Sound Source Localization using TDOA

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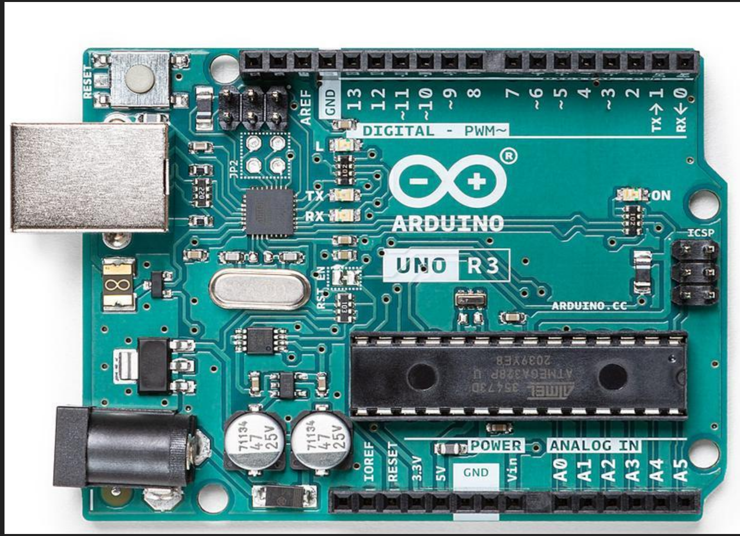
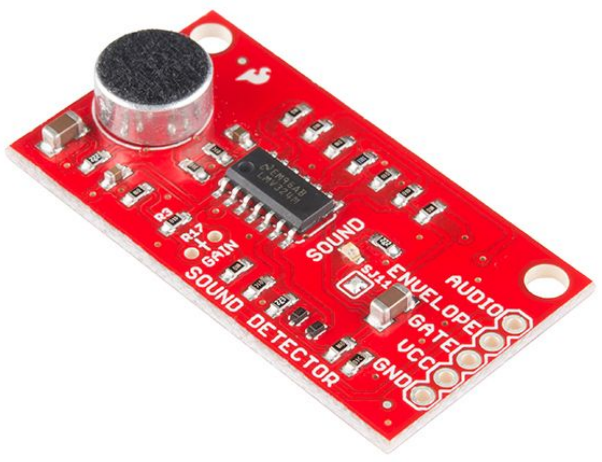
Project Overview

- Use arduino and electret microphones to do low-cost sound source localization
- Sample analog ‘loudness’ signal from the electret microphone on the Arduino
- Assess the data in Matlab
- Hardware:
  - Arduino Uno R3
  - 3 x Sparkfun SEN-12642
  - Laptop w/ Matlab installed



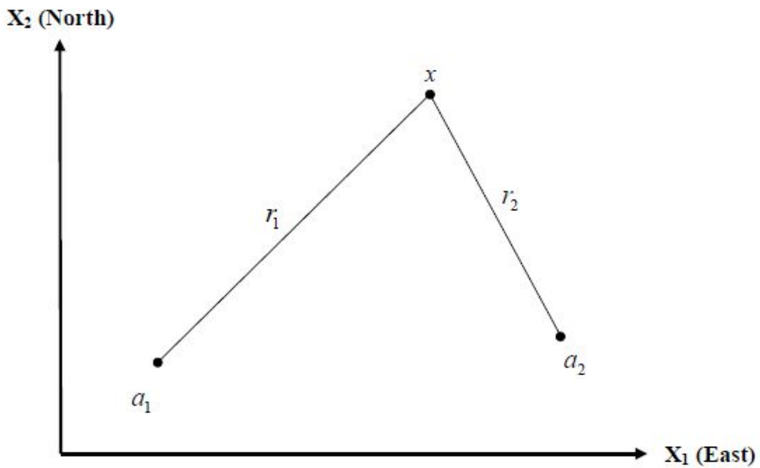


Equations and Methods

If r_1 and r_2 are the ranges from the sensors to the target as shown in the figure below, then

$$c \cdot \text{TDOA} = r_1 - r_2$$

where c is the speed of light.



