Multi-Sensor Context Awareness for Ubiquitous and Wearable Computing

thanks to: Stavros Antifakos, Florian Michahelles, Nicky Kern

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Human Computer Interaction

- Explicit Interaction
  - keyboard, mouse, ...
  - speech, gesture, multi-modal input, ...
  - human takes initiative

- Implicit Interaction
  - modeling and recognizing context
  - context: location, social context, task/activity, ...
  - context-aware & proactive user interfaces
  - also system takes initiative

- Sensing
  - important or even required
Perceptual Computing

- Perceptual Computing
  - concerned with efficient methods to index, search, structure, and fuse sensor data
  - sensors and sensor data may become abundant
    - sensors become very small and cheap - ubiquitous sensors

- Sensor Data is Rich Source of Information about Humans:
  - Distributed Sensors - model context of humans and environment
  - Wearable Sensors - model human and environment from a first-person perspective
    - see and hear what the human sees and hears
    - may be always with you

- Sensory Augmented Computing
  - computers may have access to “ubiquitous sensors”
  - potential: may fundamentally change human-computer interaction
Perceptual & Sensory Augmented Computing

- Issues of Robustness, Ambiguity & Uncertainty
  - major limitations today
  - i.e. computer vision:
    - significant progress during last decades (examples: quality control, face recognition, recovery of CAD models for specific objects, ...)
    - most successful in very specific domains - limited degrees of freedom
    - limited robustness and generality
  - similar for other sensors (like audio)
Perceptual & Sensory Augmented Computing

• Potential of Multi-Sensor Integration
  - integration of multiple sensors and modalities to overcome limitations of single sensors
  - may facilitate robustness and resolve ambiguities, and handle uncertainty in environments of realistic complexity
  - improve sensing and fusion algorithms is critical

• However...
  - uncertainty, ambiguity and robustness issues will remain!
  - context awareness for HCI: think about who and how context information will be used
  - making context-awareness useable!
Overview

1. Projects for Multi-Sensor Context-Awareness
   - Proactive Instructions for Furniture Assembly
   - Context-Aware Notification for Wearable Computing
   - Annotation of Live Meeting Recordings using Wearable Sensors

2. “Improving Interaction” with Context-Aware Systems
   - Displaying Uncertainty/System Reliability
   - Importance of Trust in Context-Aware Systems

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Proactive Instructions for Furniture Assembly

Stavros Antifakos, Florian Michahelhes, and Bernt Schiele
Proactive Instructions for Furniture Assembly

- **Today’s Instructions**
  - mostly linear (‘single’ solution)
  - human has to link ‘virtual instructions’ and physical object

- **Usage of Instructions**
  - no distinction of beginner vs. expert
  - beginner: step-by-step instructions
  - expert: help on demand (reference manual)
Proactive Instructions for Furniture Assembly

- **Assembly Plan as Finite State Machine**
  - states: states of the assembly
  - transitions: actions performed by user

- **Attach Sensors to Assembly**
  - recognize states of assembly and actions of user

- **Proactive Instructions**
  - beginner: complete guidance
  - intermediate: guidance on failure
  - expert: only guidance on demand
Proactive Instructions for Furniture Assembly

- Sensors attached to different parts of the assembly
  - boards with accelerometer, force sensor
  - screwdriver with gyroscope

- Recognition of Actions (state transitions)
  - all actions composed of sub-actions (hammering, moving, screwdriver, ...)
  - example: join horizontal board to side board

Markov Chain

M: boards moving
N: nothing happening
S: screwing
F: force difference
Proactive Instructions for Furniture Assembly

MetricsIts Sensor Board (EU-project)
- Sensors: accelerometers, pressure, microphone, light, temperature
- SIGGRAPH 2003, emerging technology demonstration

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Proactive Instructions for Furniture Assembly

- Smart-Its Sensor Board (EU-project)
  - Sensors: accelerometers, pressure, microphone, light, temperature
  - SIGGRAPH 2003, emerging technology demonstration

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Context-Aware Notification for Wearable Computing

