Acoustic Detection Array

High Impulse Sound Locator

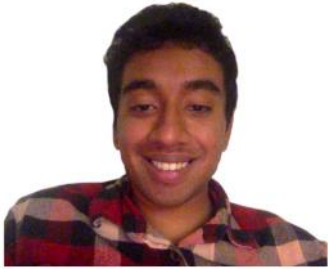
Team

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



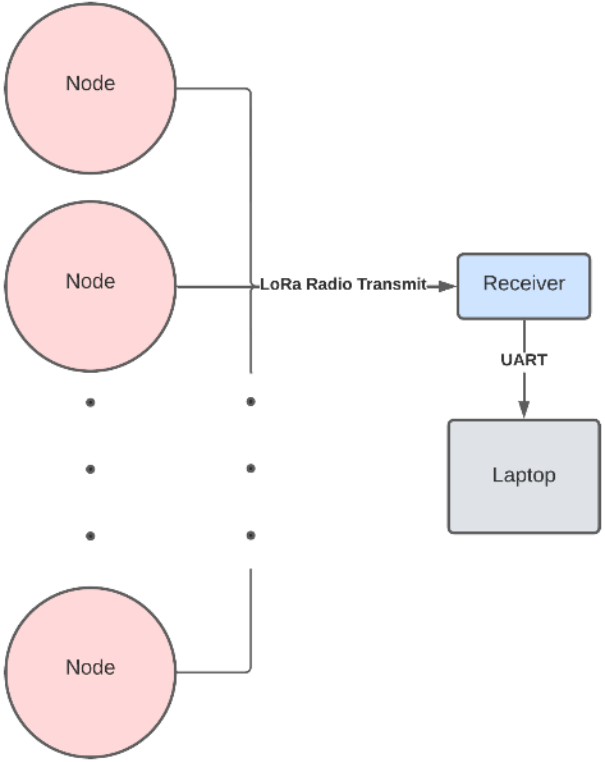
Venkat Krishnan:
Hardware Interfacing,
PCB design

Project overview

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

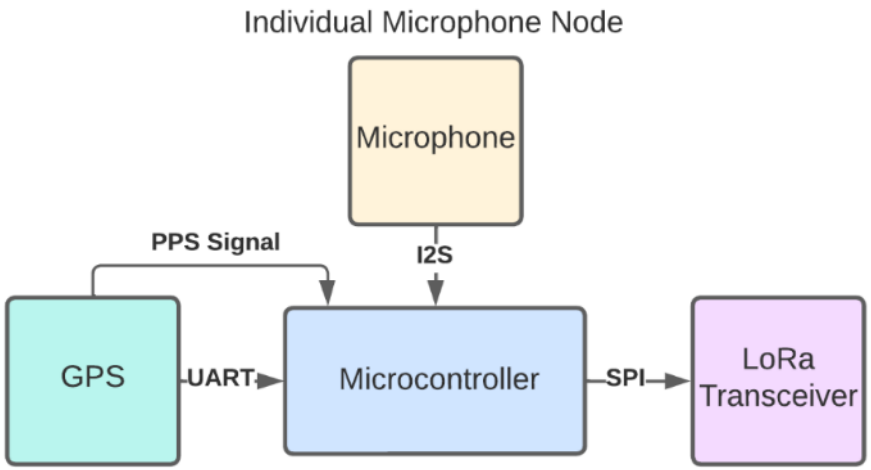
System Overview

- 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?

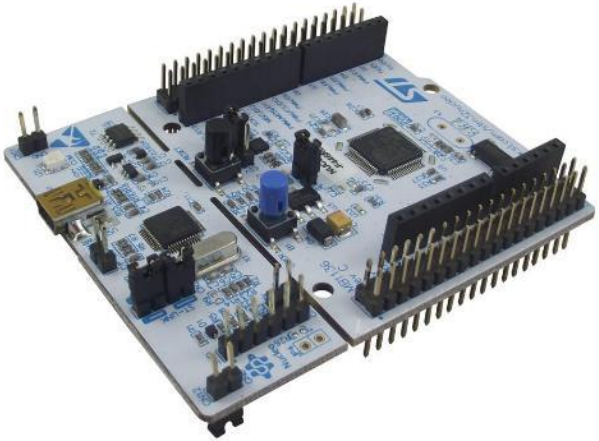
- STM32 microcontroller
  - Sample audio data
  - Communicate with GPS
  - Transmit time, location and audio signal
- 20 Hz - 20 kHz range microphone
- GPS module
- Wireless module (LoRa)



