An Indoor Localization Mechanism Based on RFID and IR Data in Ambient Intelligent Environments

María V. Moreno, Miguel A. Zamora, José Santa and Antonio F. Skarmeta

Dept. of Information and Communications Engineering
Computer Science Faculty
University of Murcia
Campus de Espinardo, 30071 Murcia, Spain
Email: {mvmoreno, mzamora, josesanta, skarmeta}@um.es

***Abstract*—Smart spaces provide users with seamless, invisible and proactive services adapted to their preferences and needs. Smart buildings comprise a key part of smart spaces, where the provided services, such as climate and lighting control or security, can be offered intelligently if one considers the static and dynamical status of the building and the location of residents. This work is focused on providing an autonomous system capable of collecting a wide range of monitoring information to ensure a comfortable atmosphere in a building and assist residents with smart automation. Location plays an important role in many context-aware applications and it is used in this work in the form of an adaptive localization mechanism based on RFID (Radio-Frequency Identification) and IR (Infra-Red) to implement a tracking system based on a Radial Basis Function Network and a Particle Filter, which is capable of providing location user with a low error. A theoretical study about models of transmission power losses in indoor environments has also been tackled, hence the number and position of sensors and the accuracy of measurements are optimized. A real scenario that exploits the capabilities of the system is described and used to gather results that demonstrate how this localization mechanism enhances the experience of users in smart buildings through a set of services.**

***Keywords*-indoor positioning; smart building; context awareness; rfid**

I. Introduction

Nowadays we are immersed in a great technological evolution which has impacted on our daily habits. A recent research area which is on the rise is *smart spaces*. The aim of a Smart Space is to provide us with seamless, invisible and proactive services adapted to our preferences and needs. These services operate by acquiring contextual information of both users and the environment in a nonintrusive and natural way. Smart Buildings, a research field within smart spaces, is growing on interest these days [1], due to the time people spent indoors daily.

Automation systems in smart buildings take inputs from the sensors installed in corridors and rooms (light, temperature, humidity, etc) [2] and use these data to control certain subsystems such as lighting, HVAC (heat, ventilation and air conditioning) or security. These and more extended services can be offered intelligently, taking into account environmental parameters and the location of residents [3]. The work presented in this paper follows this line, providing an autonomous system capable of ensuring a comfortable atmosphere and smart control in the building through extensive monitoring measurements.

Location plays an important role in many context-aware applications. For many different services that can be offered in a smart building it is usually needed information about the number and location of residents. Their identities are also relevant, since one of the aims of smart buildings is to deploy personalized services. Depending on the service requirements, a different localization scheme would be required, varying the number of needed sensors, the algorithms used and assuring a tradeoff between comfort and energy efficiency. In recent years, there has been a large technological progress on indoor localization systems, but most of them present problems such as the time required in the calibration process, poor robustness or a high installation and equipment costs [4]. In addition, the user privacy is a key issue, and some sensors cannot be installed in Ambient Intelligent Environments (AIE) if current laws want to be obeyed. For instance, video cameras could not be used in offices. These problems cause localization systems to be unsuitable to be used in AIEs, where it is needed to have non intrusive, ubiquitous and cheap systems which do not need the installation of expensive hardware equipment. Furthermore, intelligent buildings would need that localization systems provide information about the identity of users, so that AIE can learn and manages to be adaptive towards the residents.

In this paper, we present a novel localization mechanism that integrates RFID (Radio-Frequency Identification) and IR (Infra-Red) data to solve technical drawbacks of RF and non RF-based localization techniques [5], so our solution meets the accuracy, cost and complexity requirements given our localization problem. It also solves the non-intrusive identification problem by using cheap technologies. In addition, this paper describes an exhaustive theoretical study of the transmission power looses problem when location sensors are used in indoor environments, so that propagation models help us to implement a robust tracking mechanism.

