A Survey of Context-Aware Mobile Computing Research

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Outline

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Introduction

- Users can move around with devices at hand and access information anytime, anywhere
  - Portable computers and wireless communications
  - Computers are shrinking and the bandwidth of wireless keep increasing
- Context-aware computing is a mobile computing paradigm
- Applications can discover and take advantage of contextual information
Definition of Context (1/2)

- General Definition (Merriam-Webster’s Collegiate Dictionary)
  - The interrelated conditions in which something exists or occurs

- Three categories defined by Schilit
  - Computing context
    - Network connectivity, communication cost, communication bandwidth, nearby resource
  - User context
    - User profile, location, social situation
  - Physical context
    - Lighting, noise, traffic condition, temperature
  - Time context
    - Time of a day, week, month and season of the year
Definition of Context (2/2)

- Schmidt et al
  - Knowledge about the user’s and IT device’s state, including surroundings, situation, and to a less extent, location

- Dey
  - Any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves

- Context in mobile computing has two different aspects
  - Context is the set of environmental states and setting that either determines an application’s behavior or in which an application event occurs and is interesting to the user
Context-aware Computing (1/2)

- Four categories defined by Schilit
  - Proximate selection
    - A user-interface technique where the objects located nearby are emphasized or otherwise made easier to choose
  - Automatic contextual reconfiguration
    - A process of adding new components, removing existing components, or altering the connections between components due to context changes
  - Contextual information and commands
    - Which can produce different results according to the context in which they are issued
  - Context-triggered actions
    - Simple IF-THEN rules used to specify how context-aware systems should adapt
Context-aware Computing (2/2)

- How a mobile application can take advantage of context
  - Active context awareness
    - An application automatically adapts to discovered context, by changing the application’s behavior
  - Passive context awareness
    - An application presents the new or updated context to an interested user
    - An application makes the context persistent for the user to retrieve later
Examples of Context-aware Application

- Call Forwarding
- Teleporting
- Active Map
- Mobisaic Web Browser
- Shopping Assistant
- Cyberguide
- Conference Assistant
- Fieldwork
- Office Assistant
- ......
Call forwarding

- Passive context
  - None
- Active context
  - User’s location
- Description
  - Based on active badge system, the location context is presented to the receptionist
  - The location context becomes active to help automatically forward the phone calls to the destination user’s nearest phone
  - People want to express more control over depending on their current context
Context-aware Application (3/4)

- **Shopping Assistant**
  - Passive context
    - None
  - Active context
    - Customer’s location within the store
  - Description
    - The device can guide the shoppers through the store (provide details of items, help locate items, point out items on sale, do a comparative price analysis ...)
    - There is a privacy concern since the store maintains the customer profiles
    - Customers are divided into two classes (regular customers, store customers)
Context-aware Application (4/4)

- Conference Assistant
  - Passive context
    - Current activity (presentation)
  - Active context
    - Attendee’s location, current time, schedule of presentation
  - Description
    - The assistant examines a variety of context information to help conference attendees
    - When the user enters a presentation room, the conference assistant automatically displays related information (the name of presenter, the title of the presentation ...)
    - Audio and video equipment automatically record the contents of the conference
Sensing the context (1/5)

- To be able to use context in application, we need a mechanism
  - To sense the current context
  - To deliver it to the application

- Sensing the Location
- Sensing Low-level Contexts Beyond Location
- Sensing High-level Contexts
- Sensing Contexts Changes
Sensing the Location

- **Outdoors**
  - GPS (Global Positioning System)

- **Indoors**
  - GPS doesn’t work indoor
    - Signal strength is too low to penetrate most building
  - Developed a new tracking systems
    - Ultrasonic signal, Radio signals, Footstep force profile of a person, Camera

- **Issues**
  - No uniform way to track locations with fine granularity that works both indoors and outdoors
  - Sensed data may have uncertainty due to environmental noise or sensor error
  - Context sensed from different sensors may conflict to each other
Sensing the context (3/5)

Sensing Low-level Contexts Beyond Location

- Other contexts and possible approaches to sense them
  - Time
    - Obtain easily from the build-in clock of the computer
  - Nearby objects
    - Querying the location database
  - Network bandwidth
    - Using API provided by a system module
  - Other low-level contexts
    - Light level (using photodiode), Tilt and vibration (using two accelerometers), Sound (using microphone), temperature, pressure, CO gas

- Concern
  - Adding sensors to the mobile device will in turn reduce user’s mobility and may require user’s cooperation
Sensing the context (4/5)

**Sensing High-level Contexts Beyond Location**

- We are also interested in high-level context information
  - Such as user’s current activity

- Some approaches to sense complex social contexts
  - Machine vision
    - Based on camera technology and image processing
  - Consult the user’s calendar
    - To find out what the user is supposed to do at certain time
  - AI techniques
    - To recognize complex context by combining several simple low-level sensors

- It is extremely hard to recognize user’s emotional context
The context source monitor polls the current context and sends the changes to some context service

- The context service is responsible to deliver the context changes to the clients who have subscribed to the related context changes

Different context has different properties

- Example
  - Location of a person and location of a printer
  - Polling rates are chosen based on people’s experience and assumptions
Modeling Context Information (1/2)

- Most research of modeling context focuses on location information

- Purpose of Location Modeling
  - To handle object mobility
  - To facilitate location-related queries

- Location Model
  - Symbolic model
    - Representing location as abstract symbols
  - Geometric model
    - Representing location as coordinates
Data structures

- Key-value pairs
  - Key: Environmental variable, Value: actual context data
- Tagged encoding
  - Based on SGML (Standard Generic Markup Language)
  - When contextual constrains in <require> tag are met, <body> will be triggered
- Object-oriented model
  - Contextual information is embedded as the states of the object
  - Object provides methods to access and modify the states
- Logic-based model
  - Expresses the existing contextual information in a domain-centralized database using an entity-relationship data model
System Infrastructure (1/2)

- It is necessary to decouple the application and the actual context sensing part
  - Large development overhead
  - To generalize the system to other applications

- A middleware layer
  - To separate the low-level sensor from high-level application
  - Collect raw sensor information
  - Translate raw information to an application-understandable format
  - Disseminate it to interested applications
Centralized Architecture
- Use a centralized context server for each user
  - Use RPC to communicate
  - Usually have scalability problem

Distributed Architecture
- Allows context be held at several places to avoid potential bottleneck
- No central server is needed
- Members can still maintain privacy
- Increasing of computation and communication
Security and Privacy

- There are two key problems in context-aware system security
  - Ensuring the accuracy of location information and identities
  - Establishing secret communications

- Perfect privacy guarantees are in general hard and expensive

- User should be able to have the control over their contextual information and over who may gain access to it
  - The system architecture needs to provide trade-offs between privacy guarantees and both functionality and efficiency
  - It is difficult to be specific about all context information
Summary

- Surveyed the literature in this area
- Research of accurately discovering context, efficiently disseminating contextual information, and making use of the available context, are still at the early stages
- Context awareness is a key factor for new applications in the area of ubiquitous computing