Microcontroller

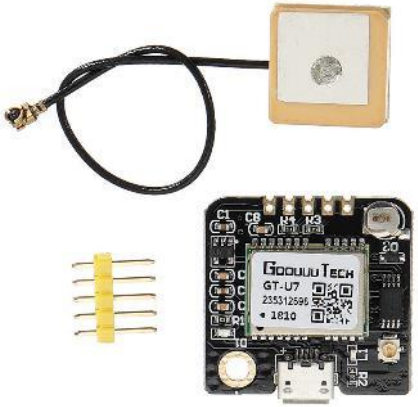
STM32F446ZET7

- ARM Cortex M4
- 144 pin LQFP package
- 512 kB FLASH, 128 kB RAM
- 180 MHz clock
- In-stock :)

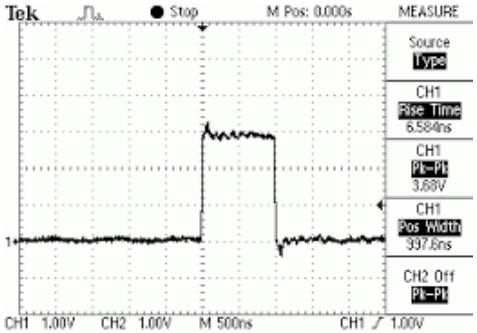


GPS Module

Generic GT-U7



- Receive location and PPS data every second
- Interfacing with the module using UART
- 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 90 MHz precision



Microphone Module

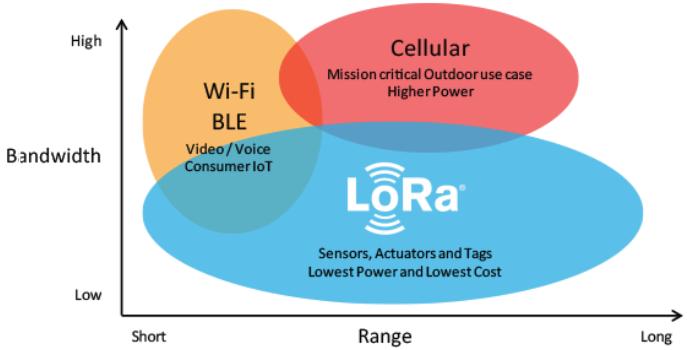
INMP441

- Omnidirectional microphone
- Interfacing with the STM32 using I2S
- 24 bit output
- 48 kHz clock
- L/R pin to choose channel
- Microphone windscreen to reduce noise