- Instead of c, use Vs=344 m/s
- I refer to this difference in ranges as delta-range

Equations and Methods

ILS Equations:

For this reason, we'll treat TDOA as a range difference. The measurement function is

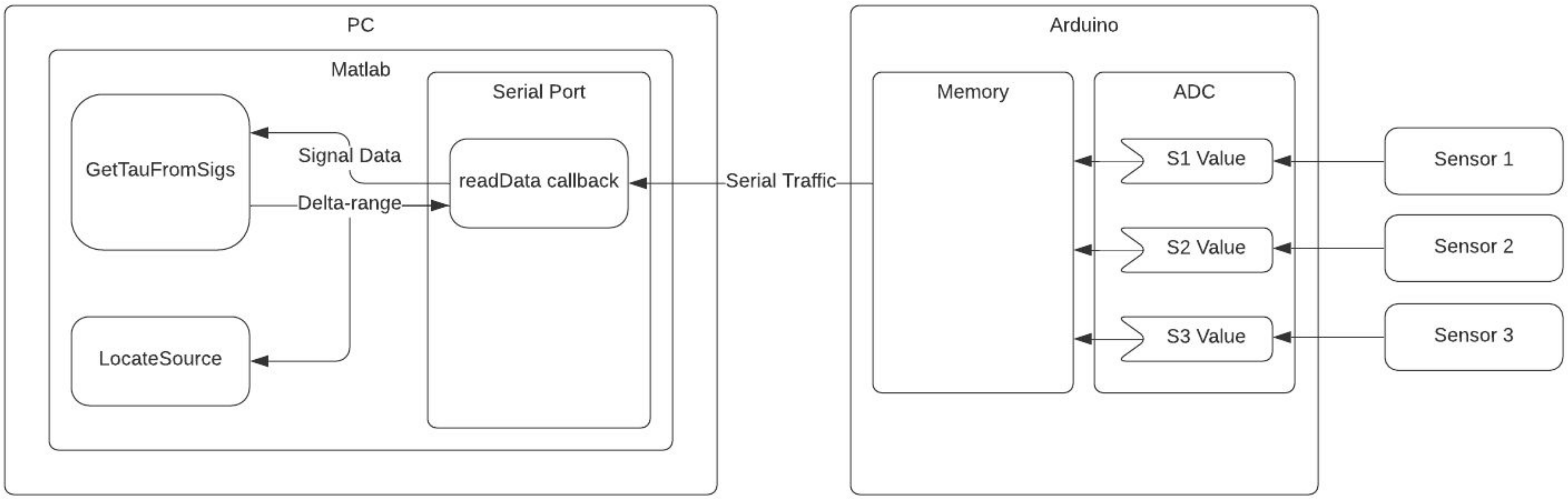
$$\text{TDOA} \propto h(x) = r_1 - r_2 = \|x - a_1\| - \|x - a_2\|$$

