Angle-of-Arrival Triangulation

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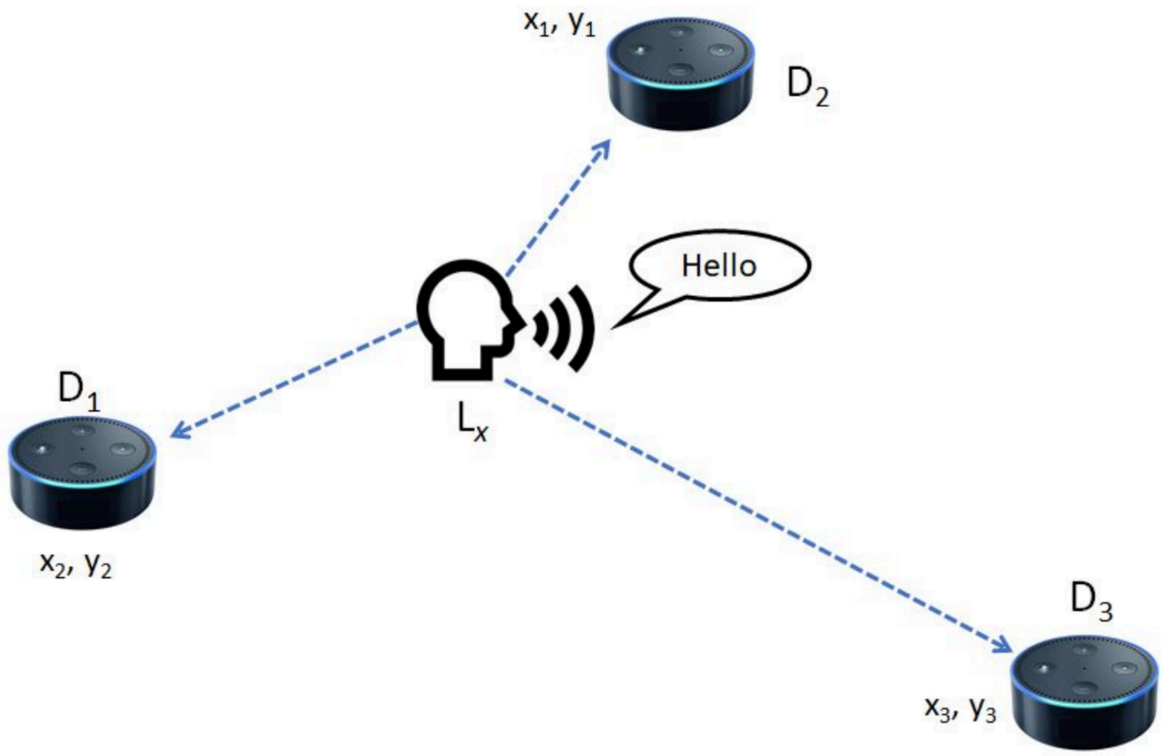
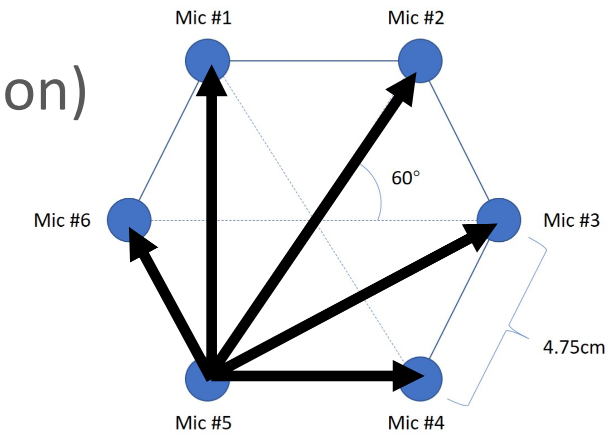


Algorithm

- Consider a microphone to be the “reference microphone”
- Find signal time delays with respect to that microphone
  - Example microphone #5 in the figure
- Do it for every microphone – 36 dimensional delay vector (R^{36} space)
- The observed_delays vector created from recorded signals
- Create mic_location vectors with respect to the reference microphone
- Create unit directional vectors in all directions (360/resolution)
- Project direction vectors on to mic_location vectors
- Convert projected_distances vectors to time delays - estimated_delays
- Do nearest space search: observed_delays and estimated_delays

