Sonar-based Measurement of User Presence and Attention

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http://empathicsystems.org
Abstract

- Novel use of laptop’s speakers and mic as a sensor
- In absence of HID input, we can determine whether user is
  1. still present
  2. or gone
- No new hardware required
Problem definition

Detect whether there is a human user present at the computer.

Motivation:
- Operating systems
- Ubiquitous computing

Goals:
- Accuracy
- Responsiveness
- Low cost
Related work

- Activity detection
- Power management
  - FaceOff - Dalton and Ellis, HotOS’03
- Ultrasonics
  - Audio networking - Madhavapeddy et al., UbiComp’03
  - Cricket localization - Priyantha et al., MobiCom’00
  - WALRUS localization - Borriello et al, MobiSys’05
  - BeepBeep acoustic ranging - Peng et al., SenSys’07
Active sonar

Our system:

- laptop’s speaker and mic
- inaudible ultrasonic tones ($\geq 20 \text{ kHz}$)
- continuous sine wave
Hypothesis

- Users will reflect pings.
- Users are always moving, at least slightly.
- User movements will cause changes in echo intensity.
- *Thus, a user’s presence will increase echo variance.*
An example recording
Feature extraction
Feature extraction

20kHz band-pass filtered
Echo Delta is the sum of these absolute differences.

Average 20kHz energy within each 100ms window (larger values are lighter)
Feature extraction

Echo Delta is the sum of these absolute differences.
Feature extraction

Echo Delta is the sum of these absolute differences.
User study goals

- Test hypothesis
- Carefully guide users through several states
- Mimic real usage scenarios
- Evaluate suitability of various microphones and speakers
Experimental setup
Active state: Typing task
Passively-engaged state: Video task
Disengaged state: Phone task
Distant state: Puzzle task
Absent state
Experiment details

- Twenty grad student volunteers
- 4 minutes spent on each task
- 50 second recordings for each task
- Tasks were randomly ordered
Sonar measurements (50 s recording)

Figure: Consistent gap between video and absent states across all users
Sonar measurement ranges (10 s recordings)

Figure: Gap remains after reducing recording length to 10 seconds
Binary state classifier

- Motivated by clear difference seen in sonar measurements
- If sonar measurement is above a certain threshold, classify as passively-engaged; otherwise absent.
- Threshold setting

\[ T \equiv (\Delta_e^{\text{passive}} \ast (\Delta_e^{\text{absent}})^2)^{1/3} \]
Classifier confusion matrix results

- Tested the binary classifier using the user study recordings (video and absent)
- Split recordings into 10 s of training and 40 s of test data
- Error rate less than 4%.

<table>
<thead>
<tr>
<th>Actual state</th>
<th>Predicted state</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>passively engaged</td>
<td>passively engaged</td>
<td>0.9632</td>
</tr>
<tr>
<td>passively engaged</td>
<td>absent</td>
<td>0.0368</td>
</tr>
<tr>
<td>absent</td>
<td>passively engaged</td>
<td>0.0248</td>
</tr>
<tr>
<td>absent</td>
<td>absent</td>
<td>0.9752</td>
</tr>
</tbody>
</table>
Conclusion

- Hypothesis supported by experimental results
  - User presence causes an increase in sonar measurement variance.
- Binary state classification for two important states was successful.
- Low computational overhead
Current and future work

Open questions:

- How common is ultrasound-capable audio hardware in laptops and other electronics?
- How much power can be saved using fine-grained sonar-based power management?

Sonar Power Manager software is available:

- Windows and Linux
- Open-source

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