AmbiSense – Identifying and Locating Objects with Ambient Sensors

“When Ambient Intelligence meets Web 2.0: Wiki-City
A City interacts with its citizen”
Aml’08 Ambient Intelligence - Erlangen, 22. November

Dr. Christian Hoene
Computer Science Department, University of Tübingen, Germany
The City is Indoors...

- at least in Minneapolis, MN
Skyways
Outline

- Introduction
- Application Scenario

- Overall system
  - Robots and localization
  - Vision-based object recognition
  - World model
  - ERP/Database
  - Visualization and Interaction

- Results
- Conclusion and Outlook
Project AmbiSense

AmbiSense

Reliable Networks for Mobile Systems and Ambient Sensors
(Prof. Carle, Tübingen)

Autonomous Mobile Systems and Biomimetic Algorithms
(Prof. Zeil, Tübingen)

Service-Oriented Integration Architecture for Mobile Systems and Ambient Sensors
(Prof. Spath/PD Weisbecker, Stuttgart)

Prototyping Platform for Ambient Intelligence Sensor Technology
(Prof. Rosenstiel, Tübingen)

Human-Machine Interface with Augmented Reality
(Prof. Straßer, Tübingen)
What AmbiSense is about

- **Focus of interest**
  - **What** is located in the environment of a mobile system?
  - **Where** are entities (objects, mobile systems, humans) located?
  - **Which** information is required in a particular context?
  - **How to** present relevant information?
Application Scenario

- **Key component of the project:**
  - Continuous integration into a real-world demonstrator
  - Test bed for developed algorithms and techniques
  - Illustrate practicability and usefulness

→ **Need reasonable/extensible application scenario**

- **Warehousing and retail:**
  - We expect goods to be labeled individually with RFID tags in the near future

  → **Robot-assisted inventory in a supermarket**
  → **Synchronizing product stock automatically**
Application Scenario

- The **AmbiSense lab** at the University of Tübingen:
  - >400 individually RFID tagged products (passive UHF, EPC Class 1 Gen. 2)
  - Typical shop shelves
  - Ambient technology (WLAN, Bluetooth, RFID)
  - Robot with UHF RFID reader (ALR-8780)
Overall System
Overall System
Robots and Localization

- Robot navigation
  - Robots need to know their **current position**
  - Laser scanners are **accurate** but **expensive**

  → **Exploit existing infrastructure**

- Robots
  - Laser scanner (ground truth position information)
  - Color cameras (object recognition)
  - Alien technology ALR-8780 UHF RFID reader
  - WLAN
  - Bluetooth
  - Touch screen monitor for interaction
Introduction

- **Positioning**: Position estimation in a given environment by means of sensor information.
- Position information highly relevant for context-aware services and tracking purposes.
- Potential scenarios:
  - Patient and asset tracking
  - Product localization
  - Warehousing and logistics
  - Positioning for mobile systems, e.g. transport containers, autonomous vehicles, persons with laptops
- GPS fails indoors ⇒ requirement for alternatives
- Desirable: reuse of existing, inexpensive infrastructure
Robots and Localization

- Localization using **RFID**
  - Stationary tags (known positions)
  - Multiple detected tags allow for estimating position
  - Use of explicit sensor model of the antennas
    - manually or automatically generated
  - Fingerprinting-based method
    - Distribution of tags is learned in a training phase

- Localization using **Bluetooth**
  - Mapping RSSI to Bluetooth landmarks in the environment to distances

- Localization using **WLAN**
  - Based on ToF of signals between WLAN devices
Focus on Radio Frequency Technologies

Expected coexistence of common RF technologies:

Passive UHF RFID
(EPC Class 1 Gen. 2)
- 868 MHz
- Range: up to 7 m
- Measurable: detection rates

Bluetooth
(IEEE 802.15)
- 2.4 GHz
- Range: class 2 typ. 15 m
- Measurable: RSSI

WLAN
(IEEE 802.11)
- 2.4 GHz
- Range: up to 100 m
- Measurable: time of arrival
Positioning – General Idea
Particle Filtering