We show the evaluation of our system in both a simulated environment and a real scenario. Firstly, the theoretical results obtained by simulation are detailed, which shows that our location system performs quite good according to the needed accuracy. This evaluation is carried out using the radio planning software tool *Radiogis* [6]. Furthermore, an evaluation in a real scenario is shown. This is located in a test lab inside our reference building, the Technology Transfer Center of the University of Murcia (http://www.um.es/otri/?opc=cttfuentealamo), which was designed as a smart environment since the early stages of design. The results obtained in real experiments support the good performance reflected in the simulations.

The structure of this paper is as follows. Section II presents the problem formulation, with the theoretical analysis of the problem and configuration decisions made for the tesbed. Section III explains the details of the localization mechanism proposed. Section IV shows the results obtained after applying this mechanism in simulated and real scenarios. Finally, conclusions and future works are included in section V.

II. Problem Formulation

The main objective of context-aware systems is to acquire and use context information through a set of devices or sensors to provide services in accordance with the user, place, time and detected events. Location plays an important role in many applications based on the context. For the different services offered it is often useful to know the amount and location of residents, and their identities to achieve personalized services.

There are a lot of developed methods to solve the location problem. These can be classified into RF-based techniques and non RF-based techniques. The latter include audio, visual, ultrasonic, infrared, and laser sensors, whereas the RF-based localization techniques are mainly based on GPS, wireless local area network (WLAN), and RFID localization. By nature, the RF signals have certain advantages over non-RF signals, as it is collected in [5].

Depending on the accuracy need by the final application, a different technological solution should be chosen. For example, for small scenarios where a location system with a room accuracy is enough, it could be used the Received Signal Strength Indication (RSSI) of RF sensors. However, in emergency situations, for example in evacuation planning in case of fire, it would be necessary a positioning system that provides an accuracy lower than 1.5 meters.

Since each location algorithm has its advantages and its disadvantages in terms of accuracy, cost and complexity, the integration of several of these algorithms should improve the overall system performance. Due to this, and given that our system provides various services with different requirements in terms of accuracy, this paper researches on a hybrid solution that includes location information from different sources and uses smart data fusion algorithms to process it.

Maintaining an updated image of the operation environment is essential in the localization system designed. In order to offer our service of comfort and energy efficiency in a future, firstly it is necessary that the location mechanism can locate a user among the various areas of the building. The comfort service provides HVAC and lighting management, both designed to meet the needs of an inhabitant inside a limited area. The architecture of our system has been setup for a level of service by regions, lighting is provided as a service greatly customized for each $1.5m^2$ and climate control has been established as a service customized for each $4m^2$. Then, the positioning needs, in terms of accuracy of the location, is given by about $1.5m^2$.

Previous works use RFID technology for indoor localization [7], [8]. The relatively low cost of RFID technology makes this solution a popular candidate to deal with localization and tracking needs. Furthermore, RFID systems solve the privacy problem avoiding the common intrusion problem of the cameras. The power transmitted from the RFID tag to the reader can be expressed as (1) shows, also called the Friss equation [9]:

$$P_{rec} = PIRE \cdot G_{reader} \cdot \left(\frac{\lambda}{4\pi d}\right)^2 \qquad (1)$$

In (1), λ is the wavelength of the carrier and d is the distance between the reader and the tag. But this model is a representation of the power considering free space. RFID systems are NLOS (Non Line of Sight) communication systems, therefore that are influenced by signal reflections due to obstacles, attenuations, absorptions, etc. The Friis transmission equation is a good approximation to simplify the analysis and simulation of the location problem, however realistic indoor scenarios present a challenge for researches, due to the vast number of objects that block signals. This is one of the main problems presented in many studies that address the problem of indoor location.

In this paper a theoretical study of the RFID power distribution in an indoor environment has been performed using the radio planning software tool *Radiogis*. The propagation model used to simulate the RFID signals transmission indoors is based on the application of geometrical optics (GO) and Uniform Theory of Diffraction (UTD) using ray tracing techniques [10]. With this method it can be predicted the electric field created by direct, reflected and diffracted contributions of RFID signals.

Location technologies based on RFID can be classified into four categories [11]: tag-based, reader-based (which ignore the transceivers) and hybrid. Our location mechanism is based on a mix of RFID and Infrared data, thus the problem of low accuracy of RFID algorithms due to signal block is mitigated with the support of non RF-based information. Our system is based on reference tags, these tags are located at a distance of one meter among them, with this configuration the results obtained, in terms of accuracy, can be compared with the results indicated in [7].