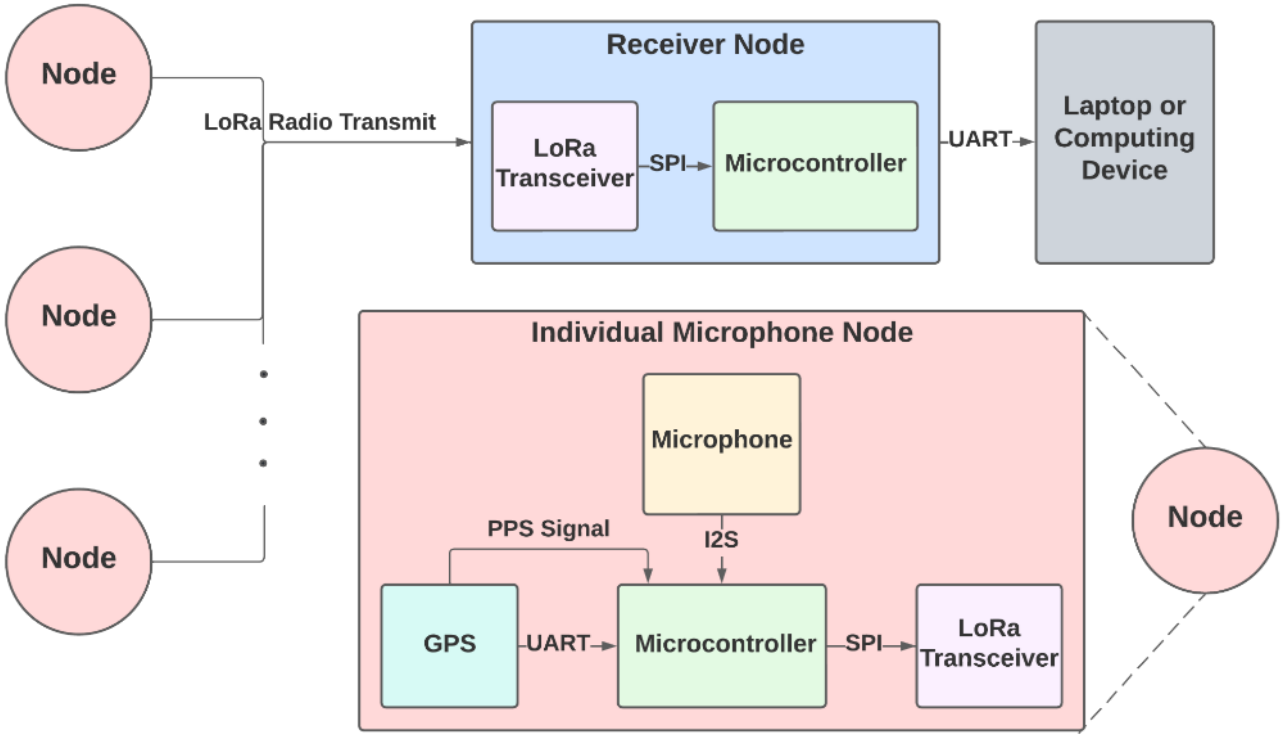
LoRa Module

Semtech SX1276

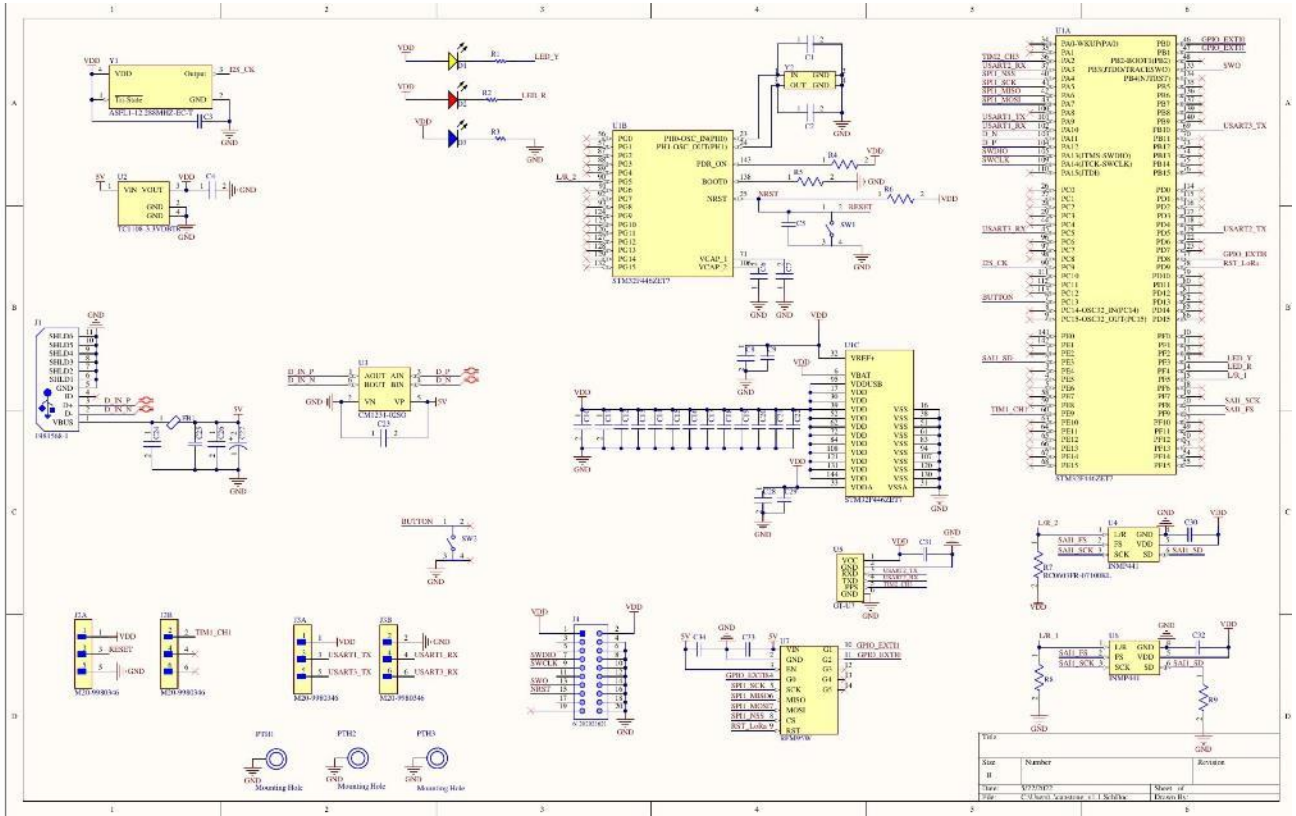
- Long range and power efficient communication between end nodes and central computing device
- Interfaced with SPI
- Ideal range for our purposes:
  1-2 km depending on terrain
- Pings audio data and PPS timestamps to central node for multilateration computation



