Acoustic Detection Array

High Impulse Sound Locator
Matt Hahn: GPS Interfacing, Full System Setup
Aidan Murphy: Multilateration, LoRa interfacing, Graphic Design
Rafael Luna-Cruz: Hardware Interfacing, PCB Design
Kevin Yuen: Audio Processing, LoRa interfacing
Venkat Krishnan: Hardware Interfacing, PCB design
Project overview

- We implement a network of microphones that can use triangulation to locate the origin of a high impulse sound.
System Overview

- Minimum 3 nodes for the multilateration algorithm to work properly. Additional nodes increase accuracy by reducing margin of error.
- MCU processes microphone data in order to detect a high impulse sound.
- Each node sends its location, the time it heard the sound, and the sound to a central computer.
- Central computer uses a correlation technique to determine precise time differences and multilateration to find original position of sound.
How do the nodes work?

- STM32 Microcontroller
  - Sample Audio Data
  - Communicate with GPS
  - Transmit Time, Location and Signal
- 20 Hz - 20 kHz range Microphone
- GPS Module
- Wireless Module (LoRa)
STM32F446ZET7

- ARM Cortex M4
- 144 Pin LQFP Package
- 512 kB FLASH, 128 kB RAM
- 180 MHz Clock
- In-stock :)
GPS Module

- Interfacing with the module using UART
- Receive Location and PPS data
- Uses PPS signal to synchronize internal clocks to 1 second accuracy for precise time of arrival recording
- The internal clock of the STM32F4 is used for this timing, providing up to 84MHz precision.
- This time is combined with the audio data and relayed back to the main computer
INMP441 Mic Module

- Omnidirectional microphone
- Interfacing with the STM32 using I2S
- 24 bit output
- 48 kHz Clock
- L/R Pin to choose channel
LoRa

Why use LoRa?

- "Long Range" Wireless
- Best option for communications over hundred of meters
- Low power consumption
- Coverage range from 5 to 15 km depending on terrain
- Limitations: low bandwidth
  - 37.5 kbps and under
Interfacing LoRa

- LoRa radio done with RFM95W breakout board from Adafruit, running a Semtech SX1276 transceiver
- Used to communicate between end nodes and central computing device
- Pings audio data and PPS timestamps to central node for multilateration computation
PCB Layout
PCB Design
Detecting a high impulse noise
Detecting a high impulse noise
Matching timestamps with Audio Data

Procedure:

1. Moving average crosses threshold and ready flag is set
2. Unset ready flag and capture current counter value
3. Extrapolate counter value for N previous samples based on 8MHz timer frequency and 44kHz audio clock
4. Send counter value followed up N bytes (N/2 bytes prior to impulse and N/2 bytes after impulse)
5. Once receiver processes data, send command to node to reset ready flag.
Calculating time difference of arrival (TDoA)

- Difficult to do this based on time difference of passing magnitude threshold
- Calculate correlation between signals,
  - Higher correlation -> smaller TDoA
  - Lower correlation -> larger TDoA
Correlation of Signals
Location origin of Sound

- Difference in time of Arrival
- Trilateration/Multilateration
- Optimization

\[
\frac{\sqrt{(x-x_B)^2 + (y-y_B)^2} - \sqrt{(x-x_A)^2 + (y-y_A)^2}}{C} = t_B - t_A
\]

\[
\frac{\sqrt{(x-x_A)^2 + (y-y_A)^2} - \sqrt{(x-x_C)^2 + (y-y_C)^2}}{C} = t_A - t_C
\]

\[
\frac{\sqrt{(x-x_B)^2 + (y-y_B)^2} - \sqrt{(x-x_C)^2 + (y-y_C)^2}}{C} = t_B - t_C
\]
Implementation

- Facilitates the solving of non-linear systems of equations
- Data is noisy and not very precise
- Least squares regression used to estimate final location
- Bayesian Regression tool determines Initial Guesses
## Spring Quarter Goals

<table>
<thead>
<tr>
<th>Week</th>
<th>Goal</th>
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<tbody>
<tr>
<td>1 - 2</td>
<td>• Assemble PCB and program it</td>
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<td>• Fine tune impulse detection parameters</td>
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<tr>
<td>3 - 4</td>
<td>• Field testing, trying different sounds / configurations (indoors / outdoors / distances) to understand performance of device</td>
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<td>• Make casing for device</td>
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<tr>
<td>5 - 6</td>
<td>• Analyze field testing data and iron out bugs</td>
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<tr>
<td>7 - 10</td>
<td>• Continue to debug any remaining issues and work on presentation materials</td>
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Thanks

- Thanks to our professor Yogananda Isukapalli for his knowledge and advice
- Special thanks to our sponsor CACI for their funding and guidance throughout the year