Hawk(less)Ear

Senior Design High Level Design

December 10, 2018

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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.

2 Problem Statement and Proposed Solution

Problem Statement:

Previous versions of this project have successfully recorded bat signals and produced useful data for the research project, but the group hopes to improve upon that design by using directionally and honing in on specific groups of bats. With previous iterations of the device, 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. Furthermore, only using two microphones made it impossible to achieve true directionality.

In addition, the harsh desert environment in which the device was used allowed dust to get into the SD connector, which caused many data recordings to be lost. The group considered replacing the SD card with an EEPROM to store the data and a using a bluetooth chip to later transfer the information to a laptop, but EEPROM write speeds and storage capacities prevented this upgrade.

Finally, the battery used in previous versions was extremely small and as a result, 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 and nearly impossible to synchronize the ultrasonic data with separate video recordings being done at the same time.

Proposed Solution:

This year's 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 to minimize noise from other areas. This will be accomplished 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 using sixteen microphones in a two dimensional grid and summing all sixteen signals together, the signals coming from the direction of interest will be amplified and the signals from other bats will be minimized using destructive interference. To further minimize the noise, the microphones used will 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, this iteration will 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, there will no longer be 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, a summing amplifier will be used to add the signals from each microphone and accomplish the beamforming in analog. The resulting data will then be digitized and stored in an SD card connected to the microprocessor. To prevent dust from interfering with the SD card connection, the card will be enclosed in a sealed case and use a bluetooth module to transfer the data from the device to a laptop.

Since weight is no longer a constraint, a more robust power system to the device than what was used in the past will be added. A rechargeable LiPo battery that will last for the duration of each recording, and can be recharged overnight to be used the next day will be used. A smaller coin cell battery will also be used to preserve the date and time while the battery is recharging and disconnected.

3 System Requirements

The main goal of our system is to take nightly recordings of bat signals, store the data, and later transfer it to a laptop for analysis and signal processing. The device must be able to record signals with the intensity of a common bat signal from thirty feet away. The recordings must also achieve a high level of directionality, and filter out the majority of the signals from other directions. The device must be able to process and store up to 1 GB of data for each night of recording, and be able to record for over an hour. This requires a significant amount of storage on the board and a large enough rechargeable battery to keep the device active for this period of time. The device will also require a smaller battery source to preserve the system’s date and time while the main battery is disconnected. This battery must be able to perform this function every night for several weeks while the larger battery charges.

The microcontroller must be able to sample and process the data at a high enough rate to preserve the full signal and to prevent aliasing. It also must be able to write the data to an SD card or other storage component at this rate. When not recording, the microcontroller must be able to read data from storage and transfer it to a bluetooth module for communication with a laptop. This bluetooth connection does not require a long range, since the researchers will collect the device from the cave after each recording, but it should have a high transfer rate due to the large amount of data it will need to process.

The system must have an interface that allows the user to start and stop recording from the device, as well as adjust the gain setting of the variable gain amplifier. While this interface does not need to be wireless, it would drastically improve the device to be able to control it remotely with the bluetooth module already on the board. Since it will be operated in a harsh desert environment, the sensitive device components, especially the microphones and SD card connection, must be protected from potential dust that could distort or disrupt the signal.

4 System Block Diagram

4.1 Overall System:

The overall block diagram for the system is shown in Figure 1 below. As shown, there are two major components of the system: the analog circuit and the data storage. Both of these are controlled by the user interface. More detailed block diagrams of each subsystem are shown below.

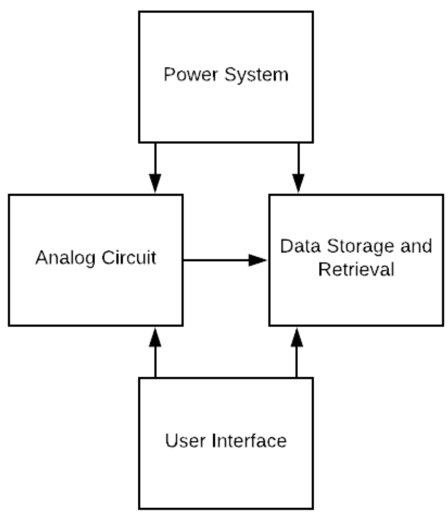

Figure 1. Overall System Block Diagram

4.2 Subsystem and Interface Requirements:

The block diagram for the Analog Circuit subsystem is shown in Figure 2, and specific details on the system are addressed below.

