Poster Abstract: Exploiting Environmental Properties for Wireless Localization

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Wireless sensor networks are usually deployed to monitor environmental fields. In this work, we take a different viewpoint by dual-using the wireless sensor networks beyond their original purpose and exploit the general spatial information fields associated with wireless networks to assist position verification and refine conventional localization results. We developed the $Flex-EP$ algorithm. And further our experimental evaluation results provide strong evidence that our approach can achieve the similar performance as traditional localization algorithms, without requiring the deployment of a localization infrastructure.

I. Introduction

The rapid advancements in sensor technologies, both in terms of the sensor itself as well as the networking technology used to convey sensor readings, is leading to a future where sensors will become pervasively deployed. Although the data associated with such sensor readings might be intended to drive specific applications, e.g. the remote monitoring of temperature and humidity, this wealth of data may also be dual-used for additional purposes. In particular, since the purpose of a sensor network is to provide sampling of a physical phenomena across a wide geographic/spatial distance, the close link between sensor data and location may be used to assist in applications involving location and position verification [1].

In this paper, we propose the use of spatially varying environmental properties to support localization, without requiring the deployment of a localization infrastructure and additional access points (or landmarks). We present the problem of localization using general spatial information fields. We examine the use of physical properties, such as temperature and ambient acoustic/RF energy, and explore whether the inherent spatial variability may be used to localize the position of a mobile entity. In our model, an array of sensors has been initially deployed for environmental monitoring. The data collected by this sensor network is used as a baseline database, and a claimant reports the physical readings at its location. We deploy an algorithm called $Flex-EP$ algorithm to determine the claimant's location based on it's readings. Through our experiments on various parameters, we observed that the environmental parameters monitored by sensor networks have localizing capability. Moreover, by using environmental readings plus received signal strength (RSS) from one access point, we found that utilizing the additional environmental parameters for localization provides qualitatively the same performance as traditional localization schemes employing RSS with at least four access points or landmarks.

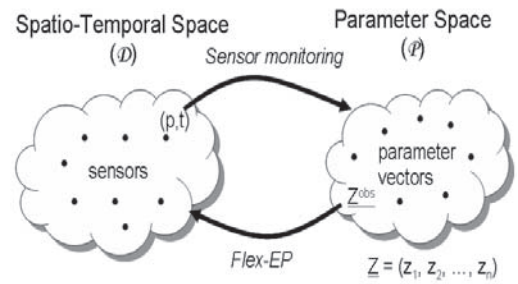


Figure 1: *Theoretical model for utilizing environmental properties for wireless localization*

In summary, our contribution include: (1) A novel localizing mechanism that makes use of the existing sensor network readings and do not need to setup additional localization infrastructure. (2) Assisting conventional localization infrastructure: using these additional readings to refine the conventional localization results. (3) A location-verification method that can be used in location related applications such as location-based access control.

II. Algorithmic Approach

We start with a generalized localization model and then present our algorithm.

Generally speaking, each sensor node in the phys-

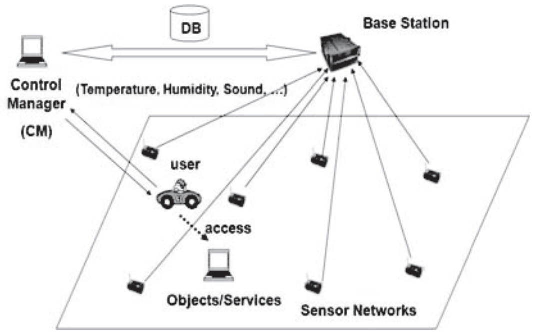


Figure 2: *Position verification for spatio-temporal access control*

ical domain continuously monitors the environment by periodically reporting the values of environmental parameters, such as temperature, humidity, and ambient acoustic energy. Assuming z_i is for the environmental parameter i and $\underline{Z}(p,t) = \{z_1(p,t), z_2(p,t), ..., z_n(p,t)\}$ is the vector of environmental parameters that are monitored by the sensors. These parameters have the property that they are recorded across space and time.

