Pervasive/Ubiquitous Computing

Ubiquitous Computing

• “The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.”, Mark Weiser 1991
**Xerox PARC: Tab**

- PARCTAB (or “tab”)
- Touch sensitive panel (use with finger or stylus), with 128x64 resolution, can flip for left-hand use
- 3 buttons, speaker (different tones)
- Infrared (19.2k baud)
- Localization using “room-sized communication cells”
- 12MHz Intel 8051 microcontroller
- Can operate for 10mins/hour, 8 hours per day, 1 week before recharging

**Xerox PARC: Pad**

- Pad (Tablet), prototype pen computer (9x11x1”)
- 4 hour battery life
- 5 lbs
- Motorola 683xx processor w/ 4MB RAM
- PCMCIA
- PAR Pen w/ built-in microphone
- 640x480 display
- Infrared
Xerox PARC: Board

- Bulletin boards, whiteboards, flip charts, book case, ...
- 40” by 60”, 1024x768
- Wireless electronic “chalk”

Active Badge

- Olivetti Research, Roy Want
- Workers could automatically unlock areas to which they had been granted access
- Phone calls routed to wherever they are
- Create running diaries of meetings
- Could be tracked (Olivetti’s public web site allowed visitors, at one point, to find location of employee)
Active Badge

- Identity + Room level location + Button
- Relatively “simple” technology led to lots of applications
  - Door opens only to right badge wearer (Bill Gates’ house)
  - Rooms greet people by name
  - Telephone calls automatically forwarded
  - Computer terminal can quickly pull your settings from “home computer” (“teleporting”)
  - Automatic diary
During one of his talks, Weiser outlined a set of principles describing pervasive computing (also called ubiquitous computing):

- The purpose of a computer is to help you do something else.
- The best computer is a quiet, invisible servant.
- The more you can do by intuition the smarter you are; the computer should extend your *unconscious*.
- Technology should create calm.

**Calm technology**

- “A technology that *informs but doesn’t demand our focus or attention*”,
  (Designing Calm Technology, Weiser and John Seeley Brown)
Invisibility

• One does not need to continually rationalize one's use of a pervasive computing system.

• Having learnt about its use sufficiently well, one ceases to be aware of it.

• It is "literally visible, effectively invisible" in the same way that a skilled carpenter engaged in his work might use a hammer without consciously planning each swing.

• Similarly, when you look at a street sign, you absorb its information without consciously performing the act of reading.

Famous Quote

• There is more information available at our fingertips during a walk in the woods than in any computer system, yet people find a walk among trees relaxing and computers frustrating.

• Machines that fit the human environment instead of forcing humans to enter theirs will make using a computer as refreshing as taking a walk in the woods.
Common Terminology

- Ubiquitous Computing
- Pervasive Computing
- Calm Technology
- Internet of Things
- Things that think
- Everyware
- Pervasive Internet
- Ambient Intelligence
- Proactive Computing
- Augmented Reality

Related Areas

- Sensor Networks
- Mobile Computing
- Wireless Networks
- Embedded Systems/Control
- Human-computer Interaction
- Artificial Intelligence
- Autonomic Computing
Challenges

- Natural interfaces
- Context-aware applications
- Automated capture and access
- Continuous interaction
- Privacy
- Security
- Visibility
- Control

Natural Interfaces

- Classic input devices: keyboard & mouse
  - Characters and x,y coords
  - Most natural interfaces try to convert to first class type (pen to text, speech to text)
- Can we ever capture subtleties of natural human communication?
- What different natural interfaces might exist??
  - Nintendo Wii
    - Trauma Center, Wii Sports
  - iPhone
- How is accidental communication handled?
  - StarTrek
    - “Computer: play music”
Context Aware Computing

• Who
  – Currently generally tailored to one user
  – How important are others in determining our behavior
    • How could this be captured?
• What
  – Attempt to figure out what is currently happening
  – Sense environment, use calendar software etc.
  – What is the cost of the wrong guess?
    • TiVo Problem
• Where
  – Location based information
  – GPS
  – Most explored of context information
• When
  – Easily obtained information – Computer good at remembering time
    • Although determining when one event stops and another begins is not easy
• Why
  – Even harder than the “what” question, biometric sensors might help

Automated Capture and Access

• Recording information and data as it occurs
  – Computers are inherently good at recording, people are not
  – People freed up to summarize and understand
  – Most work in academic/classroom settings
    • Time stamping lectures, digital whiteboards
• Challenges in capture and access
  – Sometime we don’t know we want to capture something until after it happened
    • How could the computer know that?
    • If it captures everything then we need a system of sorting and filtering (access)
  – Access is a problem because capturing of raw data can be burdensome for sifting through... systems need to recognize important events to facilitate access
Continuous Interactions

• Continuously present interface
  – No current model of continuously present interfaces, even people are not continuously present
  – Create an interface that doesn’t get annoying
• Determine what information should require my attention and what should be displayed peripherally
• Comfort and style
  – If constantly worn or carried must be stylish and comfortable

Privacy, Security, ...

• Privacy
  – Potential for misuse
  – How should users be informed of computer monitoring (don’t be invisible?)
  – Is it ok to give up this privacy in some settings, e.g., healthcare
  – Do we give hackers too much power
• Security
  – Constant monitoring takes away personal responsibility
  – What happens if I lose my data
Key Technological Challenge: Energy

- “Power is considered as the most important constraint in embedded systems”

Energy

Running the same multimedia application.

