See Through Walls with Wi-Vi

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Can your cellphone give you X-ray vision?
Wall reflection is 10,000x stronger than reflections coming from behind the wall

Tracking people from their reflections
Applications

Police avoids ambush

Firefighters check for humans

Personal security

Gesture interface from behind a wall
Wi-Vi: Small, Low-Power, Wi-Fi

• Eliminate the wall’s reflection
• Track people from reflections
• Gesture-based interface
• Implemented on software radios
How Can We Eliminate the Wall’s Reflection?
Idea: transmit two waves that cancel each other when they reflect off static objects but not moving objects

Wall is static → disappears

People tend to move → detectable
Eliminating the Wall’s Reflection

Receive Antenna:

Transmit Antennas
Eliminating the Wall’s Reflection

Receive Antenna: \[ y = h_1 x + h_2 \alpha x \]

\[ \alpha = -\frac{h_1}{h_2} \]
Eliminating All Static Reflections
Eliminating All Static Reflections

\[ y = h_1 x + h_2 \alpha x \]

Static objects (wall, furniture, etc.) have constant channels

\[ y = h_1 x + h_2 \left( -\frac{h_1}{h_2} \right) x \]

People move, therefore their channels change

\[ y = h_1' x + h_2' \left( -\frac{h_1}{h_2} \right) x \]

Not Zero
Enhancements

• Power boosting

• Iterative nulling
  – Goal: further null the residual signal from reflection from the static objects after power boosting
  – Challenges: cannot distinguish signals from static objects vs. signals from moving persons
  – Approach: iteratively estimate $h_1'$ based on $h_2$, and estimate $h_2'$ based on $h_1 \Rightarrow$ converge fast
How Can We Track Using Reflections?
Tracking Motion

RF source

Direction of reflection

Antenna Array
Tracking Motion

Direction of motion

At any point in time, we have a single measurement

Antenna Array
Tracking Motion

Direction of motion

Antenna Array

Direction of motion
Tracking Motion

Direction of motion

Direction

Human motion emulates antenna array
Inverse Synthetic Aperture Radar (ISAR)

- Compute $A[\theta, n] = \sum_{i=1}^{W} h[n + i] e^{j \frac{2\pi i \Delta \sin \theta}{\lambda}}$
  - Measure the signal along the spatial direction $\theta$ at time $n$
A Through-Wall Gesture Interface

- Sending Commands with Gestures

- Two simple gestures to represent bit ‘0’ and bit ‘1’

- Can combine sequence of gestures to convey longer message
Gesture Encoding

Bit ‘0’: step forward followed by step backward
Bit ‘1’: step backward followed by step forward
Gesture Decoding

Matched Filter

Peak Detector

Gesture interface that works through walls and none-line-of-sight
Implementation and Evaluation

• USRP software radios:
  – Wi-Fi signals: 2.4GHz, OFDM
  – 5MHz to enable real-time channel estimation
  – 10mW transmit power

• Old and new buildings on MIT campus
• Eight human subjects
  – 200 experiments
Tracking Multiple Humans

One moving person is indicated by a single curvy line
Tracking Multiple Humans

- Number of distinct curves at the same time corresponds to the number of humans
## Automatic Estimation: Number of People

Classification algorithm in the paper

<table>
<thead>
<tr>
<th>Actual</th>
<th>Detected</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<tbody>
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<td>0</td>
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<td>85%</td>
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<tr>
<td>3</td>
<td>0%</td>
<td>0%</td>
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<td>90%</td>
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Building Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Accuracy (%)</th>
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<tbody>
<tr>
<td>Free Space</td>
<td>100</td>
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<tr>
<td>Tinted Glass</td>
<td>100</td>
</tr>
<tr>
<td>1.75&quot; wood door</td>
<td>100</td>
</tr>
<tr>
<td>6&quot; interior wall</td>
<td>100</td>
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<tr>
<td>8&quot; concrete</td>
<td>87.5</td>
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</tbody>
</table>
Related Work

- Designed for military [RCP10]
  - 2 GHz bandwidth
  - Large power source
  - Huge antenna array
- Attempt at using Wi-Fi [CSW12]
  - Needs to install a receiver in the imaged room and connect it to a receiver outside the room via wire
- Upcoming work in Mobicom’13 [PGGP13]
  - Focus on gestures as opposed to x-ray vision