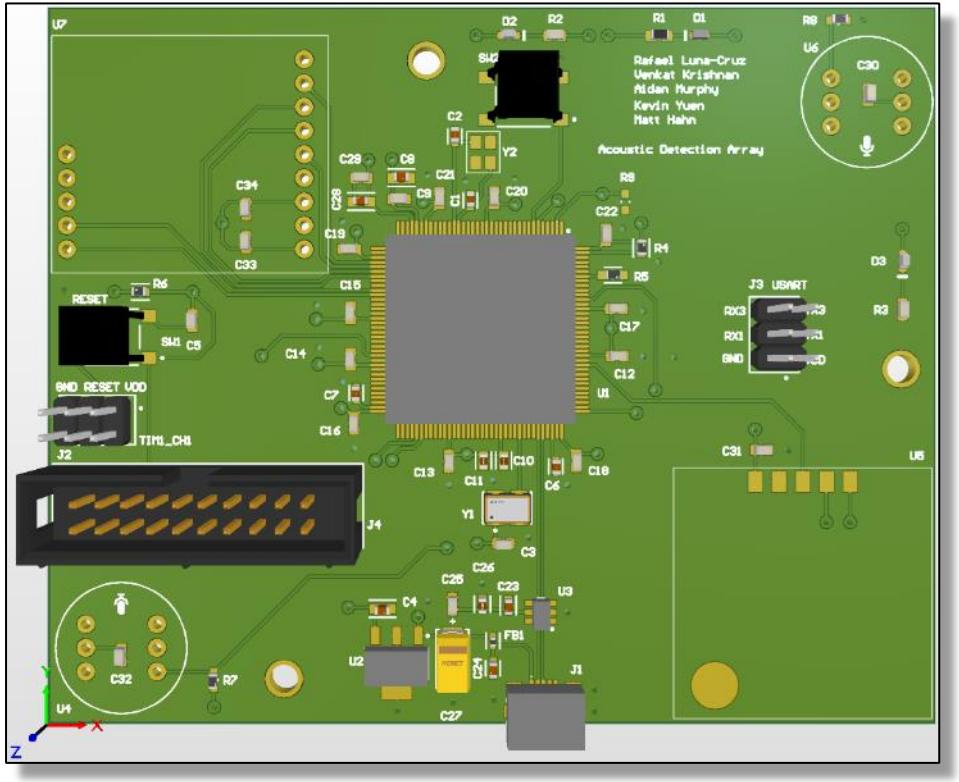
Full System Overview



PCB Schematic

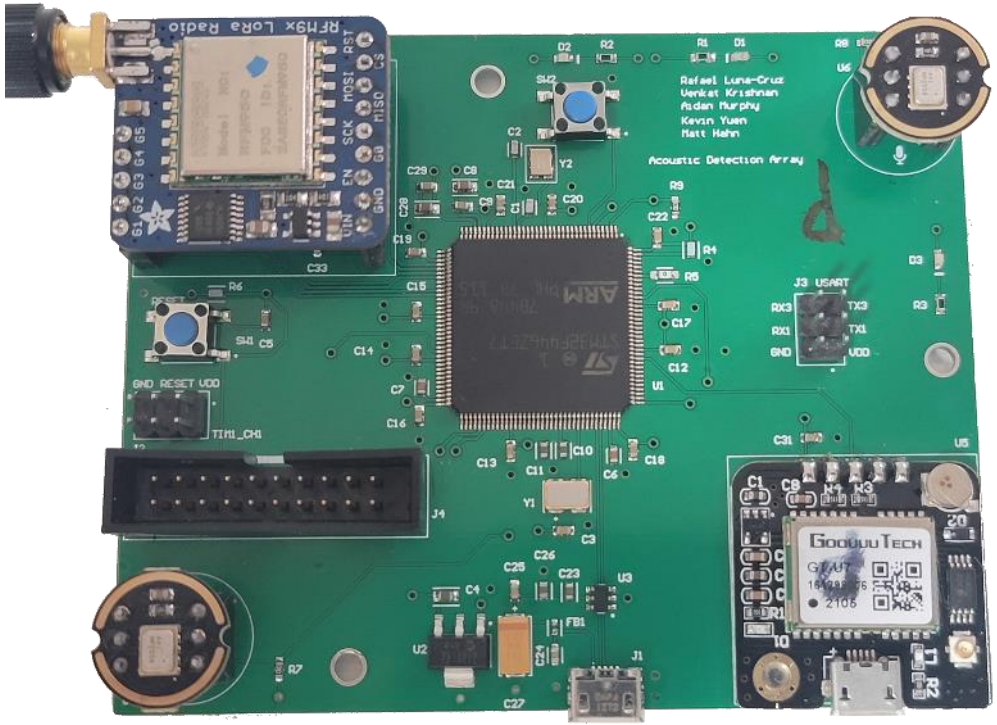


PCB Layout


Rafael Luna-Cruz
Venkat Krishnan
Aidan Murphy
Kevin Yuen
Matt Hahn
Acoustic Detection Array
J3 USART
RX3
RX1
