Hawk(less)Ear

Senior Design Proposal

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1 Introduction

As the sun sets into dusk on a June evening over a cave in Arizona, a feat of nature commences. Around half of a million Brazilian free-tailed bats emerge from the cave in a dense, undulating stream at speeds of 25 mph. Each produces ultrasonic, frequency modulated downsweeps of 60 to 20 kHz at intense levels of 100 to 120 dB around 10 milliseconds in duration. Though their only goal is to forage for food, they demonstrate remarkable swarming behavior and echolocation in navigating towards food sources. They impressively achieve this level of echolocation while traveling in tightly packed clusters without colliding or jamming each other's biosonar chirps. Understanding how bats modify their echolocation strategies to avoid interference has far-reaching implications for signal processing and Naval technology, such as missile swarms. For this reason, Dr. Robert Stevenson of the Notre Dame Electrical Engineering Department and Dr. Laura Kloepper, an expert on bat bioacoustics, received a grant from the Office of Naval Research to explore the Brazilian free-tailed bats' swarming and biosonar behavior.

Our team will assist them in the third iteration of their project, a microcontroller with an ultrasonic microphone that records biosonar signals and stores the data. Previous teams designed a device that was mounted on a hawk's head as it flew through the bat swarm in order to record the chirps. This year, our team will improve upon their design. The microphone will be replaced with a 4 by 4 array of microphones to achieve directionality in recording the bats' ultrasonic sweeps. In addition, a means of wireless communication will be installed to prevent Dr. Stevenson and Dr. Kloepper from having to insert and remove an SD card in order to access collected data. This is particularly important in the harsh Arizona climate where dust easily gets lodged into the SD card connector and inhibits the device performance. Lastly, more battery power will be connected to the device, as it will no longer be mounted on a hawk and will not have previous weight constraints.

2 Problem Description

Last year's Hawk Ear 2.0 team did a good job in tackling some of the previous years' problems. However, they were unable to address all of them, and some new problems arose. Our group is hoping to address the following issues:

1. While previous iterations were successful in recording the ultrasonic bat signals, the recordings were complex and noisy due to the omnidirectional nature of the microphone. Too many chirps from bats were present to be able to effectively isolate the signals and make sense of the data. In an attempt to solve this problem, two microphones were put on the board, mounted inside synthetic bat ears, to achieve a level of directionality. However, due to limitations of the microcontroller, it was impossible to use both of the microphones simultaneously and directionality was not accomplished. The fake ears were also unsuccessful in aiding with directionality.
2. Because of the high sampling rate needed to capture bat signals, reading samples from two microphones and writing them to an SD card was pushing the limits of the

microcontroller clock in the last iteration of the project. The harsh desert environment also allowed dust to get into the SD connector and caused many data recordings to be lost. The group considered replacing the SD card with an EEPROM to store the data and a bluetooth chip to transfer it off the board later, but EEPROM write speeds prevented this upgrade.

3. The battery used in previous versions was extremely small, and thus did not hold charge for very long. Since the battery kept having to be reset, it was difficult to keep a real time clock running. Due to this, all the dates and times on the audio data were incorrect.

3 Proposed Solution

Our version of Hawk Ear will address some of the obstacles encountered in previous years, while also adding more functionality to the device. The main improvement over the past projects is adding directionality to the microphones, enabling us to capture bat signals from a specific direction and minimize noise from elsewhere. We will accomplish this by implementing a 4 by 4 microphone array and using the concept of beamforming. Beamforming works by accounting for the slight time differences a signal will take to reach each microphone from the direction of interest. By delaying the signal from each microphone the appropriate amount of time before summing them together, the sound from the direction of interest will be amplified while noise from any other direction will be mostly eliminated. To further minimize the noise, we will ensure that the microphones we use have a flat frequency response across the desired bandwidth.

The second major change from previous iterations is the size and location of the board. While in the past, the electronics have been attached to a hawk, which then flew into the swarm of bats and collected data, we intend for this iteration to be mounted at a static location. It will either be placed about 30 feet outside of the cave pointed up toward the swarm or attached to a motorized trolley moving up and down a cable near the cave. In the latter scenario, the device will be pointed towards the cave to capture the signals as the bats emerge. By not using the hawk, we will no longer have the size and weight constraint that was critical in the past.

In order to overcome the I/O and processing limitations encountered by previous teams, we will use a summing amplifier to add the signals from each microphone and accomplish the beamforming in analog. We will then digitize and store the resulting data in the microprocessor. Since we will only be storing one signal instead of two, this will help us avoid problems with write speeds and allow us to explore the use of EEPROMs in lieu of removable SD cards. Care will be taken in choosing an EEPROM that can store the necessary amount of data. To transfer the data from the device after recording, we will add a serial connection to the microcontroller.

