Ear Beamer

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The Team

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A Familiar Scenario
Outlining the System
Outlining the System
A Goal to Solve the Problem

- The Problem: People with moderate to severe hearing loss have difficulty listening to a specific conversation within a noisy environment.

- The Goal: Develop a hearing aid system that gives user ability to individually amplify multiple targets of his/her choice and attenuate unwanted targets, independent of body or head position of the user.
Causes of Hearing Loss

- Presbycusis - Age related hearing loss
  - Affects 1 in 3 Americans over age of 65
  - 1 in 2 over 75\(^1\)

- Noise Induced Hearing Loss
  - 15% of Americans aged 20 - 69 have symptoms of NIHL\(^1\)

\(^1\)National Institute on Deafness and other Communication Disorders
A Concerning Problem

- **Hearing Loss in adults is associated with increased risk of Major Depressive Disorder**
  - In a study of 2,304 adults with hearing loss, those without hearing aids were 50% more likely to suffer from sadness, depression

- **Hearing Loss is associated with an increased rates of dementia, cognitive decline**
  - Hearing impaired performance declined 30 – 40% faster than healthy population


Current State of Hearing Aid Market

Current hearing aids have been developed to hear speech in a noisy environment:

- **Directional Microphone Hearing Aids**
  - Amplifies sounds coming from the front of the user, and attenuates background noise

- **Beam Forming Array Hearing Aids**
  - Use of omnidirectional microphones to selectively tune into sounds in front of user

No selection and must be front of target to hear

Beamforming

\[ y[n] = \sum_{m=0}^{M-1} x[n - m\tau] \]

\[ \tau = \frac{d \cos \theta}{v} \]

\[ m_1(t - \tau_1) + m_2(t - \tau_2) + m_3(t - \tau_3) \]
Beamforming

$$y[n] = \sum_{m=0}^{M-1} x[n - m\tau]$$

$$\tau = \frac{d \cos \theta}{v}$$
Polar Plot

Image Credit: Matlab, "Grating Lobes", Web
Outlining the System
Outlining the System
Outlining the System
Determining Ideal Beamwidth

\[ \theta = 2 \arctan \left( \frac{w}{2d} \right) \]

\[ \theta = 14.83^\circ \approx 15^\circ \]
Requirements

- Capture necessary audio signals on the human speech frequency spectrum (500Hz to 3.5kHz)
- If target is within 20 feet, it should appear in the user interface and become selectable
- If target is selected on user interface, the processor should measure azimuth of the target and calculate delays for the beam forming algorithm
- If multiple targets cannot be separated into distinct sectors, the system treats them as one and this is reflected in the user interface
- Delay from Reception of signal to output of hearing aid must be less than 300ms (ITU-T G.177)
Our Solution

Sensors
- Microsoft Kinect
- People Objects Coordinates

Processing
- Windows Computer
  - Audio Processor
  - Delay Calculator

Output
- Phone Application
  - Target Selection
  - WiFi Coordinates
  - Bluetooth Audio

Audio
- Microphone Array
- Audio Signals
- ADC Array
- Audio Data
- Headset

USB 3.0
Target Tracking: Kinect

Two main uses for our system:

- Skeleton Tracking API used to identify human targets within frame
  - Returns three dimensional coordinates of joints, with resolution in millimeters
  - Tracks up to six targets
  - New data may be accessed via polling or event-based system

- Infrared depth sensor
  - Depth sensor has effective range of 4.5 meters
User Interface – Mobile Application

- Simple functionality
  - Top-down view of room
  - Orientation reference
  - Live updates of target position
  - Volume Control

- iOS Development
  - Touch input
  - Polling model from App to Windows Computer
  - Web server model
Beamwidth Considerations

What happens when two targets cannot be isolated within two distinct beams?

- Tie the two targets together – when one is muted, the other is muted as well
Analog to Digital Converter

- Convert the analog audio from the microphones into a digital signal that is sent to the audio processor

Sampling Rate and Filtering:
- Low pass filter microphones to 3.5kHz
- Sample at 8kHz to prevent aliasing

- NI ADC for testing and development for MDR, custom solution for FDR
Considering a Microphone Array: Spatial Aliasing

A microphone array samples spatially – analogous to sampling a signal in time.