The linearized model matrix is computed as follows

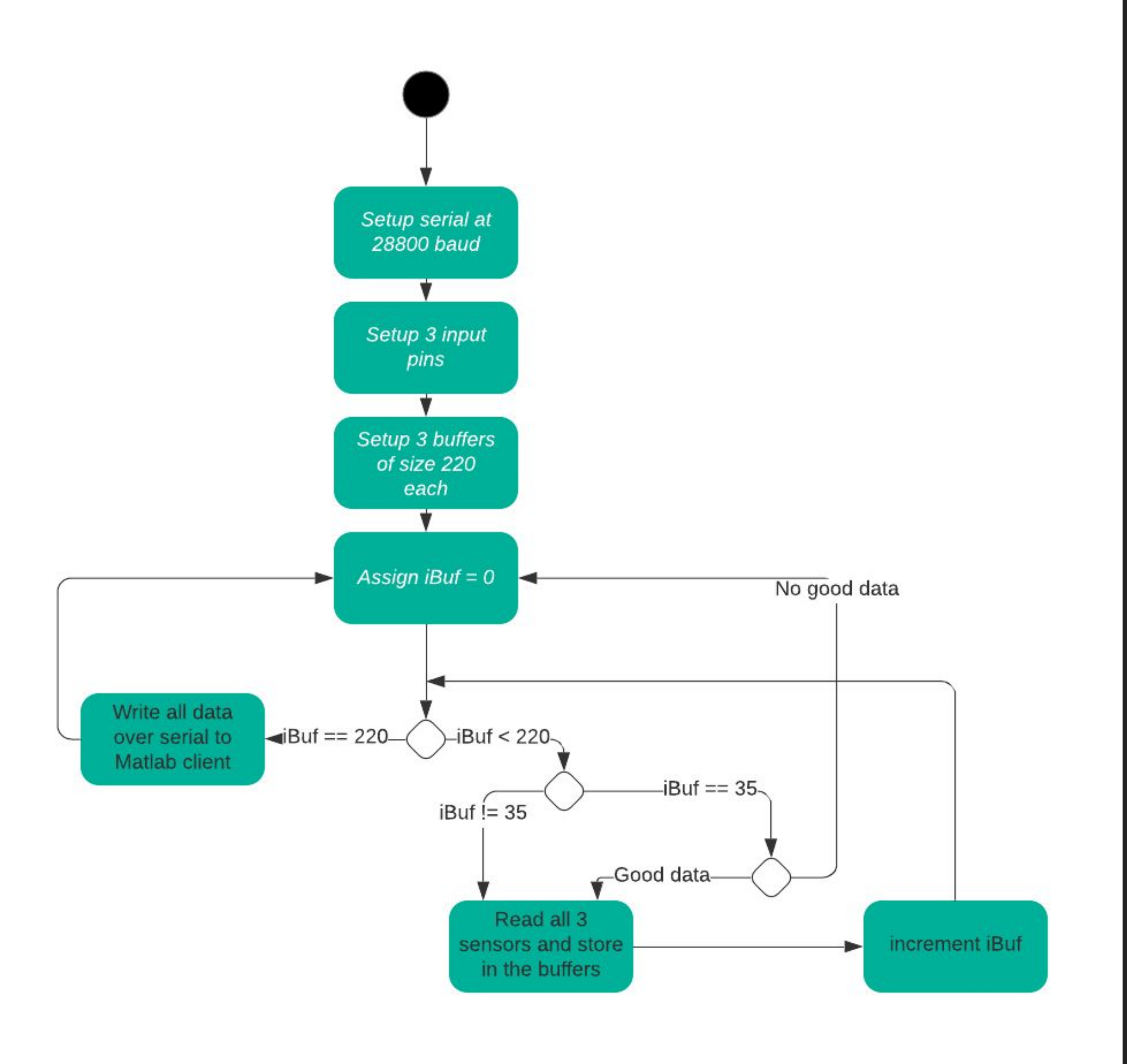
$$H = \frac{\partial h}{\partial x} = \left(\frac{1}{r_1}\right)(x - a_1)^T - \left(\frac{1}{r_2}\right)(x - a_2)^T = u_1^T - u_2^T$$

where u_1 and u_2 are unit vectors from the sensors to the target.

