Tools for Ubiquitous Computing Research

MIT House_n Consortium

PlaceLab:
Proactive Health

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House_n
Massachusetts Institute of Technology
Outline

• Motivation: Health care crisis
• House\_n research agenda
• House\_n Tools for studying behavior
  – The PlaceLab living laboratory
  – Portable kit of sensors (MITes)
Some statistics

From the 2000 census of population

- Nearly 1 in 5 U.S. residents suffer some kind of disability
- Approximately 40% of people 65 and older have a disability
- Over 20% require continuous monitoring and help performing activities of daily living (ADLs)
Some statistics

From the 2000 census of population

• In 2030, nearly one out of two households will include someone who needs help performing basic ADLs
House\textsubscript{n} research agenda

Goals

\begin{itemize}
  \item Increase the time that people remain healthy, independent and safe in the comfort of their homes.
  \item Enable novel context-sensitive applications to be built and piloted
\end{itemize}
Health care interventions

**Three levels** (in increasing order of difficulty and importance):

1. **Responding to crisis** (requires a few good sensors)  
   - Medical staff
2. **Early warning of emerging problems** (requires ubiquitous sensors)  
   - Changes in behavior (dementia/independence)
3. **Proactively keeping people healthy** (requires ubiquitous sensors & communication)  
   - Encouraging healthy behavior

[Diagram showing the flow from one level to the next, with arrows pointing to the next level and the corresponding text.]
Current work: proactive health

- Switch/bend sensors
  - Doors
  - Cabinets
  - Drawers
  - Thresholds
  - Appliances
  - Objects
- Wearable sensors
  - Accelerometers
  - Heart rate monitor
  - Self report
- Multi-purpose sensors
  - People-locator tags
  - Auditory sensors
  - Optical sensors

- Activity recognition
  - Eating meals
  - Talking
  - Sleeping patterns
  - Taking medications
  - Cleaning
  - Cooking
  - …

New ML algorithms detect change in activity; Motivate behavior changes

Health applications
House$_n$ tools:
The PlaceLab Living laboratory
PlaceLab

• Is not to show off “new technology”
• It is a residential observational research facility

Goals
- Run different research studies
- Real people living at PlaceLab 24/7 (weeks/months)
- Collect necessary data for doing research

Design constraints
- Reliable sensing infrastructure
- Add/remove sensors on the fly (Modular)
Why another live-in laboratory?

Our design benefited from lessons learned by those who created prior “living labs”:

- Georgia Tech Aware Home (Abowd, Mynatt, and others)
- UVA’s Smart Home Monitor (Alwan)
- Smart House (Matsouoka)
- Welfare Techno House (Suzuki)
- Philips HomeLab
- Sleep laboratories
- Others…
Why another live-in laboratory?

The PlaceLab combines these unique characteristics:

- A unified, extensible, multi-modal, and truly ubiquitous sensor and observational infrastructure
- Designed for shared data generation/distribution and collaboration
- Sensors integrated into architectural aesthetic
- Genuinely live-in
Goal: Context-aware technologies at home

Three key challenges (among others):

1. Need for complex, naturalistic environments
   *Simulated behavior is overly simplistic*

2. Need for comprehensive sensing
   *Activity occurs throughout environment; realistic datasets costly to obtain; head-to-head comparisons*

3. Need for labeled training datasets
   *Many context-recognition algorithms need labeled example data; annotation required for evaluation*
Testing ubicomp technology in the home

Ethnographic/ HCI research → Laboratory prototyping → Larger n, in-home studies → Innovative design ideas
The PlaceLab: filling a gap

Ethnographic/HCI research → Laboratory prototyping → The PlaceLab → Pilot Data → Design insight → Important questions → Innovative design ideas → Larger n, in-home studies

House_n
PlaceLab can complement...

- Surveys and interviews
- Experience sampling
- Direct observation
- Portable kits of sensors for in-home studies
- Demonstration labs
- Short tests in parts of live-in labs; tests with limited sets of sensors
The PlaceLab Infrastructure
PlaceLab

A lower floor unit of full-service condominium building.

The apartment can be entered both from the lobby and from the side yard.
PlaceLab
Interior entrance
Living room
Living room

- Most visible technology a standard TV
Living room
Kitchen

- Apartment allows the study of natural home behavior

- Interested in complex behavior such as
  - Decision making
  - Interruptions
  - Searching
  - Communication
Sensor integration

- Sensors blend into aesthetics of environment (so easy to ignore)
Kitchen
Office
Bedroom
Master Bath
Embedded sensors

Emphasis on ubiquity and quantity over quality

Reasonable locations

- Microcontroller; connections server closet
- Speakers
- Optional: CO2 sensor
- Optional barometric pressure sensor
- Humidity sensor
- Temperature sensor
- IR video camera
- Color video camera
- Top-down counter camera
- Light sensor
- IR illuminators
- Microphone
- Switches to detect “open/close”
- Temperature sensor
- Subwoofer
Easy access to sensor infrastructure
Wireless object movement MITes

- Real-time, wireless transmission
- Receivers scattered throughout apartment
- 100-200 sensors depending on task
MITes sensors installation

Installation procedure for stick-on MITes

Single point of contact, no multi-point alignment is required
Object usage MITes
**Activity recognition from sensors in the environment**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparing lunch</td>
<td>59%</td>
</tr>
<tr>
<td>Toileting</td>
<td>71%</td>
</tr>
<tr>
<td>Preparing breakfast</td>
<td>45%</td>
</tr>
<tr>
<td>Bathing</td>
<td>87%</td>
</tr>
<tr>
<td>Dressing</td>
<td>64%</td>
</tr>
<tr>
<td>Grooming</td>
<td>89%</td>
</tr>
<tr>
<td>Preparing a beverage</td>
<td>36%</td>
</tr>
<tr>
<td>Doing laundry</td>
<td>86%</td>
</tr>
</tbody>
</table>