Nicky Kern and Bernt Schiele
Context-Aware Notification for Wearable Computing

- Many applications require the user’s attention:
  - phone, sms, e-mail, navigation hints, stock market monitoring, ...
- Mediate *Notifications* depending on context
  - to notify or not to notify
  - choose best modality

- Trade-Off:
  - Utility - Importance of event
  - Cost - *Interruptability* of the user

- Estimate interruptability of user from wearable sensors
  - to mediate notifications proactively
Interruptability Model

User’s Interruptability
“Personal Interruptability”

Interruptability of the Environment
“Social Interruptability”
Estimating Interruptability

Difficult to model entire situations

Either:
  too unspecific for interruptability estimation

Or:
  too many special cases
Interruptability Estimation Example

Tendencies for low-level context $s$:

$$T_s(x, y)$$

Sensing Score at time $t$:

$$l(s, t)$$

Location: Lecture Hall
Activity: Sitting
Activity: Standing
Social Activity: Conversation

Interruptability Estimate:

$$Intr(x, y, t) = \sum_s T_s(x, y) \cdot l(s, t)$$

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Improvements through Learning

- Find Low-Level Contexts Unsupervised
  - find recurring low-level contexts automatically $\rightarrow$ clustering

- Learn Tendencies from Data
  - divide space in bins $(\hat{x}, \hat{y})$
    every bin is a constant
  - interruptability estimation becomes:
    \[
    Intr(\hat{x}, \hat{y}, t) = \sum_{s} \hat{T}_s(\hat{x}, \hat{y}) \cdot l(s, t)
    \]
  - learning: given ground truth:
    \[
    GT(\hat{x}, \hat{y}, t) = \sum_{s} \hat{T}_s(\hat{x}, \hat{y}) \cdot l(s, t)
    \]
  - over-determined set of linear equations
  - calculate tendencies using least-squares
Hardware Platform

- 12 x 3D Acceleration Sensors
  - Shoulders, Elbows, Wrists, Hip, Knees, Ankles
- Microphone
- Location ‘Sensor’
  - closest WLAN access point
- Wrist-Mounted Display for Data Annotation
- Runs 6h continuously
General Results

- **single sensor modality performance:**
  - acceleration > location > audio
- **location+audio+acceleration best results**
  - audio+acceleration very similar
Reducing Number of Acceleration Sensors

- best results: all acceleration sensors
- best result with 4 acceleration sensors:
  - (left wrist+left hip+both feet) + location + audio

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Wearable Sensing to Annotate Live Meeting Recordings

Nicky Kern, Bernt Schiele
Holger Junker, Paul Lukowicz, and Gerhard Tröster
Live Life-Recorder

• Imagine:
  ➢ to wear a camera and microphone to record your entire audio-visual life...

• Storage:
  ➢ ‘only’ 500 TB
  ➢ assume: 100 year lifespan, 24h recording per day, 10MB per minute Audio-Visual-Recording...

  → We can store the life-recording soon!

• Retrieval is the challenge!
  → today’s methods are not sufficient for large audio-visual databases!
Retrieval: What can we do?

- Observation:
  - Humans not only retrieve by date & time
  - Human memory works associatively
    - e.g. personal situation and sequence of events important

- Our approach:
  - use of wearable sensors
  - Annotate Recordings with Situation Awareness Data

- Test Scenario: Live Meeting-Recorder
  - Meetings in rooms, but also in coffee corner, hallways, ...
  - interesting information:
    - who is talking, how long, when presentation, discussion
    - when was I walking, shaking hands, getting up
    - activities during a break
Live Meeting-Recorder

- Retrieval example using user activity:
  - “Show me all parts of the meeting when I was......”