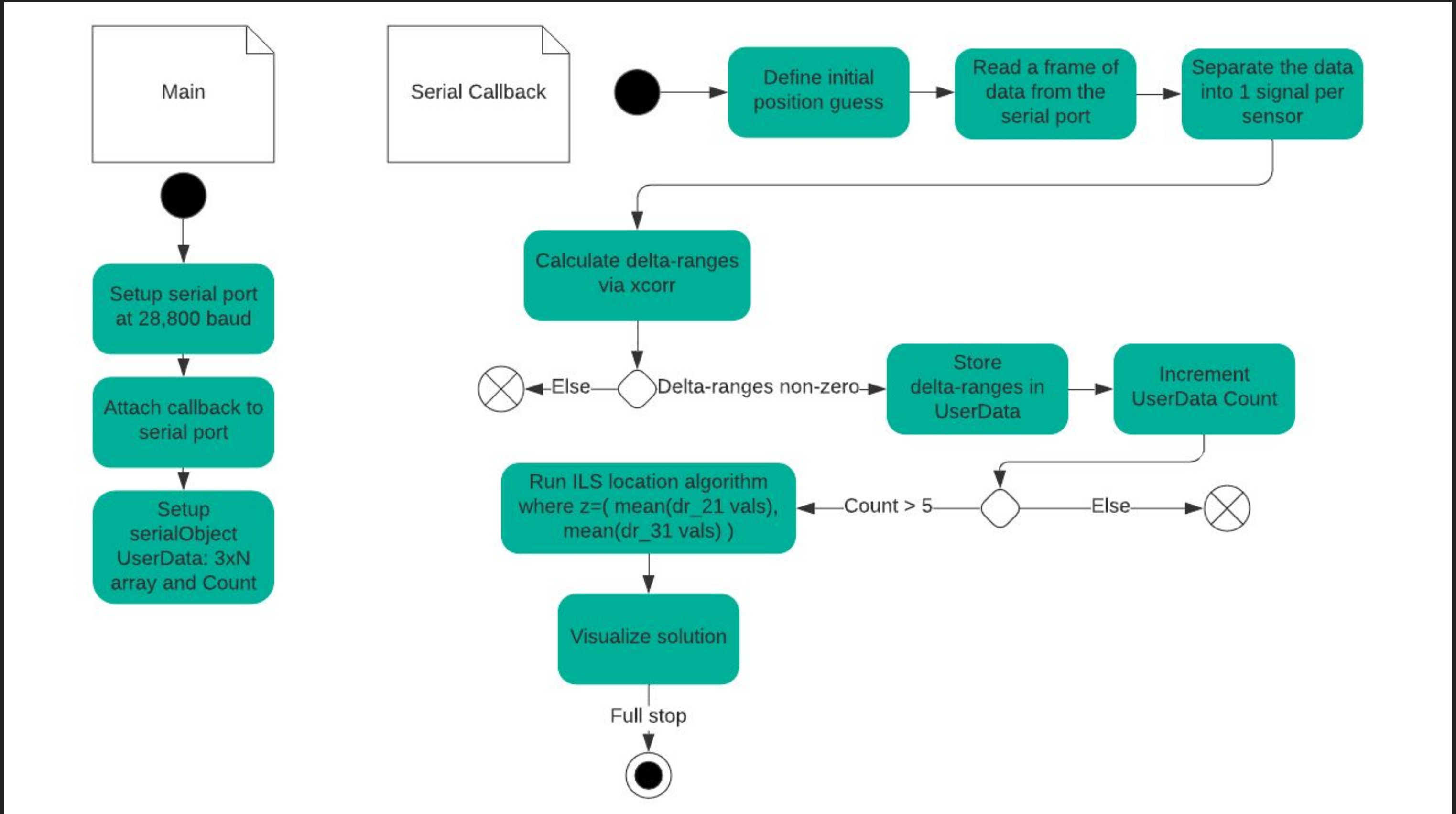
Block Diagram



Arduino Code



Matlab Code


Main
Serial Callback
Define initial position guess
Read a frame of data from the serial port
Separate the data into 1 signal per sensor
Setup serial port at 28,800 baud
Attach callback to serial port
Setup serialObject UserData: 3xN array and Count
Calculate delta-ranges via xcorr
Else
Delta-ranges non-zero
Store delta-ranges in UserData
Increment UserData Count
Run ILS location algorithm where z=(mean(dr_21 vals), mean(dr_31 vals))
Count > 5
Else
Visualize solution
Full stop

