Exploiting Environmental Properties for Wireless Localization and Location Aware Applications

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Introduction

- Environmental properties such as temperature, light, humidity, wind, acoustic noise, magnetic force, and spectrum usage... vary over time and space - rich in spatio-temporal information.

- Sensor networks monitor physical phenomena across a wide geographic/spatial distance – Can the wealth of data be dual-used to support pervasive computing applications involving localization and position verification?
Motivation

- Traditional approach:
  - Deploying enough landmarks with known locations to assist in localization

- Problems:
  - Not sufficient landmarks in the area of interest
    - Cost limitations
    - Environmental constrains
  - Additional landmarks would be wasteful
    - Very high accuracy of location results is not needed

- Goal: Employing environmental properties from sensor networks to augment location services without requiring
  - The deployment of a localization infrastructure
  - Additional landmarks in the area of interest
Contributions

- A localizing mechanism that makes use of the existing sensor network readings
  - does not need additional localization infrastructure
- An environmental parameter evaluation and selection method
  - optimizes the subset of parameters for localization
- An approach to assist conventional localization infrastructure
  - using these environmental readings to refine conventional localization results.
Roadmap

- Introduction and motivation
- Contributions
- Infrastructure
- Theoretical Approach
- Experimental Evaluation
- Conclusion
- Related Work
Sensors periodically report environmental readings to Base Stations.

User sends its environmental readings to Analysis Manager (AM).

AM compares user’s reading with data reported by sensors and calculates user’s location.

Utilize existing sensor networks, no additional infrastructure!
To localize: Given an observed environmental parameter vector $E^{obs} = (e_1, e_2, \ldots, e_n)$, find a corresponding position $(p, t)$ in the physical space.
How can we effectively use environmental properties to achieve better localization results?

- **Combining** more parameters may increase the ability to distinguish between points across space and time.
- Using a **small subset** of parameters reduces the cost of localization (i.e. communication and computational cost).

**Objective:** Evaluate the environmental parameters and select a subset of them that will optimize the accuracy of localization.
Parameter Evaluation

- **Parameter Dispersion**: For a parameter or a set of parameters, the more disperse the values are, the better discriminative power they have.

- Parameters with high dispersion and spatial correlation dominates localization accuracy.

![Spectrum energy](Image1.png)  ![Ambient noise](Image2.png)

(a) Max 2.435GHz Wi-Spy  (c) Ambient noise (daytime)
Parameter Selection – SCWM

**Spatio-Correlation Weighting Method**

- Calculate $W(K)$: a sum of pairwise weighted distances in physical space, given a subset of parameters $K$.

$$W(K) = \sum_{p_i, p_j, i \neq j} \omega_{i,j} \frac{d_{i,j}}{2}$$

*With $\omega_{i,j} = \frac{1}{1 + \tau \| e_K(p_i) - e_K(p_j) \|^2}$*

- Results: parameter subset with **minimum** value of $W(K)$ is the **optimal** parameter combination.
Effectiveness of SCWM (Example)

Good cases:

- \( \{P_2, P_3\} \):
  - Close locations, similar readings.
  - \( \omega_{2,3} \) is large, \( d_{2,3} \) is very small
  - \( W(K) \) is small

- \( \{P_1, P_4\} \):
  - Faraway locations, different readings.
  - \( \omega_{1,4} \) is small, \( d_{1,4} \) is very large
  - \( W(K) \) is small

Bad cases:

- \( \{P_1, P_3\} \) & \( \{P_1, P_2\} \):
  - Faraway locations, same/similar values.
  - \( \omega_{1,3} \) is large, \( d_{1,3} \) is very large
  - \( W(K) \) is large

Prediction: The parameter subset \( K \) with most of its readings follow the good patterns results in small \( W(K) \).
Algorithm Model

- **Data Normalization**
  - Data from different environmental parameters have different units and ranges of values.
    - Temperature: 65.2F – 77.3F
    - RSS: -59.8dBm - -99dBm
  - Simple un-biased approach

\[
e_{norm} = \frac{e_{i} - \mu_{i}}{\sigma_{i}}
\]

- **Flexibly choosing Environmental Parameter (Flex-EP) Algorithm:**

\[P^{*} = \arg \min \quad ||E_{obs}(p,t) - E_{sensor}(p,t)||\]

