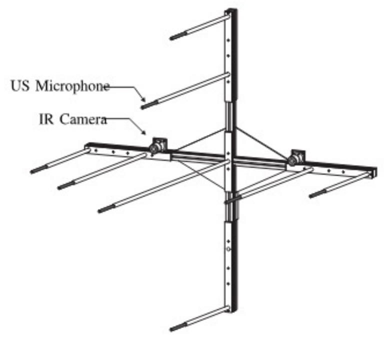
TRACKING FORAGING BATS IN THE UNION BAY NATURAL AREA

Bats in the Union Bay Natural Area

- Bats are an important ecosystem indicator, and their sonar inspires adaptive sensing designs.
- Big brown bats and little brown bats, emitting a frequency range of 10-80 kHz, inhabit the Union Bay Natural Area.
- The goal of this project is to build a microphone array which can be used to localize bat calls in the UBNA, allowing us to determine their foraging habits.
- The array must be able to record data for at least 12 hours, be easily deployable in the field, and be replicable with low effort and cost.

Bat Detector Array

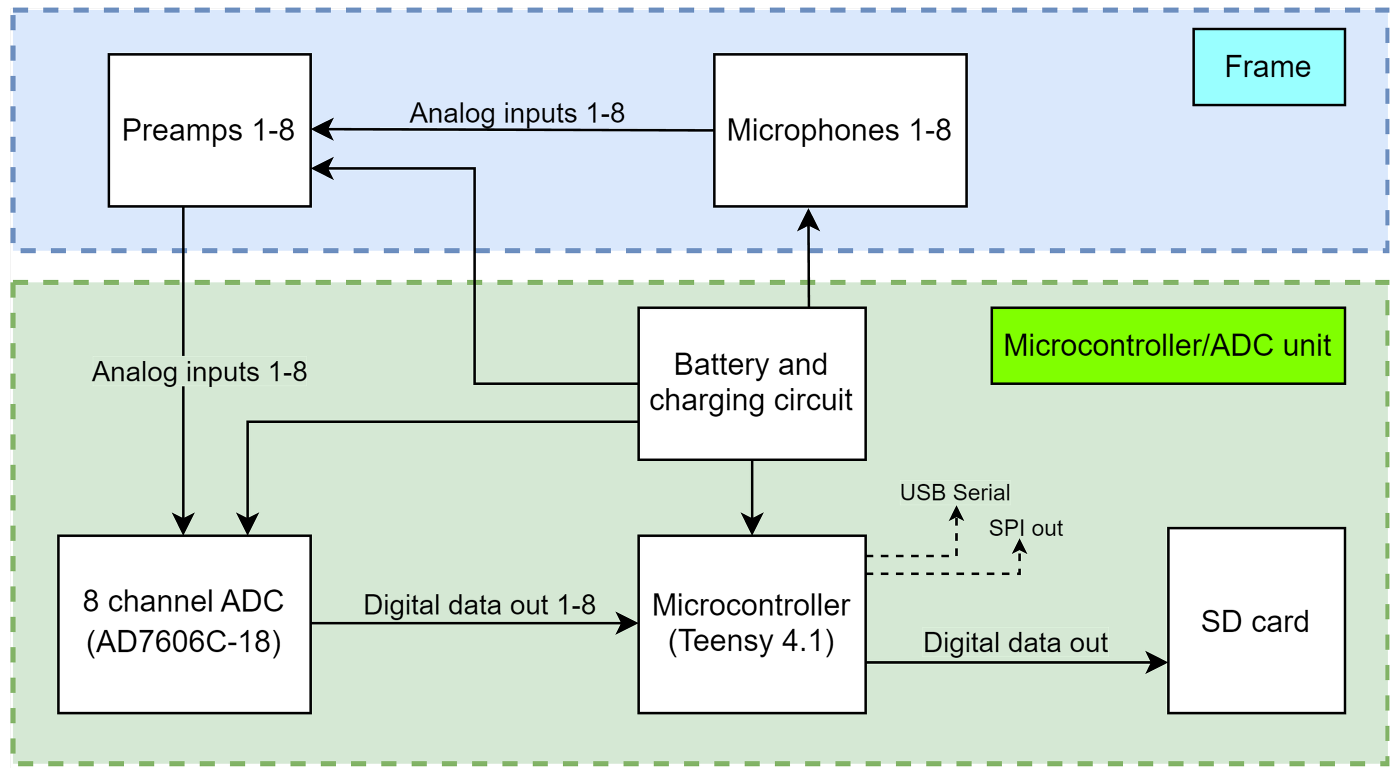
- Signals travelling in a constant speed medium can be localized using time-difference-of-arrival, or TDoA.
- All signals must be sampled simultaneously at a sampling rate of ≥ Nyquist rate.
- To localize a signal in 3d space, there must be ≥ 4 channels in > 1 plane.
- Bat signals are focused beams, which can leave out some microphones for a large array.
- An array of 8 ultrasonic microphones allows for more optimal localization of bats.