**Sampling Rate in Time:**
1 Sample / N Seconds

**Nyquist Criteria:**
Sampling Rate > 2\(f_{max}\)

**Sampling Rate in Space:**
1 Sample / N Meters

**Nyquist Criteria:**
Microphone Distance < \(\frac{\lambda_{min}}{2}\)

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Image Credit:
Matlab, “Grating Lobes”, Web
Capturing Audio: Microphone Array

Project Sauron: A Harmonic Nested Array

To Avoid Spatial Aliasing, microphone distance $d$ must be:

$$d < \frac{\lambda}{2}$$
# MDR Deliverables

<table>
<thead>
<tr>
<th>Category</th>
<th>Deliverable</th>
<th>Assignees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Identification</td>
<td>Extraction of coordinates of multiple targets from Kinect</td>
<td>Nathan</td>
</tr>
<tr>
<td>Mobile Application</td>
<td>Framework for communication between Computer and iOS App</td>
<td>Niket, Aaron</td>
</tr>
<tr>
<td></td>
<td>Display Graphical Representation of targets on screen, using mocked coordinates</td>
<td></td>
</tr>
<tr>
<td>Beamforming</td>
<td>Delay-sum beamforming algorithm implemented with simulated input</td>
<td>Aaron, Nathan</td>
</tr>
<tr>
<td>AD/C</td>
<td>Verify that a given reference tone is digitized through a single channel</td>
<td>Matteo</td>
</tr>
<tr>
<td>Theory</td>
<td>Obtain verified values from AD/C on computer</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>Identify hardware/signal processing method to narrow beamwidth</td>
<td></td>
</tr>
</tbody>
</table>
QUESTIONS?
\[ d = 0.79 \lambda \]

\[ m_1(t) \quad m_1(t - \frac{3\lambda}{4c}) \]

c = speed of sound

\[ \frac{3}{4} \lambda \]

20°
$M_1$’s output is in phase with $m_2$!
To avoid, limit phase delay between microphones to $\pi$ or less

$$2\pi \frac{\tau}{T_{\text{min}}} \leq \pi$$

$$2\pi \frac{dcos\theta}{cT_{\text{min}}} \leq \pi$$

$$d \leq \frac{cT_{\text{min}}}{2cos\theta}$$

$$d \leq \frac{\lambda_{\text{min}}}{2}$$
Person enters room or moves

Capture coordinates of people

Update people database

Is target selected?

Yes

Calculate angle to target

Calculate delay for beam

Update on UI

No

Is target selected?

User selects target

Was target selected?

Yes

Enable target

Is other target too close?

Yes

Enable other target as well

No

No

Disable target

Is other target too close?

Yes

Disable other target as well
Determining the Microphone Array

A. Greensted, Delay Sum Beamforming, The lab book Pages
An online collection of electronics information, 01-Oct-2012. [Online]. Available:
http://www.labbookpages.co.uk/audio/beamforming/delaySum.html

- 5 Elements, 0.04m Spacing, 0.2m Aperture
- 15 Elements, 0.04m Spacing, 0.6m Aperture
- 25 Elements, 0.04m Spacing, 1m Aperture

- 5 Elements, 0.08m Spacing, 0.4m Aperture
- 15 Elements, 0.08m Spacing, 1.2m Aperture
- 25 Elements, 0.08m Spacing, 2m Aperture

- 5 Elements, 0.16m Spacing, 0.8m Aperture
- 15 Elements, 0.16m Spacing, 2.4m Aperture
- 25 Elements, 0.16m Spacing, 4m Aperture
Person enters room or moves

Capture coordinates of people

Update people database

Is target enabled?

Yes

Calculate angle to target

Calculate delay for beam

No

Was target selected?

Yes

Enable target

User selects target

Is another target too close?

Yes

Disable target as well

Enable other target as well

No

Update on UI

Is another target too close?

Yes

Disable other target as well

Yes