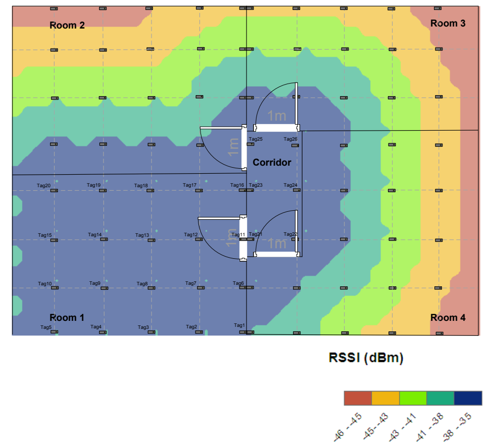
If the theoretical distribution of the received power at a RFID reader installed in a free space environment is compared with the received power in an environment where reflection, diffraction and absorption are present, it can be seen that signal losses are quite different. Figure 1 shows an example of these differences.

In this theoretical study, the transmission power by all the reference RFID tags placed at Room 1 and at corridor is simulated using *Radiogis*. Analysing the results, we can see how in the case of free space, the power losses are mainly due to the distance between the reader and the tags. In contrast, when reflections and diffractions are considered, it can be noted that there are some power points more evident than for the free space case. This is due to the contribution of reflected and/or diffracted rays, together with the components in the main direction, while in other points less power is obtained due to the losses assumed by the reflections and/or absorptions of the walls, floor, etc. For both propagation models, when a tag is close to the reader, the power level changes less than when it is placed in remote regions, nevertheless, when the distance grows, it is in the second model where losses by reflection becomes more important.

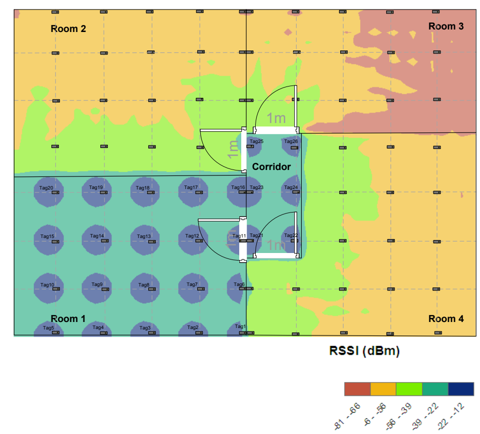
An extra problem for these location systems are dynamic environments where the simple presence of a new obstacle can vary the power received at the reader dramatically [11]. Our work deals with this issue, betting on data fusion algorithms better suited to the conditions stated. Since RFID and IR are used together, our localization system compensates the disadvantages of using a RF solution, much more exposed to the previous problem. Our system uses a single RFID reader with a coverage of 100 meters under ideal conditions. In many RFID location-based works it is common to use information from multiple RFID readers, thus a greater robustness is ensured because beaconing information comes from multiple sources. However, in the current work a single RFID reader is used in order to reduce the cost, therefore location robustness is offered by a mechanism that combines RFID and IR data, and the number of devices needed is optimized due to the theoretical study performed.

Then, our problem is solved with a single active RFID system and some low cost IR transmitters. IR transmitters provide us information related to which region a target tag belongs. In this way, RFID technology provides cost and identification advantages, while the IR technology provides stability to the localization mechanism.

In Figure 2 the RSSI values given in dBm regards to the power received at the RFID reader. Accoding to the RSSI values distribution, a space division can be done.



(a) RFID power distribution in free space.



(b) RFID power distribution considering geometrical optics and uniform theory of diffraction.

Figure 1. RSSI distribution given two different propagation models.

Once it is known the region to which a monitoring tag belongs, it must be determined its position using the information related to the reference tags. For this purpose, a mechanism is implemented based on the RSSI values, and the problem of the great dynamism of indoor scenario is solved using the IR data and an adaptive mechanism that takes into account changes in the environment.