GND
RESET
GND RESET VDD
TIM1_CH1
J2
J4
J1
U1
U2
U3
U4
U5
U6
U7
Y1
Y2
FB1
C27

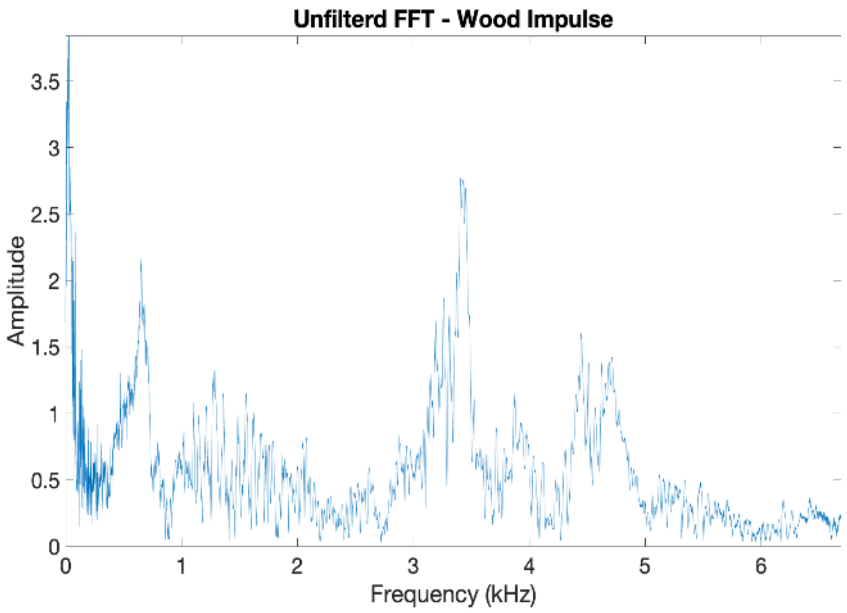
Final PCB

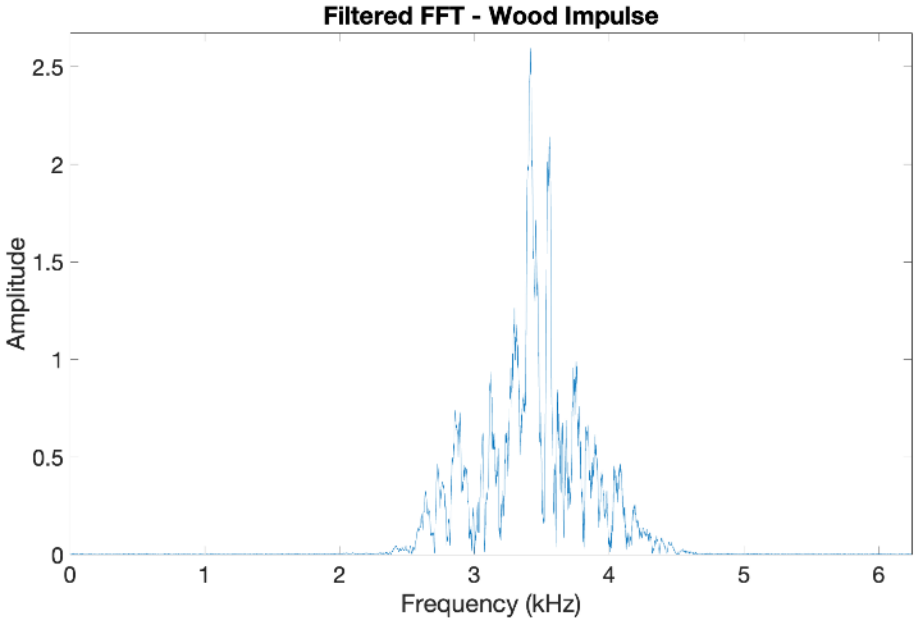
- 4 Layers
- Hand Assembled
- 95 mm (3.75 inches) by 77 mm (3.03 inches)