Activity detected at least once criteria
Example sensor data

- 100 Bathroom Toilet Flush
- 101 Bathroom Light switch
- 130 Bathroom Door
- 57 Bathroom Medicine cabinet
- 58 Bathroom Medicine cabinet
- 67 Bathroom Cabinet
- 68 Bathroom Sink faucet - hot
- 79 Bathroom Cabinet
- 88 Bathroom Sink faucet - cold
- 93 Bathroom Shower faucet
- 96 Bathroom Exhaust Fan
- 140 Foyer Door
- 120 Kitchen Light switch
- 125 Kitchen Drawer
- 126 Kitchen Refrigerator

House_n

MIT
RFID reader wristband

Determine motion when holding an object

Measures: RFID tagged objects + wrist acceleration
Range: 10cm
Cost: ≈ $181 US

Based on Intel Research Seattle RFID glove *(Perkowitz ETAL ’04)*
And in collaboration with Ambient Intelligence MIT Media Lab
Wireless limb accelerometers and HR

- Real-time, wireless transmission
- Receivers scattered throughout apartment
- Up to 5 locations
- HR monitor (Polar chest strap)
Activity recognition from wearable sensors

Activity recognition from wearable accelerometers

- 5 points
  - Right hip
  - Dominant wrist
  - Non-dominant upper arm
  - Dominant ankle
  - Non-dominant thigh
Recognition results for 20 activities

- Walking: 89.7
- Sitting & relaxing: 94.8
- Standing still: 95.7
- Watching TV: 77.3
- Running: 87.7
- Stretching: 41.4
- Scrubbing: 81.1
- Folding laundry: 95.1
- Brushing teeth: 85.3
- Riding elevator: 43.6
- Walking carrying: 82.1
- Work computer: 97.5
- Eating/drink: 88.7
- Reading: 91.8
- Bicycling: 96.3
- Strength train: 82.5
- Vacuuming: 96.4
- Lying down: 95.0
- Climbing stairs: 85.6
- Riding escalator: 70.6

Using decision trees and leave-one-subject out crossvalidation
Subject self report

- Random or context-aware self-report sampling on phone (activities, mood and other states of mind, etc.)

- Apps on phone can respond to PlaceLab sensors

- Standard surveys or ethnography can also be used
Automatic selection of most informative audio-visual views using motion and camera location heuristics
Control “closet”
Running an experiment

• Recruit participant(s)
• Participant(s) move in
• Home disconnected from Internet (data saved to portable disk)
• Minimal interaction with researchers during stay
• At end of stay, data is collected and stored
• Data annotated for items of interest
• Datasets become more valuable as more researchers annotate them
Teach MIT Researchers about Your Everyday Life

Ever get the feeling that today’s technologies and homes are not designed for you and the way you live? Help MIT researchers design better technologies and homes (with fewer frustrations!) by sharing your everyday experiences.

Live in a comfortable one bedroom apartment for 10 days. Researchers will capture your activities and experiences and apply lessons learned to developing technologies for better health and living.

For more information, contact Jason at placelab-volunteers@mit.edu or (617) 452-5679

PlaceLab  AN  MIT + TIAx INITIATIVE
Take away

• The PlaceLab is a live-in residential home laboratory developed for health and ubiquitous computing research.

• Unlike prior facilities, the home has a truly ubiquitous, synchronized, and multi-modal sensor infrastructure built non-obtrusively into the architecture.

• The lab can be used as a hypothesis generation and testing facility and can help projects transition from laboratory testing to larger-\( n \), in-home studies with portable sensors.

• We are trying to operate the facility as a shared resource.
Thank you!

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House\textsubscript{n} sensing tools:

MITes: MIT environmental sensors
A portable kit of sensors for studying behavior in natural settings
Goal: allow context awareness

Most sensors are simple and binary

Machine Learning and Pattern recognition (training/inferencing)

Activity probabilities/detection

Toileting
- Toilet Flush
- Faucet
- Soap

Activity Examples (labels)

or Activity Models

Activity Models

Sensors
Avoid microphones and cameras

- avoid using audio, visual, electromagnetic or other sensors placed in the environment

- Why?
  - Sensors may be perceived as invasive
  - Susceptible to environmental conditions
  - Signal interpretation extremely difficult
  - Difficulty of signal interpretation depends on sensor placement (increasing installation difficulty)
MITes (MIT Environmental Sensors)

Goal: collect data from hundreds of multi-modal sensors (environmental and wearable) from single receiver in non-laboratory deployments

- Easy of installation
- Ease of use
- Adequate performance
- Affordable for research
- Well characterized/tested
MITes sensor kit includes

**Six environmental sensors** (low bandwidth)

<table>
<thead>
<tr>
<th>movement</th>
<th>light</th>
<th>Proximity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>object-usage-detection</strong></td>
<td>temperature</td>
<td>current sensing</td>
</tr>
</tbody>
</table>

**Five wearable sensors** (high bandwidth)

<table>
<thead>
<tr>
<th>onbody acceleration</th>
<th>RFID reader wristband</th>
<th>ultra-violet radiation exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>heart rate</td>
<td>location beacons</td>
<td></td>
</tr>
</tbody>
</table>
Proximity MITes (MERL)
Our Hardware sensing Tool #2
MITes: Portable toolkit of sensors

Temperature and Light
MITes receiver

Single receiver
USB or serial
Connector receives
all sensor data