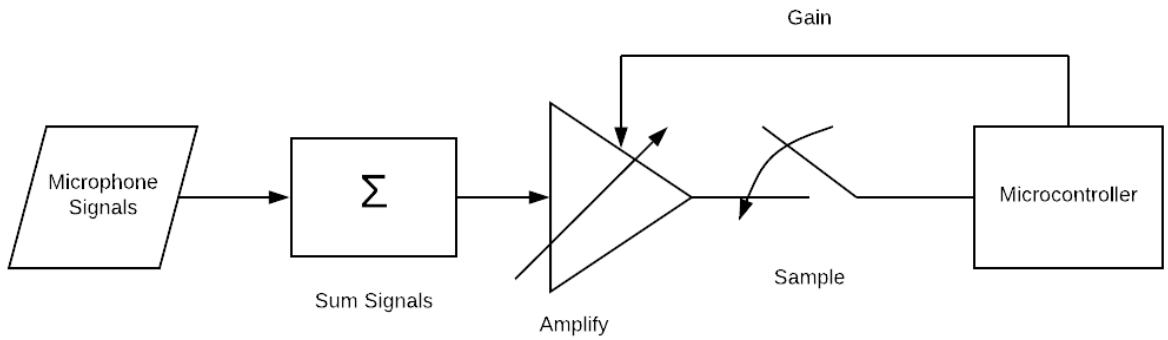

Figure 2. Analog Circuit Subsystem

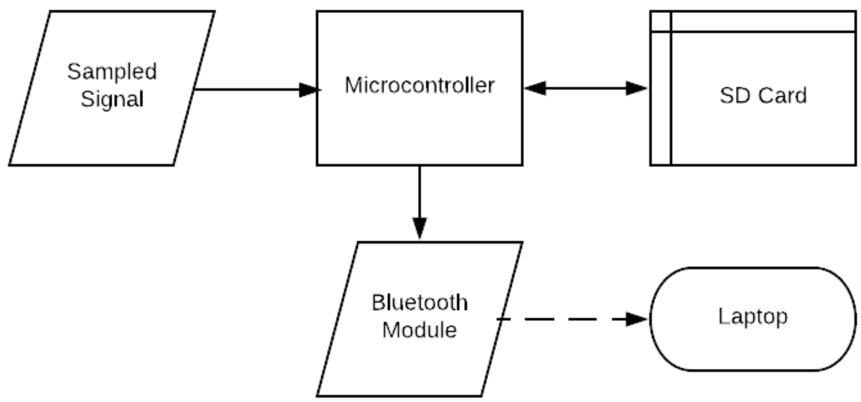

Figure 3. Data Storage and Retrieval Subsystem

1. Power Requirements: Battery
    a. A LiPo battery will be used to power the device during the recording and will be recharged after each recording session.
    b. A separate coin cell battery will also be installed on the device to preserve the date and time while the LiPo battery is recharging and disconnected.
2. Continuous Clock
    a. A reliable clock must be present to make it possible for researchers to accurately reference and analyze the recorded signals.
3. 4x4 Microphone array
    a. An array with 16 microphones will be used to perform beamforming in directionally capturing the biosonar signals from a specific group of bats. The microphones will pick up signals from the desired frequency range of 10-100kHz.
4. Bandpass filter
    a. The signals will be passed through a filter that passes frequencies between 10 and 100 kHz. Since bats chirp above 10kHz, the lower bound of the filter

eradicates non-bat, low frequency noise. The upper frequency limit prevents aliasing in the recording due to sampling rate limitations of the microcontroller.