The localization algorithm integrates a deterministic classifier that chooses the reference tags used to estimate the position of the monitoring tags. Once estimated the target positions, it is applied a probabilistic method that estimates the next position of the target following in this way a realistic motion model.

For the classifier design, a radial basis function (RBF) network has been implemented using the power values of the reference tags as the RBF centers [12], and a particle filter is used as a probabilistic technique to monitor the target object position [13] and estimate parameters of the motion model.

This location mechanism is able to solve the environment

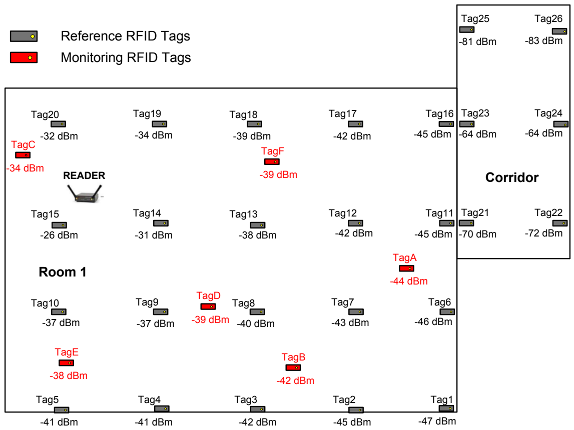


Figure 2. RSSI values obtained from the RFID reader point of view

dynamism problem.The RBF network provides us information about environments anytime.

III. Indoor Localization Mechanism

The localization scheme introduced in the previous section considers that the RFID reader processes many RSSI values that are updated every several seconds, hence the dynamics of the environment can be modeled in each new update. The location model is easily trainable to simulate the relationship between the RSSI values and the objects position.

A tracking mechanism based on the RSSI values is implemented. The input space X is the vector of RSSI values in the reader. These data can be denoted as:

$$X \in R, X = \{x_i\}, \forall x_i = \left[x_1, x_2, \ldots, x_n\right] \tag{2}$$

Where n is the number of reference tags within the chosen subarea. The target class Y represents the positions of the reference tags. This is denoted as:

$$Y \in R^k, Y = \{y_i^k\}, \forall y_i^k = \left[y_1^k, y_2^k, \ldots, y_n^k\right] \tag{3}$$

Where k is the dimension of the position of the reference tags. In our case we assume a value of $k = 2$, then given the training values $\{(x_i, y_i^k), \ldots, (x_n, y_n^k)\}$, our goal is to find a function that let us classify the tracking tag position knowing the RSSI tag values.

Artificial Neural Networks (ANN) [**?**] provide an alternative solution to the location problem. Localization can be viewed as a function approximation problem. ANN exploit the reference tags RSSI database to approximate the function that maps the reference information from the signal space to coordinates in the plane by interpolating the collected data. Radial Basis Function (RBF) is a special class of ANN. The underlying RBF architecture is scalable and can be easily applied to different RFID system setups, in which a variable number of RFID readers or reference tags (fingerprints) may be available.

The input vector x is provided as input to all functions of our RBF classifier, and the output $f(x)$ is given by:

$$f(x) = \sum_{i=1}^{c} w_i \cdot \varphi(\| x - c_i \|) \tag{4}$$

Where $\| x - c_i \|$ is the Euclidean distance between x and the RBF function with center c_i. The number of RBF is C, and w_i are the weights of the network. Gaussian radial basis are usually used to represent the RBF. However, other types of functions are common, such as thin-plate splines, multi-quadratic, linear polynomial bi-harmonic splines, quadratic tri-harmonic splines. The poly-harmonic splines are softer, and we use these functions for our RBF network:

$$\varphi(\| x - c_i \|) = \| x - c_i \|^{\beta} \log(\| x - c_i \|) \tag{5}$$

The proper value for C and the centers c_i are not trivial. These values affect the performance of the RBF network. A common practice is using each reference RSSI value to define the centers, so if there are L reference tags, there are L basis functions. However, this architecture has high memory requirements when there are a lot of reference fingerprints and when there are more than one RFID reader. In these cases, computational complexity is high both for the calculation of w_i and location estimation. In our problem, the number of reference tags and RFID readers is low, therefore there are no problems related to computational complexity, and it is possible by using the reference RSSI data as center of our basis function. For this reason, our system has a unique solution and the RBF design guarantees the exact fitting for all reference data. Our resulting RBF is small enough, easy to train, has good localization performance and avoids over-fitting.

