The Bat System

Ubiquitous Computing in Action

Robert Harle and Alastair Beresford

Laboratory for Communications Engineering
University of Cambridge
http://www-lce.eng.cam.ac.uk/
Bat History

- 1992: Initial Active Badge System (ORL)
- 1994: Room Portion Accuracy with Active Badge (ORL)
- 1998: First Bat Prototype (UofC)
- 2000: Flat Bat (AT&T Labs)
- 2002: LCE Installation (UofC)
Matrix of ultrasonic receivers in ceiling tiles
Bat Principles - ToF Measurement

- In building radio transmitter
- Tags or ‘Bats’ are attached to users and equipment
- Bats contain ultrasonic transmitter and radio transceiver
- Radio transmitter polls Bats in turn, triggering ultrasonic emission
- Ceiling receivers measure time from radio poll to ultrasonic reception
Receiver time of flight measurements are collated for each poll. Typically more measurements than required to estimate a 3D position. Extras measurements allow use of a non-linear regression model, which improves the accuracy of 3D position estimates and rejects multipath measurements, providing a reliable estimate of error.
System Scalability

- Average ceiling receiver density $0.6 \, m^{-2}$
- Offload positioning calculation to DSP
- One DSP per average room
  - Scaling is $O(n)$, but no wide-area performance hit
- One radio transmitter zone per floor
- 3\text{cm} linear error 95\% of the time
- Higher levels of error arise from, poor ceiling receiver geometry, high levels of multipath and ultrasonic noise pollution
SPatially Indexed Resource Identification and Tracking
User defined spatial zones produce CORBA events

Zone indexing performed with a quad-tree based algorithm
A map provides human readable context information
A map provides human readable context information
Applications - Teleporting

- Hot-desking
- Example of a ‘follow-me’ application
- Other follow-me applications achieved with cameras and sound
Bats contain a simple peizo-electric speaker providing basic feedback
Applications - Security

- Each Bat has a unique identity
- Identity can be used to enforce physical location security
  - Control access to parts of the office environment
  - Enforce health and safety requirements (two members in lab at all times)
  - Access can be both spatial and temporal
  - Current implementation requires trust in users
    - Identity transmitted in plain text
    - No challenge-response protocol
Applications - Active Posters

- Traditional desktop paradigm is not always efficient
- The Bat becomes the mouse, and the environment is the desktop
- Active Posters provide simple and efficient control of the ubiquitous environment
  - Toggle on or off SPIRIT services
  - Control devices, for example, a scanner
  - A plasma display becomes a dynamic Active Poster
System Experiences

- Minimise wiring requirements—it really matters!
- Use high-quality connectors
- User acceptance
- Do not deploy without applications
User Experiences

- Day-to-day use in our laboratory has provided interesting feedback:
  - Ultrasonic reflections and noise
  - Radio propagation and power
  - VNC implementation
  - Posters
  - Database
  - Always provide user feedback to button presses
User Location Privacy

- Allow users to manage their location privacy
- Applies to many domains, not just the Bat System
- Can be done in two overall ways:
  - Access control—*specification difficult*
    - Three domains: location, time and identity
    - Role-based access reduces setting preferences
    - Integration with other apps. helps, e.g. calendar
  - Anonymity—*difficult to guarantee*
    - High-res location data $\Rightarrow$ identity inference
    - Changing pseudonyms and random-walks (spatial and temporal)
Anonymizing Location Information

- Raw data of a single user
Anonymizing Location Information

- Measure fraction of timespent, i.e.

\[
\frac{T_{u,p}}{\sum_{j=1, j \neq u}^{n} T_{j,p}} > \tau
\]
Contact Details

- Alastair Beresford and Robert Harle
  arb33@cam.ac.uk and rkh23@cam.ac.uk

- Laboratory for Communications Engineering
  University of Cambridge

- http://www-lce.eng.cam.ac.uk/

- http://www.uk.research.att.com/

- http://www.ubiquitous-systems.com/