Operation

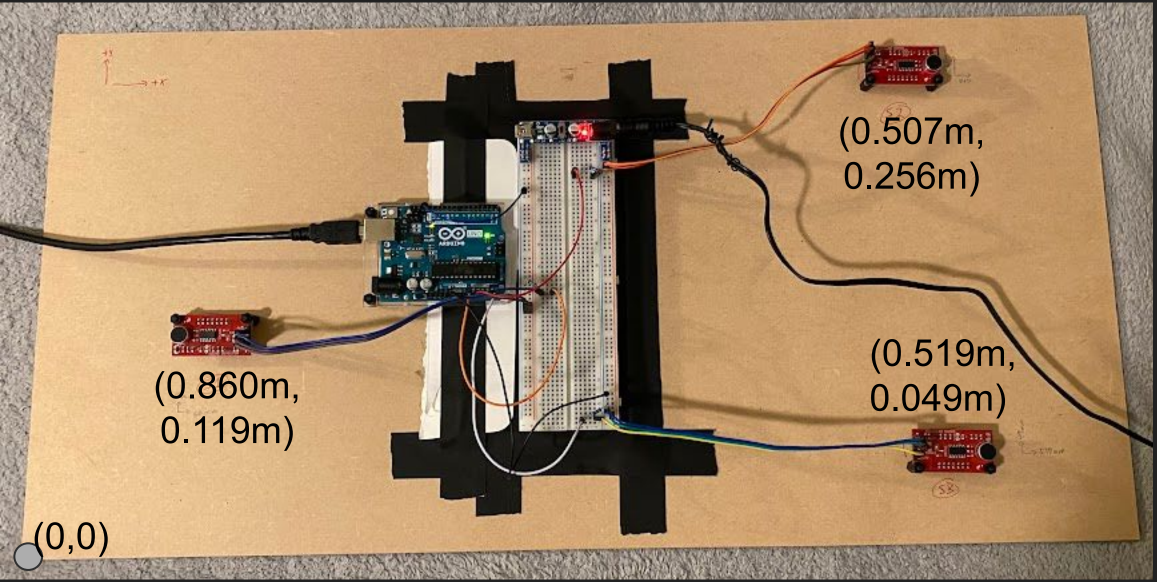
Generating Samples

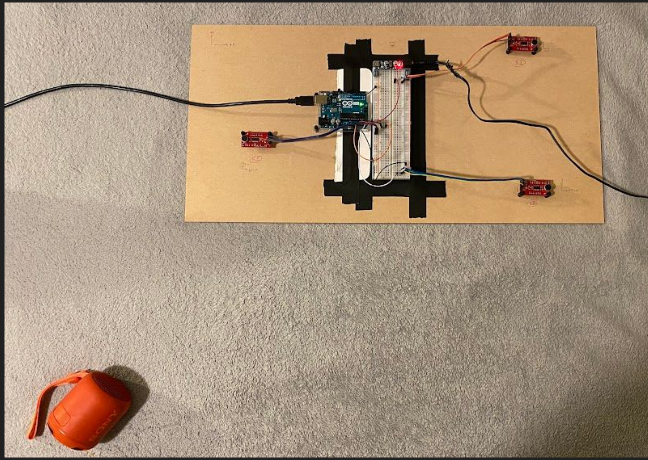
- Sample the sound sensors at 2550 Hz
- Read each sensor, buffer the value, repeat until buffer is full
- Flush the buffer over serial to the Matlab client

Deriving TDOA measurements

- Start with 220 samples recorded at 2550 Hz for each sensor
- Determine the lag between signals using xcorr method
- Tau_21 = (delay in samples) * Tsa
- DR_21 = Tau_21 * Vs

