 each from 4PCB	8	$30.00

Active Filter and Amplifier	Active filter will consist of op-amps, resistors and capacitors. Amplifier will be an op-amp	N/A	$5.00
Microcontroller	PIC32MX270F256B	1	$4.16
Total	-	-	$271.00

Table 1: Major Component Costs

8 Conclusions

Our project has a very solid base to build off of from last year's group, and we are confident we will be able to make our desired improvements to this year's build. We will face software challenges in writing two channels to memory, as well as implementing an autosave feature. We will also face hardware challenges involved in designing and building a more robust filter, and creating a user-interface board. Hopefully our successful completion of this project will allow bat sonar data to be taken easier and with more consistency, which will hopefully lead to developments in the field of sonar research.