5. Amplifier
    a. A summing amplifier will be used to amplify the signals summed in analog before they enter the microcontroller. It will operate with a supply voltage of 3.3 V.
6. Memory and Data Transfer
    a. Enough memory is needed to capture about an hour’s worth of continuous recording for each run. Multiple runs will be recorded on the SD card before the data is transferred.
    b. In order to circumvent having to physically remove the SD card to transfer data, the data will be transferred to Dr. Stevenson’s computer via a bluetooth connection.
7. Microcontroller
    a. The microcontroller will sample and process the analog data and store it to an SD card. It will also allow the data from the SD card to be exported via a bluetooth connection.

4.3 Future Enhancement Requirements

While the user can control the gain with a knobbed potentiometer, a future enhancement of gain control could include an LCD screen. The screen would depict the adjusted gain. This would make the device more user friendly and allow the user to know precisely what gain to which the amplifier is set.

While the currently planned array shape is a 4x4 square, an improved design would orient the microphones in a circle or star, to achieve the highest level of directionality. Further configurations will be modeled in MATLAB.

5 High Level Design Decisions

Microphone: The SPU0410LR5H-QB-7 omnidirectional microphone was chosen to be used for this design. This microphone has a relatively flat frequency response across the desired band. 16 of these microphones will be used to create a square, 4 x 4 array, which will add a directional capability to the device, as shown in Figures 3 and 4. They also fit our size limitations.

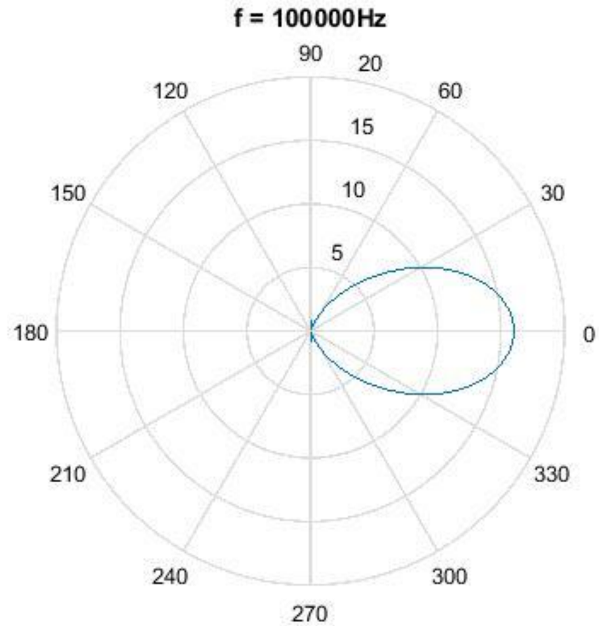

Figure 3. Theoretical polar plot for four by four square microphone array with three centimeter spacing, at 100 kHz

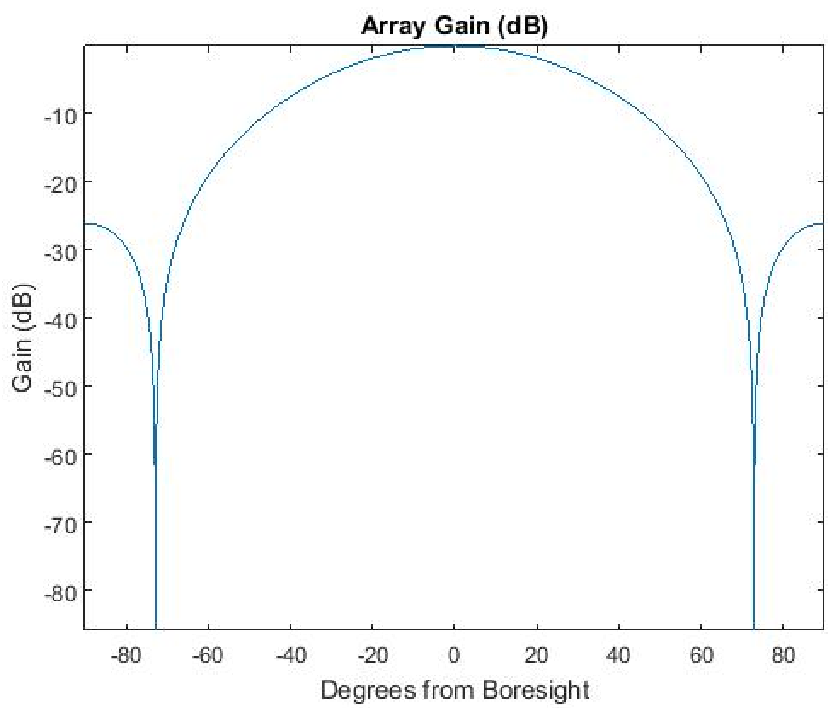

Figure 2. Theoretical gain (in dB) versus angle of incidence of 4x4 square microphone array with three centimeter spacing, at 100 kHz