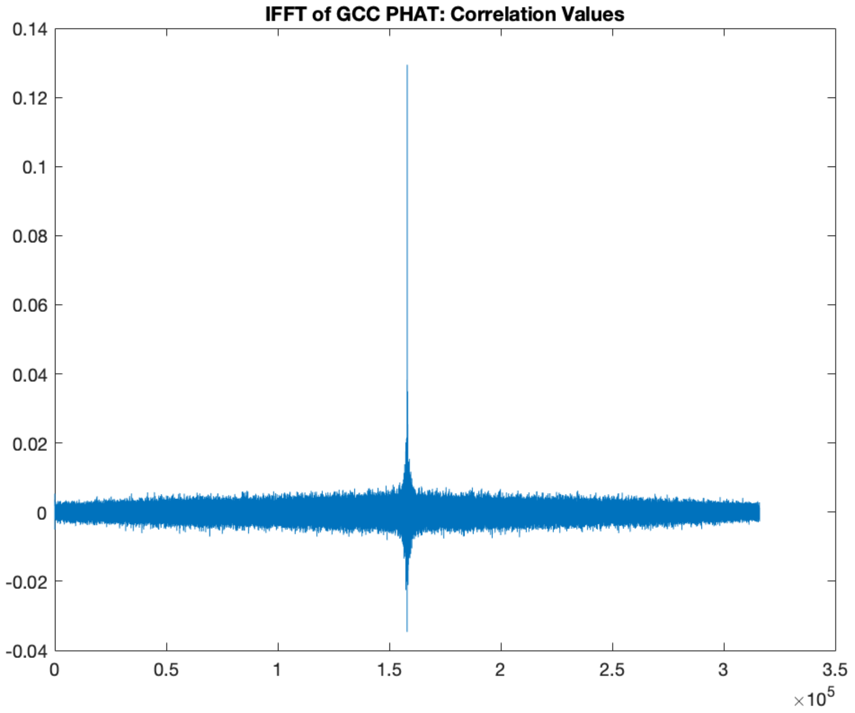


Mic #5: Reference Signal (Reference Microphone)

Time delays? GCC-PHAT

- Generalized Cross Correlation Phase Transform (GCC – PHAT)
- Cross Correlation in frequency domain
  - Correlation in time domain == Multiplication in frequency domain
- PHAT weight scheme: unity gain for all frequencies
  - Spectral whitening for all frequencies
  - Preserve phase information – relevant for time delays

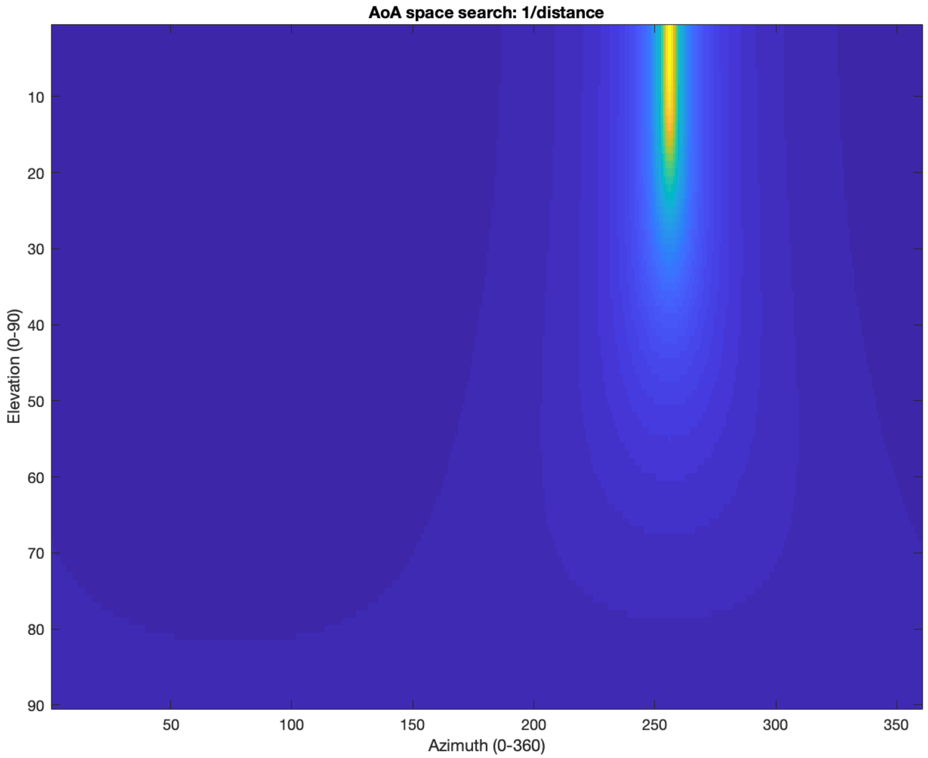
$$G_{PHAT}(f) = \frac{X_i(f)\left[X_j(f)\right]^*}{|X_i(f)\left[X_j(f)\right]^*|}$$



