Hawk Ear 2.0

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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

PROBLEM DESCRIPTION:

In last year's iteration of the project, Professors Kloepper and Stevenson ran into some significant problems which our group is hoping to address this year. The issues are listed in order of importance:

1. 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.
2. 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.
3. 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.
4. 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.
5. 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.
6. 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 problem described in (1).
7. 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.
8. The battery was 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 SOLUTION

1. Instead of an SD card we will use flash ROM to store data. As mentioned in (4), 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. 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.

2. 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 passive 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.
3. 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.
4. 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.
5. 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 in (3). 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.
6. 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.
7. 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.
8. We will use a battery which is designed to be soldered to circuit boards.

DEMONSTRATED FEATURES

1. We will demonstrate multiple trials of our battery lasting the desired amount of time.

2. Data will be able to be constantly saved and recovered in the event of a hard shutdown.
3. We will demonstrate our low pass filter having a sharp cutoff at 90 kHz.
4. We will demonstrate the ability to switch between 8 gain modes by changing the combination of the three switches.
5. We will demonstrate that the device can be powered on by the push of a button, and start recording with another push of a button. There will be two separate LED lights for each action.
6. We will show the ability to record sound data in all directions, and be able to tell the direction that the bats were in when they made the noise.
7. We will finalize a device with all of the capabilities mentioned above that weighs in at no more than 50 grams.

AVAILABLE TECHNOLOGIES

- PIC32 microcontroller will be programmed to meet all functionalities mentioned above
- MPLAB-X IDE will be used to program the PIC
- External memory chip will be connected to the PIC for memory access
- EAGLE PCB software will be used for design external and internal boards
- Anti-aliasing filters will be designed to ensure a sharper cutoff
- Op-Amps will be selected that suit our desired gain
- Specialized microphone that can pick up to 200 kHz to be used.

ENGINEERING CONTENT

Circuit Design

We will be designing two boards with Eagle. One of the boards will be designed for the hawks head and have the microphones, and the amplifiers. The board on the back will have the rest of the design, such as the microchip, the battery, etc.

Signal Processing

We will need to engineer ways to both collect and store the data from the microphones onto flash, as well as ways to transfer the data from our flash into a computer.

Amplifier Design

We will need to design 8 different gains for an amplifier that can be operated with three switches. These gains will need to be chosen ahead of time, and will need to be easy to switch between them.

Programming

We will need to program to the microcontroller. We will be programming in C and using MPLAB. Our code will need to be able to operate all of our systems as well as coordinate with the video signal.

Design

We will need to optimize the size of the parts, attempting to make them as small as possible due to them weighing down the hawk. We will need to optimize the ease of use and robustness of the design so our customer, Professor Kloepper, won't have to worry about the circuitry or programming when she is in the field.

CONCLUSIONS

The Hawk Ear 2.0 seeks to better answer questions surrounding echolocation research by improving on last year's iteration of the recording device. Shortcomings of the previous design were listed, including needs for smarter data-saving strategies, sharper anti-aliasing filters, more practical user interfaces, and smaller long-lasting batteries. Solutions were proposed with feasible goals for the end of the year, such as proving the device could use flash ROM, conveniently switch between gains, and utilizing localization methods. From C software to anti-aliasing filter design, the handling of various technology from both sides of the electronic spectrum were described to showcase the exposure to a wide line of engineering content that will be needed going forward. With these improvements, we hope to equip Professors Laura Kloepper and Robert Stevenson with the proper tools to continue pursuing new emerging sonar technologies.