Operation

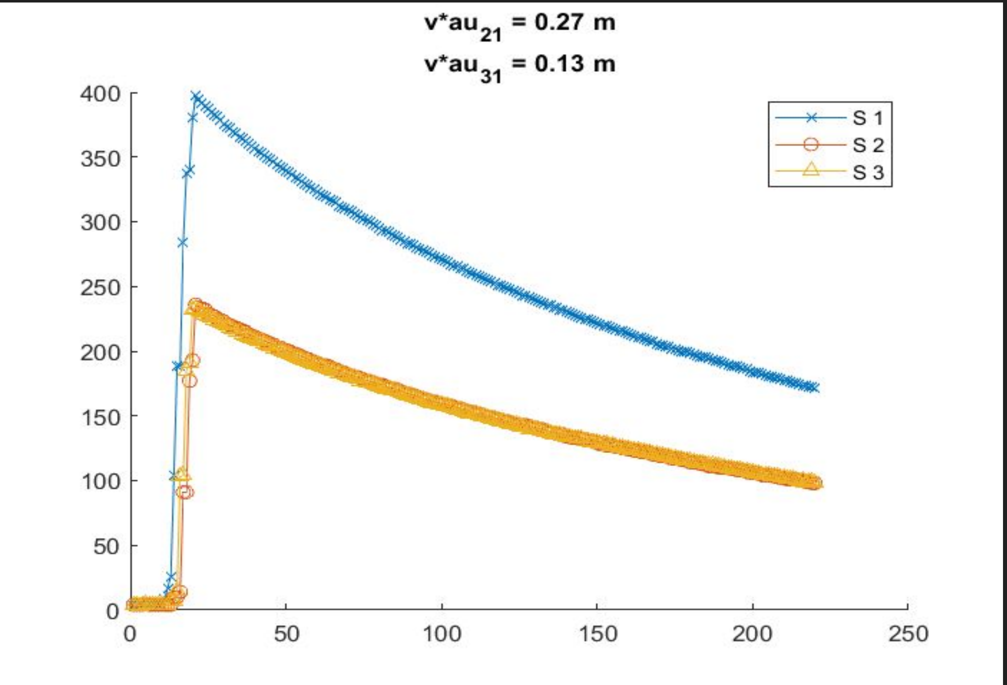




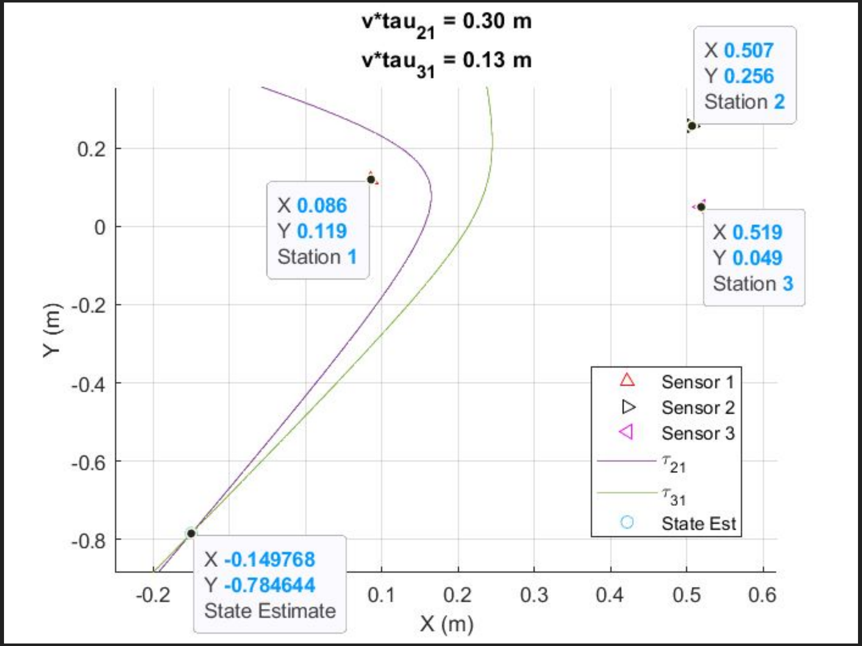
Dist S1 to S2 = 0.443 m = 3.28 Sa resolution
Dist S1 to S3 = 0.438 m = 3.25 Sa resolution

