AudioSense:
Enabling Real-time Evaluation of Hearing Aid Technology In-Situ

Syed Shabih Hasan, Farley Lai, Octav Chipara
Department of Computer Science/Aging Mind and Brain Initiative (AMBI)

Yu-Hsiang Wu
Department of Communication Sciences and Disorders
Hearing Loss in US

- 35 million people in the US have hearing loss [1]
  - leads to communication difficulties, depression & dementia
- Primary intervention is hearing aid amplification
  - only ≈ 50% of hearing aid users are satisfied with performance in noisy environments

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Underlining causes of user dissatisfaction are poorly understood

Challenge of evaluating hearing aids

- Listening contexts

**social context:** speaker familiarity, number of speakers, visual cues

**acoustic context:** indoors vs. outdoors, noise/reverberation levels
Existing Evaluation Methodologies

- Manual data collection: self-reports or diary methods
  - subjective, memory bias, scalability
- Speech-in-noise tests: assess aspects of hearing aid technology
  - not representative of real-world listening contexts
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Existing evaluation methods are poor predictors of real-world performance
AudioSense

• Provides clinicians with subjective and objective measures of hearing aid performance and listening contexts

• data is collected in real-time and in-situ

• subjective: Ecological Momentary Assessment (EMA)

• objective: measures derived from audio and GPS

• EMA has been previous used by Henry et. al.[1] and Galvez[2]

• do not collect sensor data or track patients in real-time

Architecture of AudioSense

Android
Phones

Web Server

Web Interface

<table>
<thead>
<tr>
<th>Condition</th>
<th>Last user survey</th>
<th>Last timer survey</th>
<th>Last log time</th>
<th>User count</th>
<th>Timer count</th>
<th>Compliance</th>
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<td>55</td>
<td>June 12, 2013, 10:54 a.m.</td>
<td>June 11, 2013, 8:09 p.m.</td>
<td>June 12, 2013, 11:19 a.m.</td>
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<td>7 / 63 (3 snooze)</td>
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<td>June 12, 2013, 1:10 p.m.</td>
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<td>1</td>
<td>2 / 5 (0 snooze)</td>
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</tr>
</tbody>
</table>

Extensible Analysis Environment
Architecture of AudioSense

- EMA
- Extensible user interface and effective alarms
- Energy efficient data collection, high reliability

Android Phones

Web Server

- Real-time compliance information
- Extensible data analysis environment
- Scales to support multiple concurrent users
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  - Energy efficient data collection, high reliability

- **Web Server**
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- **Android Phones**
EMA Component - Survey Delivery

- Surveys are alarm-triggered or user-initiated
- Alarm-triggered
  - randomized \( (T_{\text{offset}} + [0, T_{\text{rand}}]) \)
  - fixed \( (T_{\text{offset}}) \)
- Delivery parameters are customized by clinicians
EMA Component - Survey Delivery

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EMA Component - Survey Delivery

Collection Alarm, data collection starts

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User Interface Design

- Iterative design based on patient feedback

- patients of hearing loss tend to be older, may have impaired vision ⇒ larger fonts, bigger buttons, contrasting colors

- Surveys are adaptive
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Alarms

- Design refined over several iterations based on patient feedback
- Challenge: find sweet-spot between invasiveness and compliance
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Alarms not noticed by the subjects
Alarms

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Alarms not noticed by the subjects

- loud ringtones, screen and camera flash blinking
- subjects can switch to vibration mode
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Energy Efficiency

- Independent pipelines for processing sound, GPS, and uploading
- Shared buffering to mitigate impact of Garbage Collection
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Reliability

• Reliability in terms of uploading the data

• Issue: unreliable network connections
  • caching data locally until a connection is available
  • vast amounts of memory available
  • store several days worth of data
Performance Analysis

• Testing environment
  • surveys delivered every 5 min, sensors sampled for 3 min.
  • tested using WiFi at home to simulate natural environment
  • test run for 70 minutes
Reliability
Reliability

network disconnection
Reliability

all files uploaded
Reliability

Achieved 100% reliability in spite of network disconnections!

all files uploaded
Power Consumption
Power Consumption

High power state (acquire power-lock)
Power Consumption

Low power state (release power-lock)
Power Consumption

![Graph showing CPU and LCD power consumption over time with a cluster of reconnection attempts indicated.](image)
Power Consumption

Lasted for 3 days without recharging
Recent Results for Reliability

98.7% reliable even in a clinical deployment
Conclusions and Future Directions

• AudioSense a new evaluation mechanism for hearing aids combines EMA and sensor data (audio + GPS)
  • in-situ, just-in-time, and scalable
  • patient compliance: real-time tracking, alarms design, and energy efficient
  • reliable and real-time data collection
• Future work:
  • evaluated through a 50 user clinical study
  • study correlations between:
    • listening contexts and patient compliance
    • measures listening context and hearing aid performance
Acknowledgements

- Audiology collaborator: Elizabeth Stangl
- National Science Foundation (grant # 1144664)
- National Institutes of Deafness and Other Communication Disorders - National Institutes of Health (grant # IR03DC012551-01)
Questions?
Server Backend

- Provides three components
  - web portal, database, and audio analysis environment
- Web portal + database
  - provides secure access to real-time data via web interface
  - built on Django+SQLite
  - serves multiple concurrent clients
- Audio analysis environment
  - invoked on each audio file submission
  - uses MATLAB ⇒ extensible
    - e.g. SNR calculation
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  $\text{SNR (dB)}$

  $\text{Sample Index}$

  $x \times 10^5$
Clinician’s options