Above is an example of a microphone array. Our design satisfies 3 different planes for the most accurate reading as described to the left.

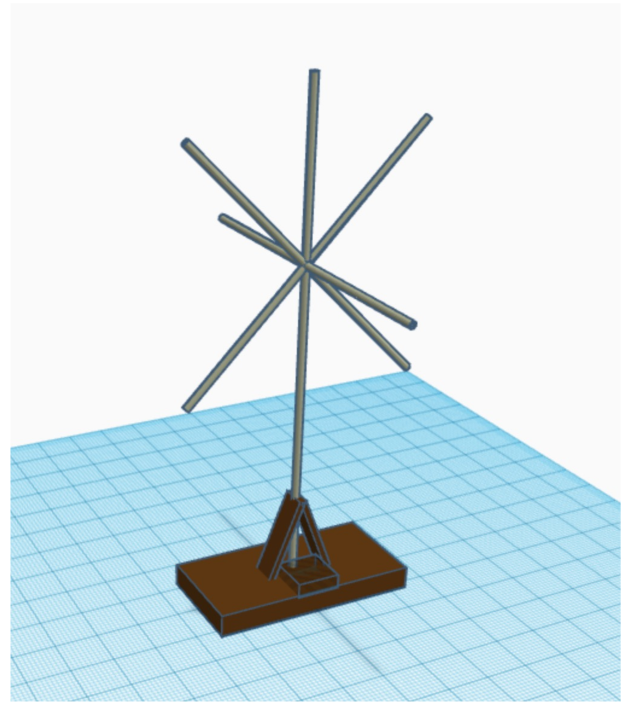
System Overview

- 8 omnidirectional ultrasonic microphones transduce pressure signals.
- The analog signals are filtered and amplified.
- All 8 analog channels are sampled simultaneously by an 8 channel, 1MSps, 18-bit ADC (AD7606C-18).
- The MCU (Teensy 4.1) triggers each sample period on the ADC.
- Data is read out from the ADC with SPI.
- The data is written to an SD card.



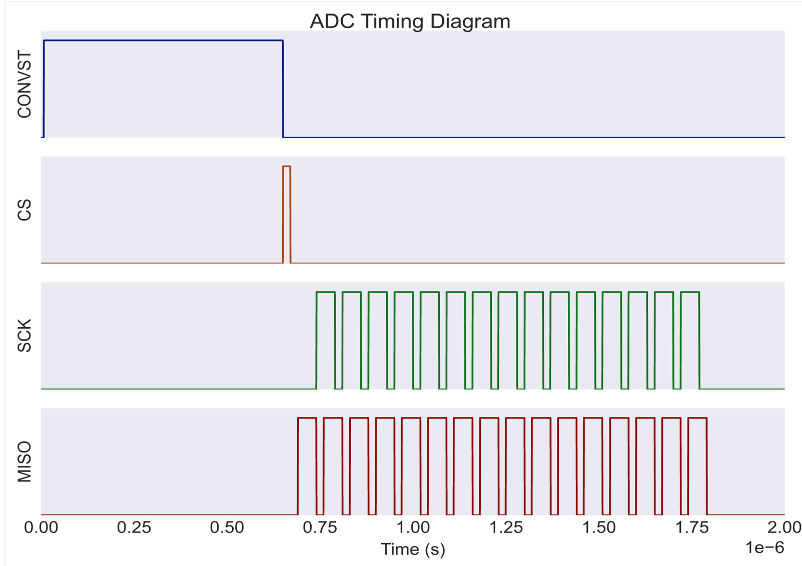
Frame Design

- The frame is designed to feature optimal microphone placement for eight separate microphones to be used for localization algorithms.
- The structure is lightweight and therefore portable for small teams to transport and install.
- The electronics are protected from the elements by waterproof material.
- PVC pipes are used for the main structure, with a 6 way joint in between to control arm directions. The base is made of wood to weigh down the structure. The array is covered with noise scattering foam material.