Final Product

Impulse Detection

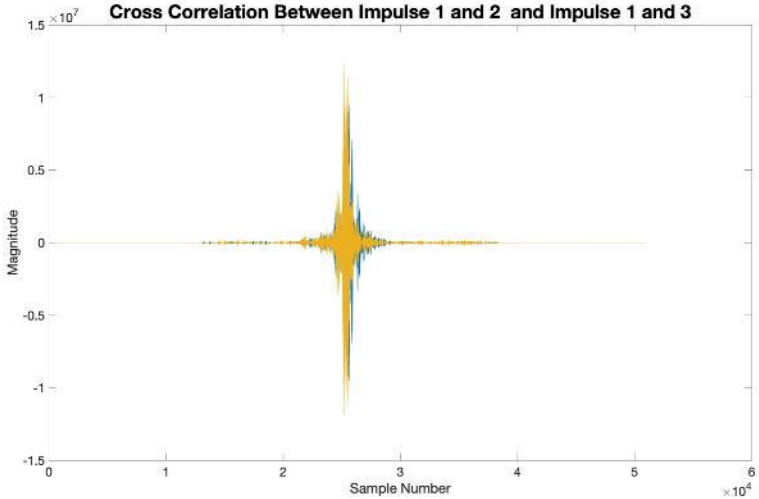




Time Difference of Arrival Calculation

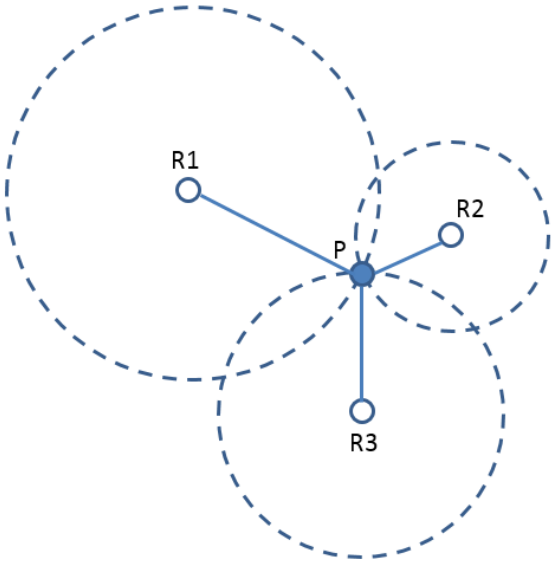
- Difficult to do this based on time difference of passing magnitude threshold

- Calculate correlation between signals,
  - Higher correlation -> smaller TDoA
  - Lower correlation -> larger TDoA



Location origin of Sound

- We need to calculate difference in time of arrival
- This is done using a method called Trilateration/Multilateration
- Multilateration is not symbolically solvable, thus optimization is necessary



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

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

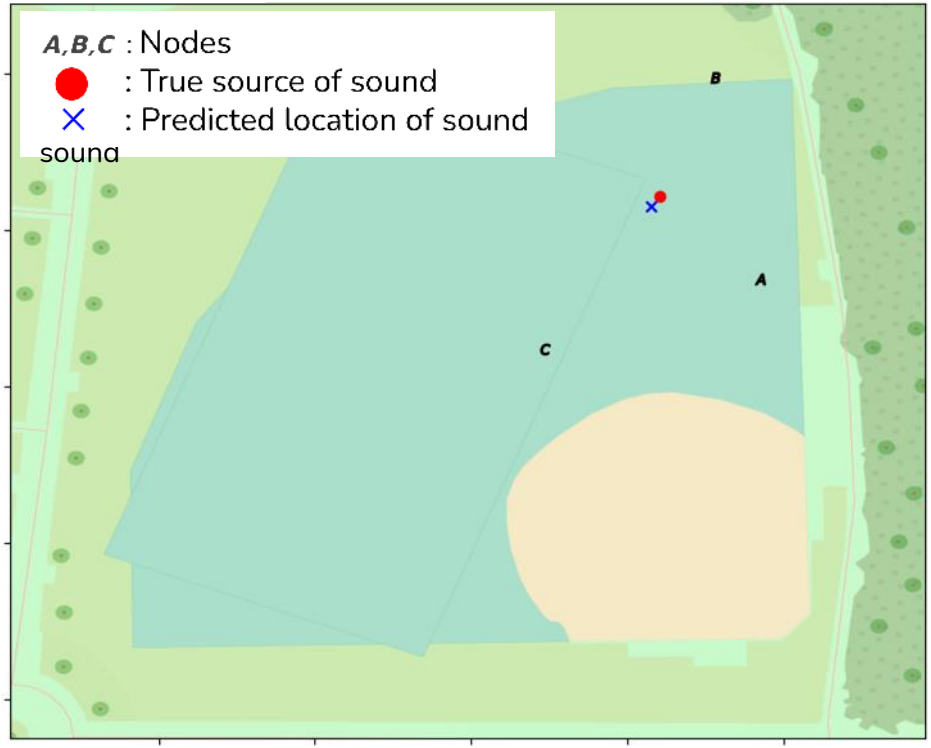
$$\frac{\sqrt{(x-x_B)^2+(y-y_B)^2}-\sqrt{(x-x_C)^2+(y-y_C)^2}}{C}=t_B-t_C$$

