World Wide Sensor Web
Wearable Personal Instrumentation

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Feasibility of Wearable Personal Instrumentation

Miniaturization of computing devices and sensors => feasibility of embedding computing devices in clothes
Future Embedded Computing Platforms
Future Embedded Computing Platforms

Transparent Personal Instrumentation
A Personal Instrumentation Example

Smart Winter Jacket
A Personal Instrumentation Example

a) Winter Jacket Prototype

b) Mica Z mote

c) MTS310 sensor board
Typical Application scenario

- Upload data collected
- Base station
- Home
- Reconstruct activity log

Log activities and location (GPS) remotely.
Mapping using GPS
Classification using HMMs

- **Input:** Observation

  - Accelerometric data
  - Feature mapping
  - Observation symbols
    - Obtain windows of observation symbols for each mote and axis
    - Concatenate observation symbols across all motes and x,y axes
  - Observation sequence

**Diagram:**
- State transitions in a hidden Markov model (example)
  - x — hidden states
  - y — observable outputs
  - a — transition probabilities
  - b — output probabilities
Static Activity Identification

![Bar chart showing the accuracy of different static activities identified by HMM and Feature vector methods. The activities are Sitting, Reading, Typing, Lying, Elevator, and Writing. The chart indicates that sitting, reading, typing, and lying have high accuracy rates, while elevator and writing have lower accuracy rates.]
Applications

- **Personal**
  - Self-browser
  - Remind me services, assisted living
  - Personal trend analysis

- **Family**
  - Remote window

- **Social**
  - Special-interest groups
    - Weight watchers (activity/weight correlations)
    - Energy watchers
Challenge 1: Layered Architecture
The “Thin Waist” of Wearable Computing

Personal Data Center

Data Mining

Personal Activity Database

XML Data Repository

Activity Identification Algorithms

Disruption Tolerant Comm. Stack

Disruption Tolerant Comm. Stack

Local Reaction

What? Where? When? How?

Context

Sensors → Filters → Disruption Tolerant Comm. Stack
Challenge 1: Layered Architecture

The “Thin Waist” of Wearable Computing

- Application 1
  - Data Analysis 1
  - Sensor Suite 1

- Application 2
  - Data Analysis 2
  - Sensor Suite 2

- Application 3
  - Data Analysis 3
  - Sensor Suite 3

Specialized architectures

Sensor evolvability – introduction of new sensors
Algorithms evolvability – new data interpretation tech.
Applications – Easy installation/devel. of new software
Challenge 2: Resources

Energy

- Sensors such as microphones and accelerometers must operate at a high frequency
- Wearable must last at least one season
- Recharging the wearables?

Scavenging kinetic energy?
Challenge 3: Protocols
Wearable Ad Hoc Networks

- Multiple items may be instrumented
- “Wear-sensitive” protocols are needed for:
  - Resource discovery
  - Who’s wearing me?
  - Time synchronization
  - Cooperative activity identification
  - Opportunistic optimization
  - General-purpose applications
- MAC (reliability, congestion, …)
Challenge 4: Privacy
A Web of Special Interest Group Applications

Queries over special interest groups:

- What’s the average weight loss of individuals on diet X as a function of time?
- What’s the average electric energy consumption of individuals at location Y?
- How many gallons of water are used annually on watering lawns in my neighborhood?
The Web of Personal Data

Aggregation Center

Personal Data Center

Subscription Based Access

Personal Data Center

Personal Data Center

Personal Data Center

Personal Data Center

Personal Data Center

Personal Data Center

Personal Data Center
Privacy-Preserving Aggregation

Problem: Aggregate statistics without disclosing private data

Example: average weight of special interest group Z (without disclosing individual weights?)

\[
\begin{align*}
W_1 + X_1 \\
W_2 + X_2 \\
W_3 + X_3 \\
\vdots \\
W_n + X_n
\end{align*}
\]

Avg. \rightarrow W(\text{avg})

\(W_i\) is the weight of individual #i
\(X\) is a random variable with zero mean
Privacy-Preserving Aggregation

- Problem: How much information is released? Really?
- Example: Privacy of repeated measurements
  - $W_1(t_1) + X_{11}$, $W_1(t_2) + X_{12}$, \ldots{}, $W_1(t_m) + X_{1m}$
  - $W_2(t_1) + X_{21}$, $W_1(t_2) + X_{22}$, \ldots{}, $W_1(t_m) + X_{2m}$
  - $W_3(t_1) + X_{31}$, $W_1(t_2) + X_{32}$, \ldots{}, $W_1(t_m) + X_{3m}$
  - \ldots{}
  - $W_n(t_1) + X_{n1}$, $W_1(t_2) + X_{n2}$, \ldots{}, $W_1(t_m) + X_{nm}$
Privacy-Preserving Aggregation

Example: average weight trend of special interest group Z.

- $W_1(t_1) + X_{11} + Y_1$, $W_1(t_2) + X_{12} + Y_1$, ..., $W_1(t_m) + X_{1m} + Y_1$
- $W_2(t_1) + X_{21} + Y_2$, $W_1(t_2) + X_{22} + Y_2$, ..., $W_1(t_m) + X_{2m} + Y_2$
- $W_3(t_1) + X_{31} + Y_3$, $W_1(t_2) + X_{22} + Y_3$, ..., $W_1(t_m) + X_{3m} + Y_3$
- ...
- $W_n(t_1) + X_{n1} + Y_n$, $W_1(t_2) + X_{n2} + Y_n$, ..., $W_1(t_m) + X_{nm} + Y_n$
Summary

- A layered software architecture for wearables
- Solving the energy problem
- A suite of “wear-sensitive” protocols
- Privacy-preserving statistics for the sensor web