- Estimation of the state of a dynamic system
  Here: location of a mobile system
- **Bayesian filtering** technique, probability density function (PDF) over state space
- Discrete approximation of the PDF by set of **weighted samples**
- **Robust and accurate**, applicable to virtually any sensor
- Iterations of prediction, correction, normalization, and resampling

Prediction (motion model)

Correction (sensor model)

Normalization + resampling
1. Positioning via Passive UHF RFID

- Near future: palettes, cartons, and products RFID-tagged
- **Mobile system carries RFID reader**
  - one reader only, lots of inexpensive tags
- Usual positioning method: proximity to tag of known position determines cell-based location
- Shortcomings:
  - Position resolved to coarse area only
  - Well-known problems of passive tags: false negatives, reflections, ...
- Our goal: accurate, **metric localization**
Positioning via Passive UHF RFID – cont’d

- Idea: Exploitation of the fact that tag **detection rates depend on relative position** between RFID tag and RFID antenna
- Detection rate model (see figure) is used in particle filtering ⇒ probabilistic position refinement over time
- See (Hähnel et al. 2004, Vorst et al. 2008)
2. Positioning via Bluetooth

- Variety of mobile devices equipped with Bluetooth radio transceivers
- Received **signal strength** (RSSI) can be measured
- RSSI values decrease with distance between sender and receiver ⇒ **distance estimation**
Positioning via Bluetooth – continued

- Each RSSI value can be assigned a **PDF over possible distances**
- Observation: **noise**, low resolution for small RSSI values
- Positioning: multilateration (e.g., MMSE), particle filtering
- PDF used for particle reweighting in correction step
3. Positioning via Wireless LAN

- Usual positioning approach with WLAN: usage of RSSI values
- Alternative: **time of arrival (TOA)**
- Idea: Position has impact on the time of flight of WLAN packages between sender and receiver
- Advantage: TOA measurements scale **linearly** with open-air propagation distances
- Challenge: **low clock resolution** of off-the-shelf hardware (1µs ~ 300 m)
Positioning via WLAN – continued

- Novel four-way TOA: TOA measurements conforming to IEEE 802.11 protocol using 4 transmission steps
- Improvement by averaging over 500-2000 packets
- Open-source software Goodtry provided on the web
- See (Hoene et al. 2008)
Experimental Setup

Mobile service robot (RWI B21)
- UHF RFID reader (ALR-8780)
- 2 Bluetooth USB sticks
- 2 WLAN PCI cards + antennas (for pings and TOA measurements)
- 240° laser scanner (reference positioning)

WLAN antennas
Bluetooth sticks
RFID antennas
Laser scanner ⇒ accurate reference positioning
Experimental Setup – Environment

Laboratory with landmarks of known positions

- 24 RFID tags (Alien Techn. „Squiggle“)
- 7 Bluetooth nodes (BTnodes, ETH Zürich)
- 6 WLAN access points
Experimental Results

- Data: 11+4 sample trajectories with RFID/BT+WLAN recordings plus accurate laser reference positions, > 5 min.
- Particle filter with 300 samples using odometry
- Investigation: **Tracking**, i.e., coarse initial pose estimate provided; mean absolute positioning errors over time

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean ± Std. dev.</th>
<th>Median</th>
<th>90th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFID</td>
<td>0.432 m ± 0.095 m</td>
<td>0.435 m</td>
<td>0.527 m</td>
</tr>
<tr>
<td>Bluetooth</td>
<td>0.494 m ± 0.149 m</td>
<td>0.474 m</td>
<td>0.678 m</td>
</tr>
<tr>
<td>WLAN</td>
<td>3.315 m ± 0.738 m</td>
<td>3.545 m</td>
<td>4.274 m</td>
</tr>
</tbody>
</table>
Video
Low-cost position tracking