Implementation

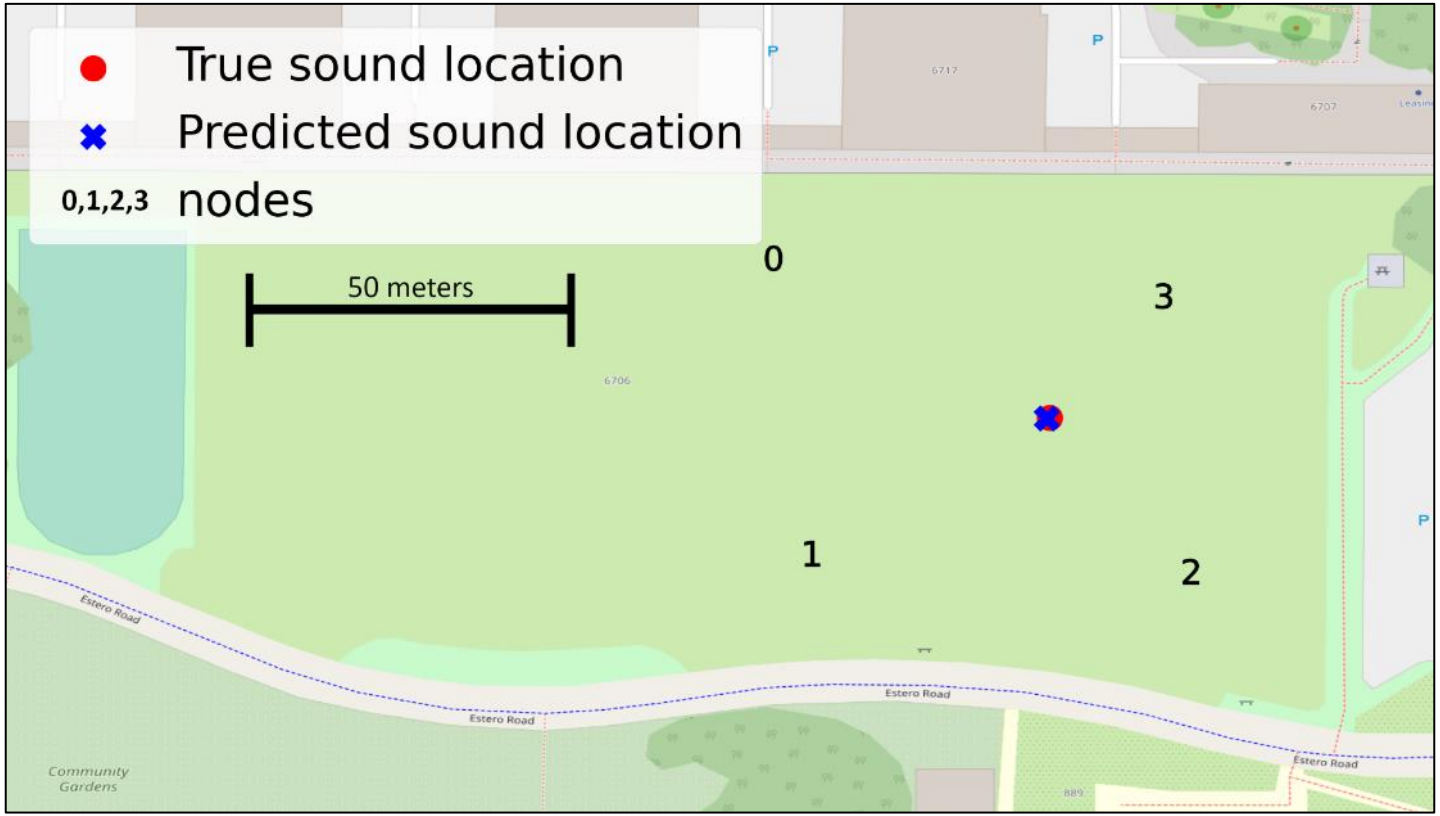
- Facilitates the solving of nonlinear systems of equations
- Data is noisy and not very precise
- least squares regression used to estimate final location