Operation: Real Data

Signals & 1 set of dr vals



Result



Issues Overview

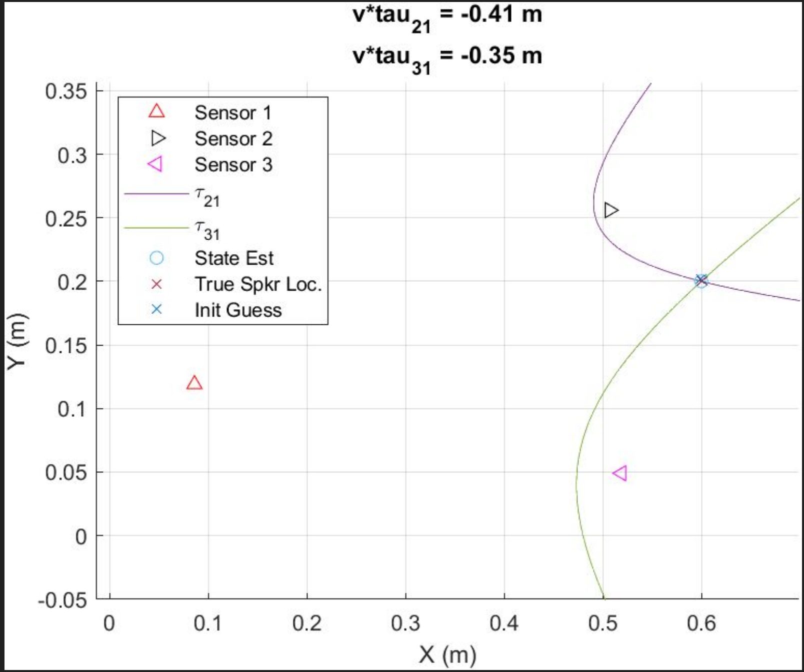
- Sampling rate is relatively slow
- Sensor geometry
- Sensor sensitivity is low

Issues: Low Sampling Rate

- Fairly low sampling rate of ~2550 Hz means low resolution.
  - Vs * Tsa = 344 m/s * (1/2550) s = 0.1349 m = 134.9 mm
- To achieve a v*tau resolution of 1 cm requires
  - Fsa = v / d = 344/0.01 = 34,400 Hz
  - Not possible with hardware being used
- Effect of a 1-sample error
  - ILS may not converge
  - Solution may be roughly 125 cm away from true position

Issues: Low Sampling Rate

Nominal solution:

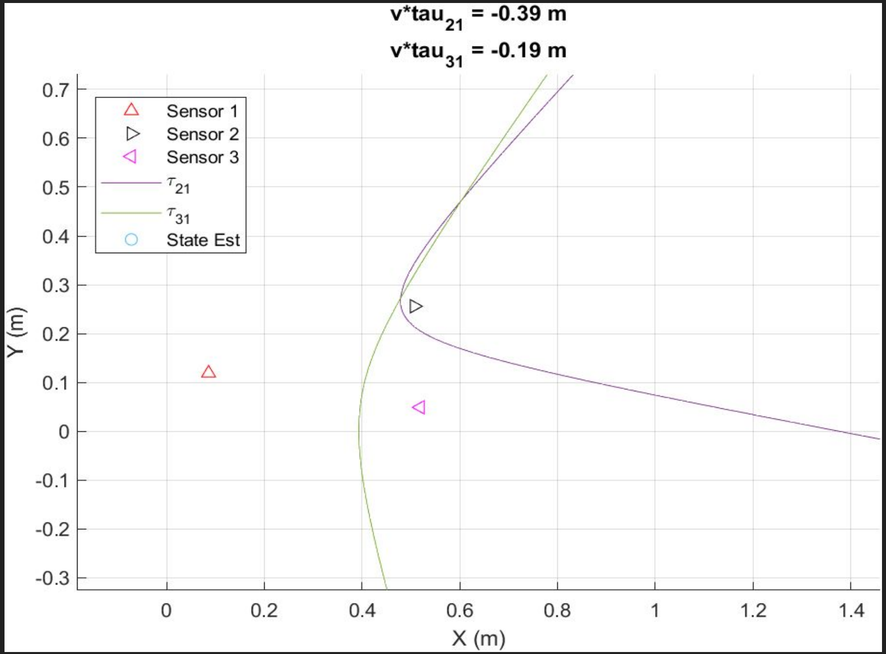


Vs:	344	m/s
Fsa:	2550	Hz
dr (Vs*tau) res.	0.1349	m
Speaker Pos x	0.600	m
Speaker Pos y	0.200	m
dr_21	-0.41	m
dr_31	-0.35	m