Every T seconds, it is evaluated whether there are sensor data to estimate the target position using the RBF network. If there is updated information, the RBF is applied to perform the estimate, but if it is not the case (loss of signal, different sampling time of RFID system), our particle filter is applied to estimate the next position based on the prior state. A particle filter is a powerful tool for the treatment of real world problems, avoiding any assumptions about intrinsic features of the process. Using this tracking technique the uncertainty about the sensor data is dealt.

To use the particle filter, first the particle set is initialized uniformly. Then all particle positions are updated according to the motion model. In our case we consider a movement in the space (x, y) that follows a random walk model to represent human motion.

Combining these two algorithms, a radial basis function network and a particle filter, a good estimate of the monitoring target position is obtained, with an error lower than $1.5m$ and, at the same time, statistical values of velocity are provided continuously, which are used to determine the user activity and adapt comfort services according to the residents behavior.

IV. Results

We use the Radiogis tool to simulate the RFID signal behavior indoors. It provides the value of the RFID signal power exchanged between each tag and the RFID reader, taking into account phenomena as reflection, diffraction, absorption, etc on the walls. The following tests allow us to determine the minimum number of IR transmitters per room that allow the localization mechanism to operate with an error lower than $1.5m$. The simulation results are presented in terms of accuracy and percentage of success cases.

The RFID system simulated is based on a real system in which the active RFID tags start the communication with the RFID reader sending their data each 10 seconds. The transmission power of RFID tags is 28 μW, and the RFID reader has two radio channels, one of them with a maximum sensitivity of -58 dBm and the other one with -108 dBm, like this it is possible configuring different ranges of detection.

First of all, it is necessary to determine the minimum number of IR transmitters that meets the accuracy requirements (i.e. an error lower than $1.5m$), therefore we compare the simulation results obtained using one IR transmitter per room with those obtained using two transmitters per room.

Using Radiogis we generate the tracks that represent the motion of an object in the space. According to these tracks, the error in the position estimation related to the location mechanism proposed is then calculated. Table I summarizes the results for the simulated problem. It describes the ratio of success and the error values obtained by using one and two IR transmitters per room.

Table I
Simulation Results given two scenarios

	1 IR transmitter/room	2 IR transmitters/room
Min error (m)	0.004	0.005
Max error (m)	3.97	1.73
Mean error (m)	0.83	0.48
Median error (m)	0.64	0.41
Std error (m)	0.71	0.32
Success (%)	87.68	99.6

From the results, the best performance is obtained using two IR transmitters per room, i.e. splitting the room into two regions. With this space configuration and using only a RFID system and one IR transmitters per maximum area of $9m^2$ (according to the specified coverage of the IR transmitter), simulation results show that our localization mechanism achieves: a performance of 99.6% of successful cases, i.e. the 99.6% of the estimated positions have an error lower than $1.5m$, good results in target tracking, non-intrusive identification, optimum number of sensors installed, and a cheap technological solution.

Using two IR transmitters per room bigger than $9m^2$, an evaluation of the developed tracking mechanism is performed in a real scenario, specifically in a test lab of the Technology Transfer Center at University of Murcia (Figure 3). This space is designed to provide smart services (such as lighting and HVAC control) using the location mechanism detailed in this paper.

Table II includes the results obtained in this case of study. At first glance it is clear that localization in real scenarios presents signal propagation difficulties not considered in simulations, such as signal reflections in walls, furniture or occupancy. These effects cause a lower performance if values are checked. A decrease in successful positioning cases is evident, but even so the obtained results are very promising, obtaining accuracy enough results for our service requirements. Furthermore, the track generated by our system are composed of the current position, movement velocity, the uncertainty about the position and velocity, and an unique identifier for the user. All these information can be used by our building system to provide smart services.