Since weight is no longer a constraint, we will add a more robust powering system to the device than what was used in the past. The major benefit of this is to keep the real time clock running, so Dr. Stevenson and Dr. Kloepper can later identify exactly when each part of the recording occurs. We intend to use standard AA batteries to power the board.

4 Demonstrated Features

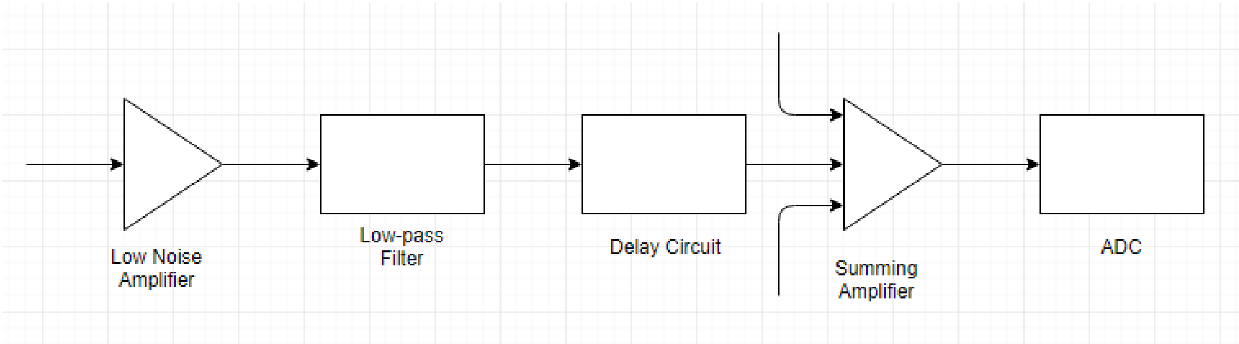
1. We will demonstrate that we have achieved directionality by testing the device with an emitter of bat biosonar signals (provided by Dr. Stevenson). A successful device will demonstrate that only signals from the direction of interest are amplified and sampled by the microcontroller, while the remaining signals are discarded as noise.
2. We will demonstrate that the analog circuitry functions as intended, and that the amplifiers do not add significant noise or distortion to the signal. We will also demonstrate the I/O capabilities of the microcontroller by sampling and storing an appropriate amount of data.
3. We will verify that the EEPROM storage can be written at the required rates and store more than enough data for one recording session. We will also show that the data can be transferred from the EEPROM to a laptop via a serial connection.
4. We will test the robustness of our power system by measuring the battery life and ensuring that it can run as long as necessary to collect the data we want (1-2 hours). We will also provide a backup power source or another method to preserve the date and time on the system even when the batteries are dead or removed.
5. We will verify that the microphones have a flat frequency response over the desired bandwidth of 20- 60 kHz by doing a frequency sweep.

5 Available Technologies

- **PIC32 Microcontroller**
- **EAGLE PCB software** for board design
- **MPLAB-X IDE** to program the PIC
- **Specialized microphones** such as the SPU0410LR5H to detect signals with frequencies up to 60 kHz
- **Amplifiers** to amplify the signals and sum them together
- **Low-pass filters** to filter the signal after it's amplified
- **EEPROM chip** to store the data once it's collected
- **Serial interface** to transfer data from the EEPROM to a laptop after collection

6 Engineering Content

The bulk of the engineering involved will be to design the signal processing circuits that will accomplish the beamforming. From each microphone, we will have to choose a low noise amplifier followed by a low-pass filter to make the signal usable. From there, we will have to design a delay circuit with the appropriate delay for each microphone, likely using a 555 timer chip. We will then need to choose a summing amplifier to combine each of the signals.



Block Diagram of Analog Circuit

We will use EAGLE to design the printed circuit board for our device, which will include sixteen different microphone circuits. We will use MATLAB to determine the optimal position and spacing of the microphones on the board to maximize the beamforming we can achieve.

This final signal from the summing amplifier will be sampled by the microcontroller at a large enough rate to preserve all the information, and the samples will be written to either an SD card or an EEPROM through a SPI interface. We'll use MPLAB to fine tune this process and program the microcontroller, most of which will involve the I/O operations and a basic user interface to tell the device when to start and stop recording.

7 Conclusions

Hawk(less) Ear hopes to improve upon the two previous years' projects by creating a new, more effective way to process data from the bats using an array of microphones. Although an attempt was made, the previous group was unable to establish any kind of directionality, which is an issue this project aims to solve using beamforming techniques. Since the hawk will not be used this year, there is no longer a weight restriction, and thus a more robust device can be designed. Hawk(less) Ear will showcase many facets of electrical engineering, and will put all of our skills gathered throughout the years to the test. We anticipate facing some challenges with the hardware and the signal processing, specifically with the beamforming circuit. However, with our efforts and ameliorated design, we hope to be able to advance the research of Professors Robert Stevenson and Laura Kloepper.