Firmware Design

- The conversion start pin on the ADC is driven at the sampling frequency with a zero-jitter hardware timer.
- Data is read out from the ADC with bit-banged SPI, with 1 SCK and 8 parallel MISO pins.
- The MSB is sent first from the ADC. If 16 of the 18 bits available are read out, for a sampling rate of 400kHz, the total bit rate is 51.2 Mbps.



Localization

- The pairwise sample delay between channels can be found with cross-correlation.
- TDoA = (sample delay) • (sampling frequency)
- For a continuous periodic signal, a delay larger than the period is impossible to extract, but bats emit signals in bursts separated by longer than the signal period.
- Given the TDOA and the microphone locations, there are many algorithms for distance localization. A linear system for 4 microphones is shown below [3].
- The below linear equation can be modified to use more than 4 microphones.

τ_{m0} is the time delay in seconds between channel m and channel 0. ***C*** is the speed of sound, 343 m/s. $\boldsymbol{x_m}$ is the x coordinate of microphone m in meters.

$$d_{m0} \equiv \tau_{m0} C$$

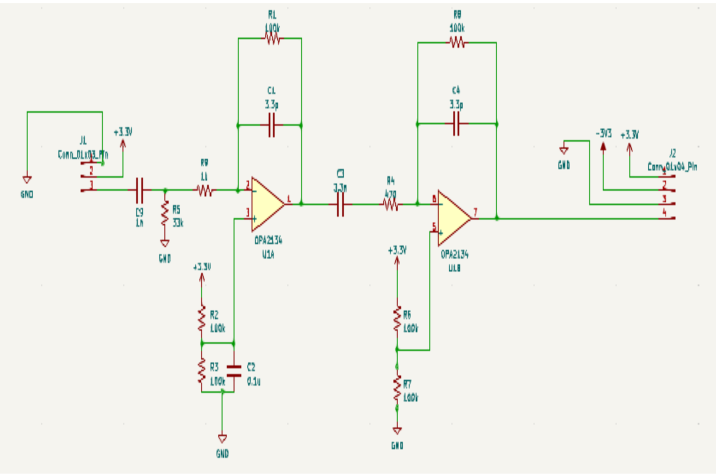
$$w_{m0} \equiv 1/2 \left(d_{m0}^2 - x_m^2 + x_0^2 - y_m^2 + y_0^2 - z_m^2 + z_0^2 \right).$$

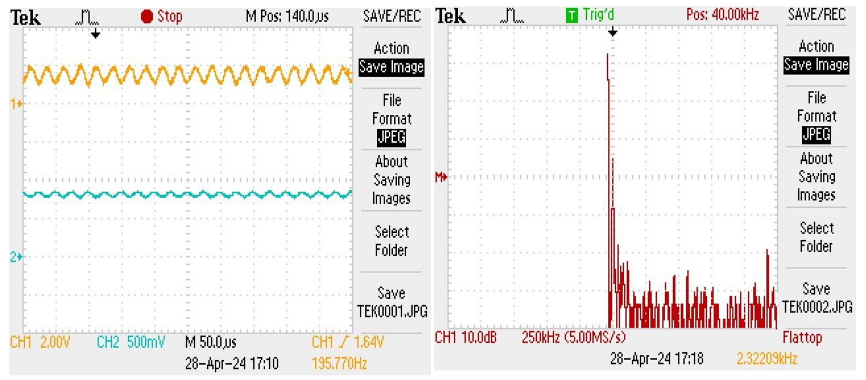
$$\begin{bmatrix} x_0 - x_1 & y_0 - y_1 & z_0 - z_1 & d_{10} \\ x_0 - x_2 & y_0 - y_2 & z_0 - z_2 & d_{20} \\ x_0 - x_3 & y_0 - y_3 & z_0 - z_3 & d_{30} \\ x_0 - x_4 & y_0 - y_4 & z_0 - z_4 & d_{40} \end{bmatrix} \begin{bmatrix} x_s \\ y_s \\ z_s \\ D_0 \end{bmatrix} = \begin{bmatrix} w_{10} \\ w_{20} \\ w_{30} \\ w_{40} \end{bmatrix}$$

- The solution to the linear system includes the source coordinates [x_s y_s z_s].