We define an n-dimensional parameter space, where each vector $\underline{Z}(p,t)$ corresponds to a point in the parameter space as shown in Figure 1. To explain further, we consider an access-control application as presented in Figure 2 where sensors periodically report data back to the access points (or base stations), while a centralized entity, the *Control Manager*(CM), is responsible to control a claimant's access to the objects and services based on its spatio-temporal location. When a claimant wants to access an object or a service, the claimant needs to send the observed information of its environment $\underline{Z}^{obs}(p,t)$ to CM. CM performs localization and verification based on the environmental monitoring information reported by the sensor network, which is stored in the database in real time.

It is desirable to choose a subset of parameters that, when used together, has optimal discriminative power to describe the uniqueness of the environment. We found that choosing parameters with large variance across the environment helps to improve localization capability. On the other hand, the correlation between parameters does not play a critical role in localizing capability.

Our algorithm, which we have called $Flex - EP$ (Flexible Environmental Parameter), performs localization utilizing environmental properties:

$$\hat{p} = arg \min_{p} \|\underline{Z}^{obs}(p,t) - \underline{Z}^{sens}(p,t)\| \qquad (1)$$

where $\underline{Z}^{sens}(p,t)$ is the collection of environmental parameters at position p and time t. Similarly $\underline{Z}^{obs}(p,t)$ is the claimant reported environments. This corresponds to the mapping from the parameter space back to the spatio-temporal space shown in Figure 1. We have also developed variants of this algorithm that returns the average of k closest positions of sensors, $FLEX - EP - Avg$, and one that uses an interpolated environmental grid, $FLEX - EP - Grid$.

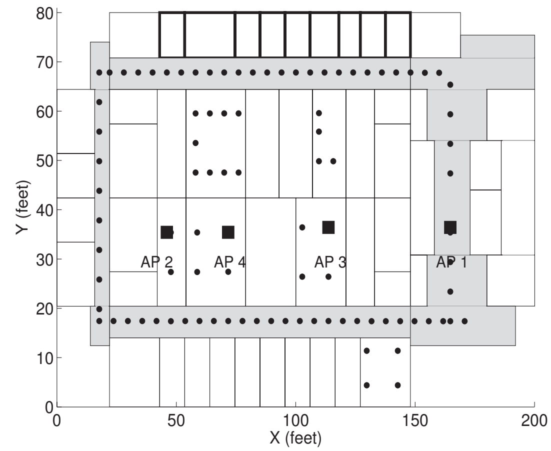


Figure 3: *Layout of the experimental floor*

III. Experimental Evaluation

We conducted experiments in the 3rd floor of the Computer Science Department at Rutgers University as shown in Figure 3. We collected environmental information at over one hundred locations on the floor, shown as blue dots, including temperature, humidity, acoustic noise, spectrum usage, and RSS from an 802.15.4 (ZigBee) network with four access points.

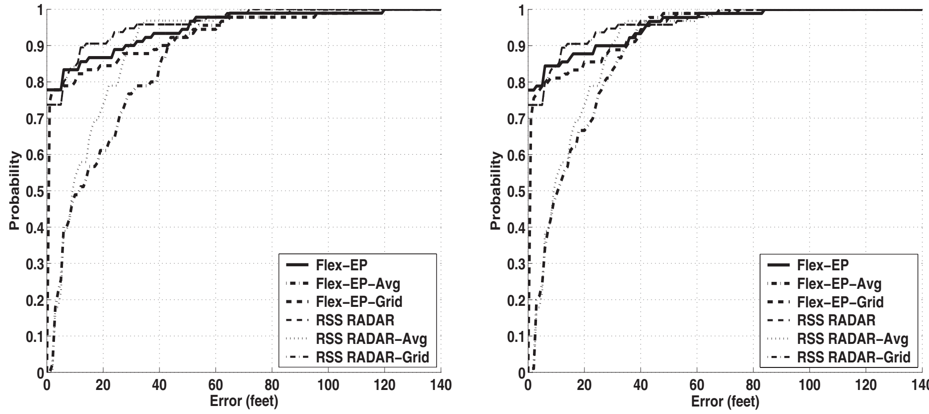
Examining the individual environmental parameters, Figure 4 shows sample maps of acoustic noise and spectrum energy at 2.435GHz across the floor. We can see that the acoustic noise does not vary much across the experimental floor, while the spectrum samples at 2.435GHz presents large variance indicating strong discriminative power to describe the uniqueness of each location in the floor.