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Live Meeting-Recorder

- Recognition of body posture and user activity
  - network of 3-axes accelerometers
  - separate boards for sensors and microcontroller
  - hierarchical network topology
    - corresponds to topology of the human body and the clothing
Live Meeting-Recorder

- Recognition of user activities

Greeting a person

-2g / +2g

0g

+1g

0g / 0g

-2g / -2g

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Live Meeting-Recorder

• Analysis of accelerometer data

Torso

Sitting  Standing up  Standing  Sitting down  Sitting

acceleration [g]

time [s]

Wrist

Arm on table  Arm moving  Arm moving  Arm resting on table

acceleration [g]

time [s]

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Live Meeting-Recorder

• Example of Result:

- Presentation
  - Standing
  - One speaker

- Discussion
  - Sitting
  - Two speakers
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Context Information

- Context Information will remain Faulty, Uncertain and Ambiguous because of
  - unobservable information
    - human’s mental states are not observable
    - personal interests and objectives are difficult to estimate reliably
  - missing information
    - history information often missing
    - not all relevant information measured or available
  - unpredictable behavior
    - ‘humans are non-linear time-varying systems’...
  - ambiguous situations and interpretations
A Context-Aware Memory Aid

A small story
“... I decide to go swimming. I start packing my towel and sunglasses. A glance at my memory-aid reveals:”

basketball training

“I switch of the memory aid. ...”

“...when I arrive at the swimming pool I notice that I have forgotten my wallet.”

What went wrong

• Inferred context was wrong
• Context was displayed as if it were correct
• User decided not to use the system
• Benefits of the system were missed
  - forgot wallet
Possible Solutions Proposed

- Increasing controllability:
  - [Mankoff et al. 2000] mediation technique, to resolve ambiguity
  - [Newberger & Dey 2003] enactor component, to monitor and control system

- Making systems observable:
  - [Greenberg 2001], [Bellotti & Edwards 2001] feedback needed to link automatic action and context
  - [Chalmers & MacColl 2003] seamful rather than seamless design
Our Approach: Displaying Uncertainty

Humans are used to dealing with uncertainty information in everyday life:

- weather forecast: tomorrow, 80% chance of rain

... and even more, with uncertain information:

- “lets meet at the cinema at 8:00 pm, ...”

Display uncertainty information about context, to let the user know how good the system is.
Memory Aid Experiment

- Goal: Measure effects of displaying system uncertainty:
  - task: remember as many numbers as possible
  - context-aware system is simulated by presenting memory-tips
Memory Experiment - Design

- 24 participants
- mixed design study with four independent variables:
  - level of uncertainty (=system reliability):
    - p=0.6, p=0.75, p=0.9
  - uncertainty display:
    - display system uncertainty
    - don’t display uncertainty
  - task difficulty
    - controlled by the task display time: 200ms, 800ms, 3200ms
  - cost variable was tested between subjects
    - low-cost group: +2 points for correct, -1 point for wrong answer
    - high-cost group: +1 point for correct, -2 points for wrong answer
- performance measure:
  - hits = correct answers
  - false alarms = wrong answers
Results: Hit Rates

High-cost group

No uncertainty information displayed

Uncertainty information displayed

Low-cost group

higher hit-rates, when uncertainty information is displayed
Context-Aware Mobile Phone

- Vision: Mobile phone adapts notification modality depending on situation
- Based on interruptability estimation with wearable sensors
- Would people use such a system?
  - trust in the system is important
- Experiment using videos of situations:
  - effects of displaying reliability information on trust
  - effects of uncertainty level
  - effects of different types of situations

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Context-Aware Mobile Phone Experiment

- Pre-experiment - 94 situations (video-clip)
  - order situations in low, medium, highly critical
  - low: standing in an elevator alone, sitting in a tram, ...
  - medium: eating at McDonald, driving a car, ...
  - high: attending a lecture, studying at university library, ...
  - assess preferred modalities (example: buzzer in lecture)

- Main experiment, ask question:
  - Would you verify the automatic settings in this situation?
Context-Aware Mobile Phone - Results

Verification Rates

- Decrease of verification rates at high reliability
- Slight increase of verification rates at low reliability
Potential and Challenges

- **Multi-Sensor Context-Awareness**
  - great potential for Human-Computer Interaction (ubiquitous and wearable computing)

- **Sensing Challenges**
  - reduce uncertainty and ambiguity
  - new sensors and sensor modalities
  - sensing and fusion techniques

- **HCI Challenges**
  - making context awareness useable
  - appropriate feedback mechanisms
  - improving trust in context-aware systems
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