Hardware Design

- Preamplifier with high-pass filter. Cutoff frequency = 5 kHz
- Max output voltage at 80kHz = 1.44 V pk-pk

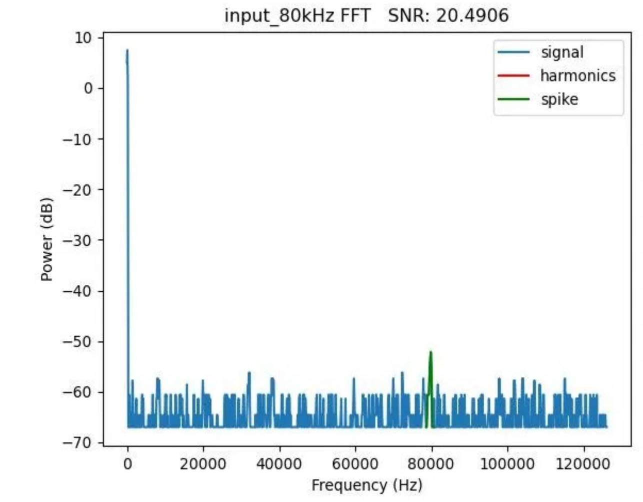




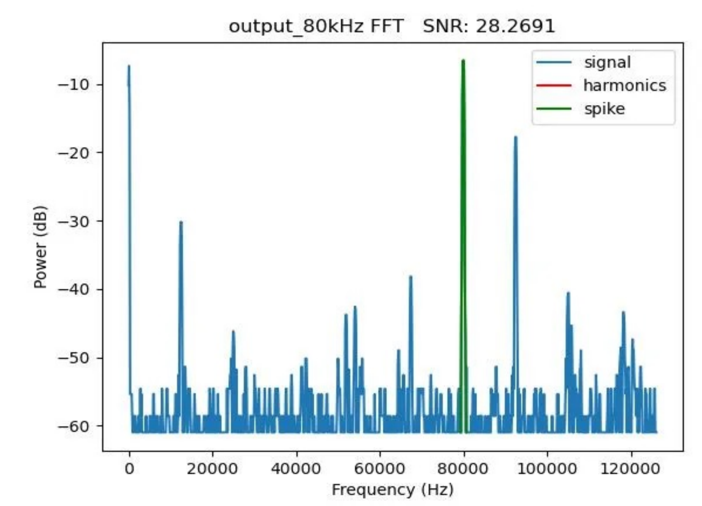
40kHz input (blue)
Preamp output (yellow)

FFT of 40 kHz signal from preamp output
Gain = 13.4 dB

- We are interested in bat calls in 25-80k Hz
- The signal with a higher frequency will be amplified more, and the gain range is about 200-300 depending on the frequency.
- FFT data of output signal generated by input sound at various frequencies was tested. There was some noise, but the target signal is clearly distinguishable.
- Generally, signal at high frequencies have a very good SNR above 20 dB.



SNR at 80kHz, input signal from transducer



SNR at 80kHz, output signal from preamplifier

Future Work, References, and Acknowledgments

The next steps for this project will be implementing:

- Ultrasonic microphone that exceeds the 80kHz range. Preferably 5kHz - 200kHz
- UI system that displays files and their respective locations
- A non-PVC based frame that has sound and vibration absorbent properties to provide the microphones a rigid structure to record off-of.
- Buffers between the high pass filter and the ultrasonic microphone to maintain the signal integrity through-out the bandpass filters.
- Adjustable cut-off frequency that utilizes potentiometer resistor(s).
- Implementation of hydrophone microphones within the existing hardware infrastructure, ensuring that there will be software compatible for this purpose.

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[1] "Frequency Response and Active Filters". Swarthmore.edu. https://cheever.domains.swarthmore.edu/Ref/FilterBkgrnd/Filters.html (March 21, 2024).
[2] "World's Smallest Bat Detector." Hackaday.io. https://hackaday.io/project/8353-worlds-smallest-bat-detector/details (April 15th, 2024).
[3] M. D. Gillette and H. F. Silverman, "A Linear Closed-Form Algorithm for Source Localization From Time-Differences of Arrival," in IEEE Signal Processing Letters, vol. 15, pp. 1-4, 2008, doi: 10.1109/LSP.2007.910324.

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