Field Testing

- Tests performed on a smaller scale at Girsh Park in Goleta
- Positioning of prediction near true source demonstrates system accuracy
- Large amounts of background noise do not interfere with the system

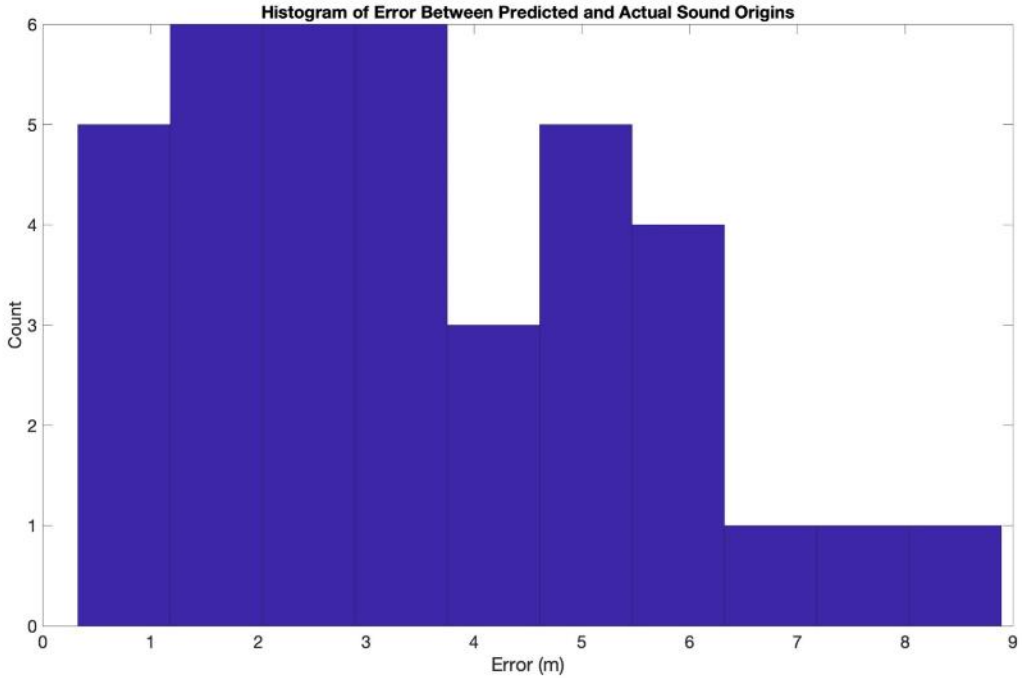


Additional Field Testing



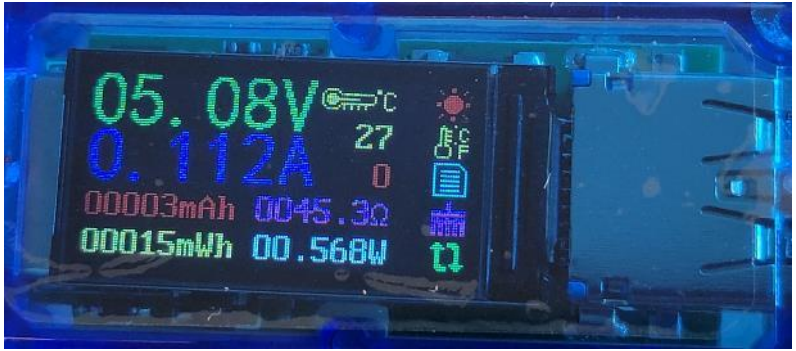
Demo Video

Field Testing Error Distribution



Power Consumption

- Used USB power meter to measure power consumption
- 110 mA in listening mode
- 220 mA while transmitting data
- Can be powered by most solar panel phone chargers



Practical Implementation - Node Cost

Part	Cost
Microcontroller - STM32F446ZET7	$12.57
Microphone - INMP441	$1.76
LoRa - RFM95W	$13.17
GPS - Generic GT-U7	$11.59
PCB Fab + Assembly	$2.15
Battery	$5.00
Total	$46.24

Conclusion

- We were able to construct individual nodes and deploy them as an array in the field successfully
- System specifications worked as expected from our test parameters
- Deployment of system is flexible for placement of 3 or more nodes
- With louder sounds like gunshots, detection can be made theoretically from up to 1,000 meters away

Thanks

- Thanks to our professor Yogananda Isukapalli for his knowledge and advice
- Thanks to our TAs Brycen Westgarth and Chris Cheney
- Special thanks to our sponsor CACI for their funding and guidance throughout the year
    - Special shoutout to Austin Hwang, Eric Nystrom, Jeff Longo, and John Buckley

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