As published by Transmeta [www.transmeta.com]
Energy Is Everywhere

- Light
- Radio frequency
- Motion and vibration
- Heat

Energy Harvesting

- **Energy harvesting** is the process by which energy is captured and stored

- This term typically refers to small autonomous devices
  - micro energy harvesting

- A variety of sources exist for harvesting energy
  - solar power
  - salinity gradients
  - thermal energy
  - kinetic energy
  - wind energy
  - radio frequency
Not a New Idea

Energy Harvesting Applications

- Low data rate, low duty cycle, ultra-low power

- **Medical and Health monitoring**
- **Body Area Network**
- **Structure Health monitoring**
- **Wireless Sensor Networks**
- **Smart building**
Tradeoffs

• Advantages
  – Mobile: no power wires
  – Easier installation
  – Lower maintenance
  – Environmentally friendly
  – Higher uptime

• Disadvantages
  – Dependent on availability of harvestable energy source
  – Strict power budget
  – Upfront cost may be higher
  – Less mature technology

Permanently Powered Sensors

• Remote patient monitoring
• Harmful agents detection
• Efficient office energy control
• Surveillance and security
• Detecting and tracking enemy troop movement
• Vineyard or other agricultural management
• Home automation
• Implantable sensors
• Long range asset tracking
• Aircraft fatigue supervision
Tree Energy Harvesting

A new MIT tree sensor system taps into trees as a self-sustaining power supply. Each sensor is equipped with an off-the-shelf battery that can be slowly recharged using electricity generated by the tree.

The sensor system produces enough electricity to allow the trees' temperature and humidity sensors to regularly and wirelessly transmit signals. Each signal hops from one sensor to another, until it reaches an existing weather station that beams the data by satellite to a forestry command center.

Energy Harvesting Sources

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Characteristics</th>
<th>Efficiency</th>
<th>Harvested Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>Outdoor</td>
<td>10–24%</td>
<td>100 mW/cm²</td>
</tr>
<tr>
<td></td>
<td>Indoor</td>
<td></td>
<td>100 µW/cm²</td>
</tr>
<tr>
<td>Thermal</td>
<td>Human</td>
<td>~0.1%</td>
<td>60 µW/cm²</td>
</tr>
<tr>
<td></td>
<td>Industrial</td>
<td>~3%</td>
<td>~1–10 mW/cm²</td>
</tr>
<tr>
<td>Vibration</td>
<td>~Hz–human</td>
<td>25–50%</td>
<td>~4 µW/cm³</td>
</tr>
<tr>
<td></td>
<td>~kHz–machines</td>
<td></td>
<td>~800 µW/cm³</td>
</tr>
<tr>
<td>RF</td>
<td>GSM 900 MHz</td>
<td>~50%</td>
<td>0.1 µW/cm²</td>
</tr>
<tr>
<td></td>
<td>WiFi</td>
<td></td>
<td>0.001 µW/cm²</td>
</tr>
</tbody>
</table>

AdaptiveEnergy ~10mW
Elastometer ~800mW
BigBelly ~40W

Sources:
- Selko watch ~5uW
- Holst Center ~40uW
- 2 channel EEG ~1mW
- AdaptiveEnergy ~10mW
- Elastometer ~800mW
- BigBelly ~40W

Computer Science and Engineering - University of Notre Dame
Harvesting Thermal Energy

Thermocouple

Thermopiles
- thermally in parallel
- electrically in serial

Harvesting Vibration Energy

Piezoelectric
- Vibration → beam bending (strain)
- Piezoelectric material converts mechanical strain into electrical energy

Electrostatic
- Vibration → motion of oscillating mass
- Comb overlap area (A) change
- Comb capacitance (C) change
- Voltage change at constant charge (Q)

Electromagnetic
- Vibration → motion of magnetic field
- Current flows in the static copper coil

\[ C = \frac{\varepsilon_0 A}{d} \quad Q = CV \]
Storing Energy

- Scavenged energy is not constant
- Power not available on-demand
- High peak power not available
- An ideal energy storage device:
  - Infinite shelf life
  - Negligible leakage
  - Unlimited capacity
  - Negligible volume
  - No need for energy conversion
  - Efficient energy acceptance and delivery

...Ideal battery doesn’t exist

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Storage Options

<table>
<thead>
<tr>
<th></th>
<th>Li-Ion</th>
<th>Thin Film Rechargeable</th>
<th>Super Cap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recharge Cycles</td>
<td>100s</td>
<td>5k-10k</td>
<td>Millions</td>
</tr>
<tr>
<td>Self Discharge</td>
<td>Moderate</td>
<td>Negligible</td>
<td>High</td>
</tr>
<tr>
<td>Charge Time</td>
<td>Hours</td>
<td>Minutes</td>
<td>Sec-Minutes</td>
</tr>
<tr>
<td>Physical Size</td>
<td>Large</td>
<td>Small</td>
<td>Medium</td>
</tr>
<tr>
<td>Capacity</td>
<td>0.3-2500mAHr</td>
<td>12-700uAHr</td>
<td>10-100uAHr</td>
</tr>
<tr>
<td>Environmental Impact</td>
<td>High</td>
<td>Minimal</td>
<td>Minimal</td>
</tr>
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Pervasive Computing - Outlook

- [http://www.youtube.com/watch?v=6Cf7IL_eZ38](http://www.youtube.com/watch?v=6Cf7IL_eZ38)