- Makes it robust to multipath/echoes as compared to time-domain correlation
- Highest peak in correlation -> delay lag for the line-of-sight signal
- Other peaks -> may correspond to echoes and multipath

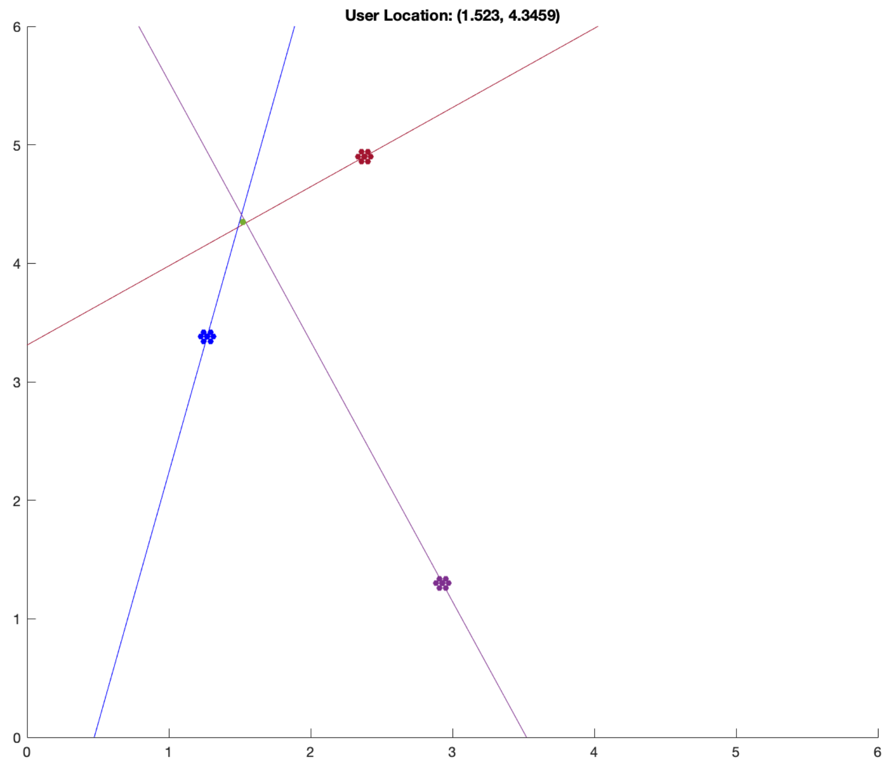
Interpolation and AoA space search heatmap

- Make GCC result better?
- Interpolate the correlation values around the highest peak
- Find max peak in interpolated signal
- Calculate offset from the reference signal -> convert to time delay
- Use observed_delays and estimated_delays to perform space search
- Plot scores in a heat map and find the highest peak - lowest norm between observed_delays and estimated_delays



User Localization

- Use angles from three mic arrays to formulate line equations
  - Line = center of array + angle (slope)
- Jointly solve three line equations as an optimization problem
- Minimize distance between three lines – essentially, least squares solution
- Three arrays along with the solution is plotted (train signal: X02).



Training Data results (10 samples)

- Mean angle estimation error: 1.84 degrees
- Median angle estimation error: 1.04 degrees

- Mean user localization error: 11cm
- Median user localization error: 7cm