Different environmental properties have different units and different range of values. In order to calculate the contribution of each parameter without bias, we normalize the data using the classical statistical approach:

$$z_i^{norm} = \frac{z_i - \mu_i}{\sigma_i} \qquad (2)$$

where μ_i and σ_i are the average and standard deviation of the parameter z_i.

Using the example of the access-control application, when a claimant requests access to some ob-

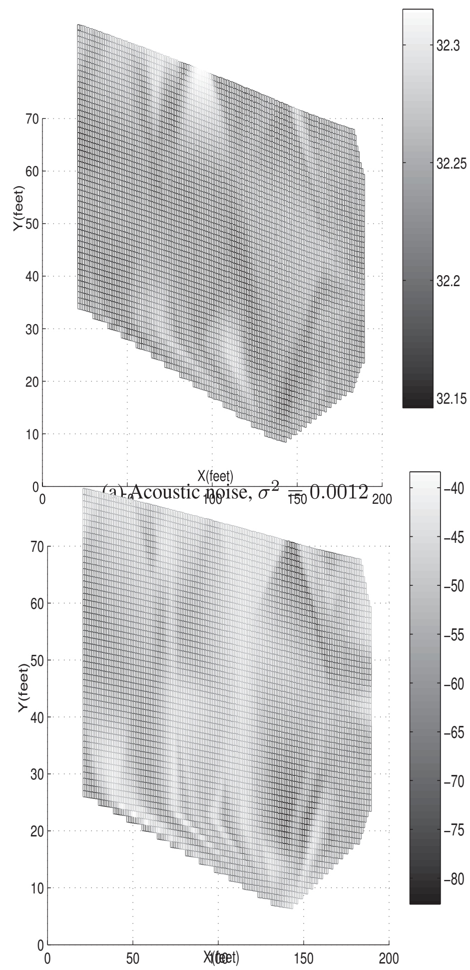


(a)

(b)

Figure 5: *Performance comparison of using environmental properties for localization to traditional RADAR algorithm, (a) parameter set: spectrum usage at 2.465GHz, RSS from AP4, acoustic noise, and temperature (b) parameter set: spectrum usage at 2.435GHz, RSS from AP1, acoustic noise, and humidity.*

jects/services, we verify the position of the claimant using the $Flex - EP$ algorithm. When selecting a parameter subset, by including only one RSS reading (from an access point) we simulated the scenario that there is only one access point available in the area of interest. We found that choosing two environmental parameters containing high discriminative power is enough to produce comparable performance to the traditional localization approaches employing RSS with at least four access points. Figure 5 presents the localization error CDF when using four environmental parameters, including spectrum usage and RSS (which have large variance across the floor), while acoustic noise, temperature, and humidity do not vary much across the experimental site. The performance using $Flex - EP$ is qualitatively similar to the performance of using the traditional RADAR algorithm [2]. The similar performance is very encouraging as it indicates utilizing environmental properties can effectively determine the location of a claimant and further to assist in applications involving location and position verification.



(a) Acoustic noise, $\sigma^2 = 0.0012$

(b) Max 2.435GHz Wi-Spy, $\sigma^2 = 84.36$

Figure 4: *Sampled data maps of individual environmental parameters.*

References

[1] S. Chen, Y. Zhang, and W. Trappe, “Inverting sensor networks and actuating the environment for spatio-temporal access control,” in *Proceedings of the Forth ACM Workshop on Security of Ad Hoc and Sensor Networks (SASN)*, 2006, pp. 1–12.

[2] P. Bahl and V. N. Padmanabhan, “RADAR: An in-building RF-based user location and tracking system,” in *Proceedings of the IEEE International Conference on Computer Communications (INFOCOM)*, March 2000, pp. 775–784.