- Presented: Three RF-based positioning techniques
  - RFID tag detection rates
  - Bluetooth signal strength
  - WLAN time-of-arrival measurements
- Accuracies obtained in tracking a mobile robot:
  \( \approx 0.4 \text{ m for RFID} \)
  \( \approx 0.5 \text{ m for Bluetooth} \)
  \( \approx 3-4 \text{ m for WLAN} \)
- Low-cost, off-the-shelf hardware
- Future work:
  - Fusion of the techniques \( \Rightarrow \) easily possible due to particle filters
  - Refinements of methods and experiments in larger environments
Overall System

RFID Scanning & Localization System

Laser Scanner
BTNode

Mobile Agent
Mobile Agent

WLAN
RFID Reader

Data Fusion & Caching
Visualization & Interaction System

ERP System
Integration Server
Vision-based Object Recognition

- Use of **local image features**
  - Scale-Invariant Feature Transform (**SIFT**)
  - Speeded Up Robust Features (**SURF**)

- **Preprocessing**
  - Database containing features of all known packages

- **At runtime**
  - Feature extraction of current view
  - Comparison with features in database

- **Benefit**
  - **Better detection rates** by using multimodal sensors
  - **Bearing information**
World Model
World Model

- **Central point of integration** for connected subsystems
  - Communication with mobile agents by **IPC** (CARMEN toolkit, real-time requirements!)
  - ERP and visualization use **SOA paradigm** (web service interfaces, SOAP-over-HTTP protocol)

- Provision of different **maps of the environment**
  - Based on sensory information from RFID readers, Bluetooth nodes and WLAN access points
  - Used by connected agents for **self-localization** and **path planning**
ERP/Database
ERP/Database

- **Service oriented integration** of backend systems
  - Provision of product information from ERP system(s)

- **Flexible integration** of ERP systems
  - non-proprietary
  - Focus on functional aspects
  - ERP integration server allows for the integration of different ERP systems
- **Universality** of business processes, mapping onto BPEL and executable services

- Service oriented integration architecture

- Connection of *near-real-time* systems with *non-real-time* ERP systems
Visualization and Interaction
Visualization and Interaction

- Photorealistic visualization in real-time using RadioLab
  - **Spatial reference** of information
    - Mobile agents and product specific data displayed at estimated positions in *virtual scene*

- Human-Machine-Interface (HMI)
  - 3D navigation
  - Interactive display of product specific data using an *integrated webbrowser*

- Ubiquitous visualization through flash-player connection
Visualization and Interaction

- Connected to visualization web service
  - multiple visualization instances on different machines possible

- Different types of visualization
  - Higher level of legibility
  - Suited for different hardware

- Visualization supports the user in
  - Planning the operation
  - Observing mobile agents
  - Localizing the products
  - Distributing the information
Results

- Live demonstration at the AmbiSense workshop in Tübingen
- Typical tasks shown:
  - **Exploration** of the supermarket to find specifically chosen product
  - **Control** of robot by specifying goal position in virtual scene
Results

→ Movie
Conclusion and Outlook

- **Presented:**
  - Novel prototype system for robot-assisted inventory
  - Suitable components for scenario

- **Current work:**
  - **Improve self-localization**
    - Fusion of different types of sensor data
  - **Increase detection rates**
    - Test different readers and exploit reader models optimally
  - **Optimize avg. access time to product data in backend system**
    - Product cache
  - **Augment visualization with live video streams**
    - Fast low-latency transmission and display
Thank you for your interest!

**Acknowledgments**

This work was funded by the Landesstiftung Baden-Württemberg in the scope of the BW-FIT project AmbiSense.
Contact

- www.AmbiSense.org

- **Thanks to** Philipp Vorst, Jürgen Sommer, Patrick Schneider, Christian Weiss, Timo Schairer, Prof. Wolfgang Rosenstiel, Prof. Georg Carle

- **Project management:**
  Christian Hoene ([hoene@uni-tuebingen.de](mailto:hoene@uni-tuebingen.de))

- **Spokesperson of the research cooperation:**
  Prof. Dr. Andreas Zell
  Wilhelm Schickard Institute for Computer Science
  Dept. Computer Architecture
  Sand 1
  D-72076 Tübingen