Amplifier: The AD8338 amplifier will be used because it meets key requirements. Its supply range is 3.0 V to 5.0 V, it has a large voltage gain range from 0 dB to 80 dB, and a relatively high input resistance of 1 kΩ. This amplifier will receive the combined signal from all 16 microphones, and amplify it based on the desired gain.

Filter: An active high pass filter built-in to the AD8338 and controlled by external capacitors will be used alongside first-order, passive low pass filters in order to achieve overall system bandpass selectivity.

Microcontroller: The PIC32MX270F256B will be used for the microcontroller, as it fulfills necessary speed, power consumption, I/O interface, and cost requirements.

Memory: An eight GB SD card will be used to store data, as it is estimated this will be enough storage capacity to save one experiment session worth of data. The SD card has the capability to store data at a rate of 50 MB/s, which far exceeds the necessary rate.

Bluetooth Module: A NRF8001-R2Q32-T bluetooth module will be used to transfer data from the board to a laptop. This module uses SPI or I2C to communicate and has an output power of 0 dB, which is more than sufficient for our needs. It also has a transfer rate of 1 Mbps.

Battery: A LiPo battery will be used to power the device during the recording and will be recharged after each recording session. A separate coin cell battery will also be installed on the device to preserve the date and time while the LiPo battery is recharging and disconnected. The specifics of the type of batteries are to be determine, but restrictions to weight as in previous years are removed, so any batteries of large enough capacity will suffice.

Clock: The microcontroller in conjunction with the coin cell battery will be used to keep a continuous clock running.

6 Open Questions

One major aspect of the project that has to be looked into is whether or not the 16 microphones will effectively be able to be summed by simply combining them into one channel. At this point, this has been tested with two microphones, and it seems to work fairly well. However, after the number of microphones is increased by a factor of eight, this method might not be as successful. Another means of summing the signals from the microphones might have to be explored.

The arid environment in which this device will be tested tasks us with finding a way to keep the microphones clear from dust and other debris. Since the microphones are small, even a little bit of dust could greatly reduce the signal received. In order to avoid this reduction, the team has to decide the best way to cover the microphones without interfering with their ability to capture sound. The idea of placing a kind of film over the microphones in order to protect them has been brainstormed, but the material that will be used to do this is still undecided.

Finally, while a user interface on the device itself is acceptable, it may be useful to control the device remotely. Using a bluetooth-enabled cell phone app, the user would be able to start and stop recording or adjust the gain from a remote location. This would require additional functionality from the bluetooth module, plus developing a cell phone app, but the team intends to look into it as a possibility.

7 Major Component Costs

Part	Cost
16 Microphones (SPU0410LR5H-QB-7)	$11.68
Amplifier (AD8338)	$11.79
Microcontroller (PIC32MX270F256B)	$4.16
Assorted Capacitors	~$30.00
Printed Circuit Boards	~$80.00
SanDisk 8GB Ultra Compact SD Card	$20.00
NRF8001-R2Q32-T Bluetooth Module	$4.26
Batteries	~$5.00
Total	$162.63

8 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 by gathering data from the array. 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 gathered skills throughout the years to the test. The team anticipates facing some challenges with the hardware and the signal processing, specifically with the summing of sixteen microphones. However, with many efforts and an ameliorated design, the team hopes to be able to advance the research of Professors Robert Stevenson and Laura Kloepper.

References:

1. http://seniordesign.ee.nd.edu/2018/Design%20Teams/bat2/index.html (last year's Bat Team website)