Smart Environments without Cameras: Electrical Field Sensing for Human-Computer Interaction

Marcel Geppert
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At Home: Kinect

There are some problems with cameras...
Illumination
Occlusion
Bandwidth

21 MB/s
Power Consumption
Privacy?
Other Sensing Methods?

• Vision is one of our main senses

• What else could we try?
Other Senses: Elephantnose Fish

- Weakly electric
- Uses electric fields to detect nearby objects

[ modified after Bullock et al (2005) ]
Modeling Electric Fields with Capacitors

- Electric Fields can be modeled with capacitors
- Plate capacitor is the simplest model
Plate Capacitor

\[ E = \frac{Q}{\varepsilon A} = \frac{U}{d} \]

\[ U = \frac{Qd}{\varepsilon A} \]

\[ A = a \cdot b \]
Capacitors in the Environment

[ Mujibiya, Rekimoto (2013) ]
Active and Passive Electric Field Sensing

Actively emit field and sense distortion

Passively sense fields from the environment

[modified after Mujibiya, Rekimoto (2013); ]
Shunt Mode

- Transmit electrode transmits electric field
- Receive electrode measures electric field

[ Smith et al (1998) ]
Shunt Mode

• Body acts as (virtual) ground
• Body „shunts“ signal to ground
• Received signal decreases

[Smith et al (1998)]
GestIC Electrode
GestIC Electrode
GestIC Electrode
GestIC Electric Field
GestIC Electric Field
Active and Passive Electric Field Sensing

Actively emit field and sense distortion

Passively sense fields from the environment
Electrical Noise at Home
Electrical Noise at Home

- Power lines (AC and received noise)
Electrical Noise at Home

- Switched-Mode Power Supplies
Electrical Noise at Home

- Dimmers
Electrical Noise at Home

- Electric Motors
Electrical Noise in Different Locations
Your Noise Is My Command

- Determine touch position on the wall
- Measure electric field that is received by the human body

[ CHI 2011, Cohn et al ]
Your Noise Is My Command

• Signal is measured at the neck

• Offline classification by trained program

• Changes in the environment are minimized
Your Noise Is My Command

Touch positions:
Your Noise Is My Command Results

Accuracy

Wall Touch: 98.5%
Touch Position around Lightswitch: 87.4%
Touch position on plain Wall: 74.3%
Location in Home (Gesture around Switch): 99.1%
Location in Home (No Wall Contact): 99.5%

Random Chance: 50.0%
Average Accuracy: 20.0%
Random Chance: 20%
Average Accuracy: 40%
Random Chance: 20%
Average Accuracy: 60%
Random Chance: 16.7%
Average Accuracy: 80%
Random Chance: 16.7%
Average Accuracy: 100%
Humantenna

[ CHI 2012, Cohn et al ]
Humantenna Segmentation

- Coarse manual frame
- Determine exact frame from change of DC Voltage

[Cohn et al (2012) ]
# Humantenna Results

<table>
<thead>
<tr>
<th>Actual Gesture Performed</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Both Arms Up: 1</td>
<td>94.2</td>
<td>0.6</td>
<td>0.5</td>
<td>0.9</td>
<td>0.9</td>
<td>0.6</td>
<td>0.5</td>
<td>0.6</td>
<td>0.6</td>
<td>1.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Arm Down: 2</td>
<td>0.5</td>
<td>94.2</td>
<td>2.8</td>
<td>0.2</td>
<td>0.8</td>
<td>1.1</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Arm Down: 3</td>
<td>0.9</td>
<td>2.0</td>
<td>92.5</td>
<td>0.2</td>
<td>2.0</td>
<td>1.1</td>
<td>0.3</td>
<td>0.6</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both Out Front: 4</td>
<td>0.8</td>
<td>0.5</td>
<td>0.2</td>
<td>95.2</td>
<td>1.1</td>
<td>1.3</td>
<td>0.3</td>
<td>0.5</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotate: 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.2</td>
<td>99.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Wave: 6</td>
<td>0.8</td>
<td>0.5</td>
<td>1.4</td>
<td>2.0</td>
<td>79.2</td>
<td>14.1</td>
<td>0.9</td>
<td>0.8</td>
<td>0.2</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Wave: 7</td>
<td>0.3</td>
<td>0.8</td>
<td>0.3</td>
<td>1.6</td>
<td>11.1</td>
<td>83.9</td>
<td>1.1</td>
<td>0.6</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bend Down: 8</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>99.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Step Right: 9</td>
<td>0.3</td>
<td>0.2</td>
<td>0.8</td>
<td></td>
<td>1.9</td>
<td>1.4</td>
<td>0.3</td>
<td>93.6</td>
<td>1.4</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step Left: 10</td>
<td>0.2</td>
<td>0.5</td>
<td>0.2</td>
<td>1.9</td>
<td>0.8</td>
<td>0.8</td>
<td>0.6</td>
<td>1.9</td>
<td>93.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Punch 2x, Kick: 11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
<td>0.2</td>
<td>92.8</td>
<td>6.3</td>
<td></td>
</tr>
<tr>
<td>Kick, Punch 2x: 12</td>
<td>0.5</td>
<td>0.6</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.1</td>
<td>93.8</td>
</tr>
</tbody>
</table>
Humantenna Location Results

Accuracy

<table>
<thead>
<tr>
<th></th>
<th>Random Chance</th>
<th>Extended Feature Set</th>
<th>Standard Feature Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Locations, Single Person</td>
<td>99.6 97.1</td>
<td>100.0 96.3</td>
<td>96.1</td>
</tr>
<tr>
<td>2 Locations across Persons</td>
<td>50</td>
<td></td>
<td>84.6</td>
</tr>
<tr>
<td>5 Locations across Persons</td>
<td>20</td>
<td></td>
<td>99.4 94.1</td>
</tr>
<tr>
<td>16 Locations, 1 Person per Location</td>
<td>6.25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5 Locations, Single Person
2 Locations across Persons
5 Locations across Persons
16 Locations, 1 Person per Location
Humantenna Interactive System

- Lower sampling rate
- Apply static threshold to DC voltage change
- Consider short periods of inactivity as active
- Compute feature set in parallel to segmentation
Limitations

• Sensible to changes in the (electric) environment
Limitations

- Needs to be trained
Limitations

- High latency in interactive system
Limitations

• Needs sensors on body
Mirage

- No body contact
- Detect distortion of electric field by human body
Mirage

Peripheral-attached sensor

Mobile sensor

[ Mujibiya, Rekimoto (2013) ]
Mirage

Detect...

• ... single gestures

• ... continuous activity (walking, running, ...)

• ... repeated events (single steps, ...)

[ Mujibiya, Rekimoto (2013) ]
Mirage Results

- Low error in event counting (8.41 %)

![Accuracy Chart]

- Activity Recognition: 96.72%
- Gesture Recognition: 92.11%
- Location classification: 98.12%

Random chance vs. Average Accuracy
Limitations

• Limited distance
Limitations

- Sensible to different footwear
Limitations

• Sensible to changes in the (electric) environment
Applications

• Gesture Detection for Mobile Devices
Applications

- Indoor Localization
Applications

• Virtual Switches
Applications

- Intruder Detection
Conclusion

Electric Field Sensing is...

• ...accurate in gesture/activity recognition
• ...accurate in location classification
• ...energy efficient
• ...cheap
• ...sensible to changes in the (electric) environment
Thank you for listening!