- Variants:
  - Chooses the k closest sensors and returns the average of the k locations.
  - Uses an interpolated sensor reading map.
Experimental Evaluation

Setup

Data collected from over 100 positions on the 3rd floor of the CS building

Table: Summary of the Environmental Parameters Collected

<table>
<thead>
<tr>
<th>Parameter</th>
<th>#</th>
<th>Devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>1</td>
<td>Thermometer</td>
</tr>
<tr>
<td>Humidity</td>
<td>2</td>
<td>Digital hygrometer</td>
</tr>
<tr>
<td>Acoustic Noise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daytime</td>
<td>3</td>
<td>Microphone and Dell laptop</td>
</tr>
<tr>
<td>Night time</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Spectrum Energy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.435GHz Max</td>
<td>5</td>
<td>Wi-Spy Spectrum Analyzer by Metageek</td>
</tr>
<tr>
<td>2.465GHz Max</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>2.435GHz Avg</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>2.465GHz Avg</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Received Signal Strength</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(RSS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AP 1</td>
<td>9</td>
<td>Telosb motes and Dell laptop</td>
</tr>
<tr>
<td>AP 2</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>AP 3</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>AP 4</td>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>
Evaluation of Individual Parameters

- Dispersion of individual environmental parameters

<table>
<thead>
<tr>
<th>Parameters and Their Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature</strong></td>
</tr>
<tr>
<td>4.15</td>
</tr>
</tbody>
</table>

**Spectrum Energy:**

<table>
<thead>
<tr>
<th>2.435 GHz Max</th>
<th>2.465 GHz Max</th>
<th>2.435 GHz Avg</th>
<th>2.465 GHz Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>84.36</td>
<td>88.21</td>
<td>2.09</td>
<td>0.08</td>
</tr>
</tbody>
</table>

**Received Signal Strength:**

<table>
<thead>
<tr>
<th>AP1</th>
<th>AP2</th>
<th>AP3</th>
<th>AP4</th>
</tr>
</thead>
<tbody>
<tr>
<td>211.63</td>
<td>136.65</td>
<td>123.31</td>
<td>127.27</td>
</tr>
</tbody>
</table>
Effectiveness of Parameter Selection

- Utilizing SCWM
  - Calculate $W(K)$ for all the possible combinations of parameters with size of set 1, 2, 3, 4.
  - Choose representative sets with smaller (Good) and larger (Bad) $W(K)$.
  - Flex-EP results in smaller average errors whenever $W(K)$ is smaller, and vice versa.

**Conclusion:** SCWM is effective in predicting the performance of parameter subsets!
Effectiveness of Flex-EP

- Cumulative Distribution Function (CDF) of localization errors

Parameter set:
- RSS from AP4
- Ambient Noise
- Temperature

Parameter set:
- RSS from AP2
- RSS from AP3
- 2.465GHz Max
- Ambient Noise
- Temperature

Comparing with RADAR

Refining localization
Conclusion

- Proposed using the inherent spatial variability in physical phenomena recorded by sensor networks to support pervasive computing applications involving localization and position verification.

- Formulated a theoretical measurement model:
  - Spatio-Correlation Weighting Method (SCWM)
  - Flex-EP algorithm

- Experimental results in real world environment provide strong evidence of the feasibility of utilizing environmental properties to assist in localization.
Related Work

- **Using Spatio-Temporal Information in WSN**
  - [S. Chen SASN,06] Utilize WSN for Spatio-Temporal Access Control
  - [M. Vuran, COMNETvol45,04] Capture the spatio-temporal correlation in WSN and enable efficient communication.

- **Localization Techniques:**
  - Localization Infrastructure: Infrared, Ultrasound, RSS
  - Physical Methodology: TOA, TDOA, angulation, hop count, scene matching
  
    In all of them, the same type of physical properties is required.
    (e.g., infrared, ultrasound, RSS, angle, time, or hop count)
    Our work: a generic approach, not restricted to a single property.

- **Most Related Work:**
  [A. Varshavsky, PerCom,07] GSM fingerprinting-based localization.
  - Addressed the problem that certain physical sources may not contribute to localization accuracy. But still only deals with one type of physical property.
  - Developed feature selection techniques. But the greedy methods may not find the globally optimal subset. Our SCWM is more robust.
Thank you!