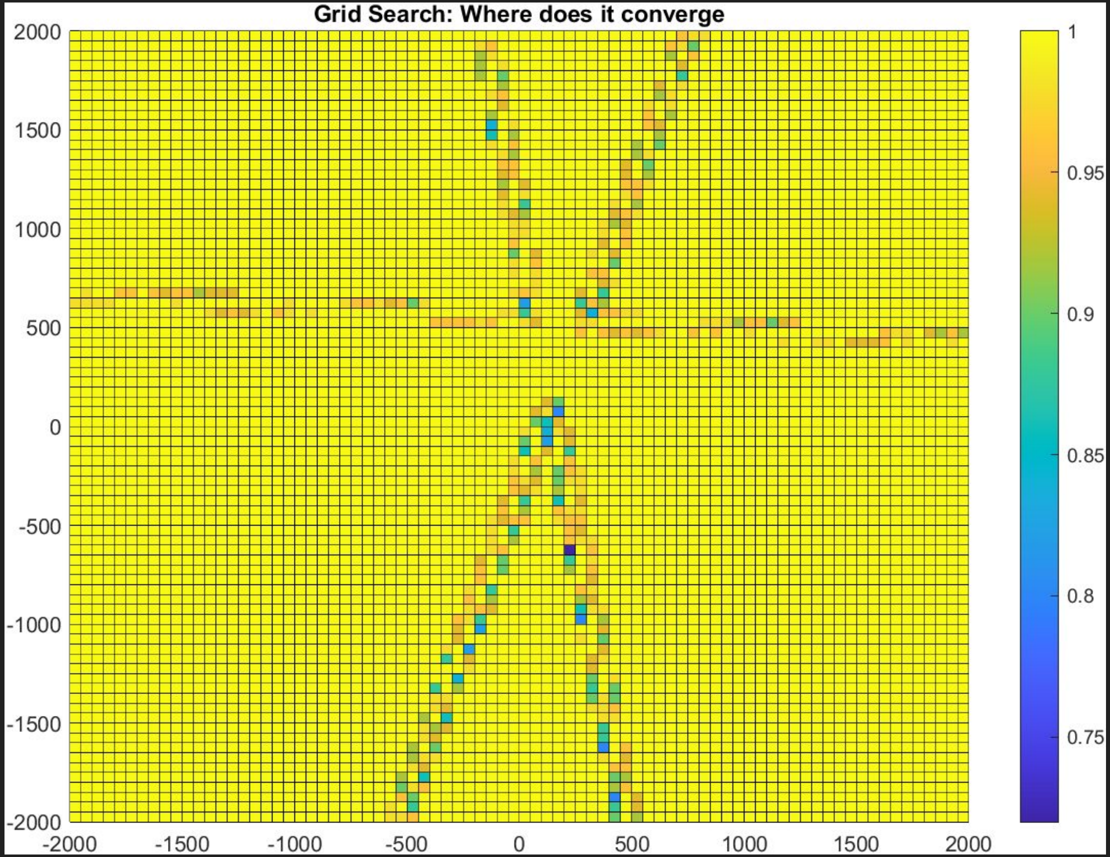
dr_21 (m)	dr_31 (m)	Solution x (m)	Solution y (m)	Pos Err (m)
-0.5449	-0.4849	-	-	-
-0.5449	-0.3500	-	-	-
-0.5449	-0.2151	-	-	-
-0.4100	-0.4849	-	-	-
-0.4100	-0.3500	0.6	0.2	0
-0.4100	-0.2151	0.4907	0.2623	0.1258
-0.2751	-0.4849	-	-	-
-0.2751	-0.3500	0.5034	0.1156	0.1283
-0.2751	-0.2151	-	-	-

Issues: Sensor Geometry

- Due to sensor laydown, I have unfavorable geometry when the sound source is off in the +x direction of the setup.



Issues: Sensor Geometry



- Illustrating where the ILS fails
- Ran ILS using canned data over a 2m x 2m grid in 50 mm steps
- Ran ILS 50 times at each point, with a small, random initial error each time
- Colorbar:
  - 1 = no runs failed to converge
  - 0 = all runs failed to converge

Issues: Low Sensor Sensitivity

- Had issues during testing finding a sound source around the house loud enough to trigger all 3 sensors
- Resorted to clapping as a simple solution
- This results in variation because my hands weren’t perfectly still from one clap to the next
- Two subsequent claps in the same location, but at different volumes, yield different delta-ranges

Conclusions

- Using low-grade computer resulted in low-resolution position solution
- Despite the issues presented, the localization worked under certain conditions