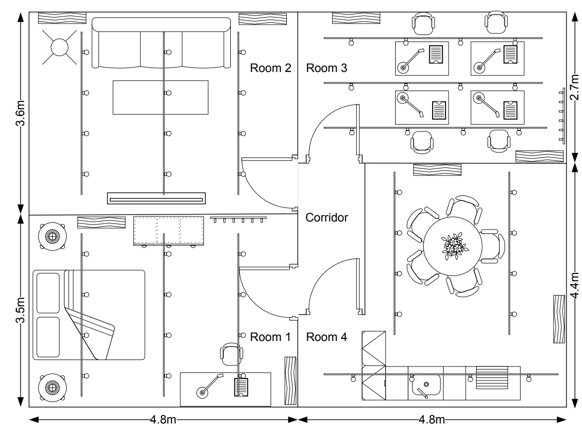


Figure 3. Test lab of the Technology Transfer Center at UM

Table II
Results of a real test

	2 IR transmitters/room
Min error (m.)	0.014
Max error (m.)	2.15
Mean error (m.)	1.02
Median error (m.)	0.87
Std error (m.)	0.66
Success (%)	77.77

V. Conclusion and Future Work

This article addresses the problem of indoor localization and identification using non intrusive technology. A theoretical study of the RFID power distribution in an indoor environment has been performed. This study researches on the phenomena that affect the accuracy of position estimation when RF localization is tackled. On the basis of that, a hybrid RFID/IR solution is proposed to get better results by data fusion and probabilistic techniques. Our localization mechanism is able to meet the accuracy requirements of most indoor pervasive services using a single RFID system and a minimum number of IR transmitters.

To design our classifier, a radial basis function network is implemented using the power values of the reference tags as the RBF centers, and a particle filter is used as a probabilistic technique to monitor the target object position and thus, it is able to estimate new states according to current system model and noise. The proposed mechanism has been tested in both simulated and real scenarios, with satisfactory results, providing a 77.7% of success in estimating positions with an error lower than $1.5m$.

Predicting user motion during long periods is an interesting issue. For the moment it is assumed that the motions follow a determinate motion patterns, a random walk model. In future works, our motion models will be generalized to subsequently predict advanced user behavior patterns. In this way our future intelligent control system will be able to better determine the activity level of inhabitants to provide an enhanced context-awareness.

ACKNOWLEDGMENT

This work has been sponsored by the Seneca Foundation, by means of the Excellence Researching Group Program “04552/GERM/06“ and “15493/FPI/10“.

REFERENCES

[1] D. Petersen, J. Steele, and J. Wilkerson, “Wattbot: a residential electricity monitoring and feedback system,” in *Proceedings of the 27th international conference extended abstracts on Human factors in computing systems*. ACM, 2009, pp. 2847–2852.

[2] J. Pargfrieder and H. Jorgl, “An integrated control system for optimizing the energy consumption and user comfort in buildings,” in *Computer Aided Control System Design, 2002. Proceedings. 2002 IEEE International Symposium on*. IEEE, 2002, pp. 127–132.

[3] M. Stunder, P. Sebastian, B. Chube, and M. Koontz, “Integration of real-time data into building automation systems,” Air-Conditioning and Refrigeration Technology Institute (US), Tech. Rep., 2003.

[4] H. Liu, H. Darabi, P. Banerjee, and J. Liu, “Survey of wireless indoor positioning techniques and systems,” *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, vol. 37, no. 6, pp. 1067–1080, 2007.

[5] J. Zhou and J. Shi, “Rfid localization algorithms and applications, a review,” *Journal of Intelligent Manufacturing*, vol. 20, no. 6, pp. 695–707, 2009.

[6] P. Juan, F. Javier, M. García-Pardo, J. María, J. Rodríguez Rodríguez, and L. Llácer, “Ragis: herramienta de gestión y de cálculo de cobertura radioeléctrica basada en sistemas de información geográfica,” *Revista AHCIET: revista de telecomunicaciones*, no. 101, pp. 8–5, 2005.

[7] L. Ni, Y. Liu, Y. Lau, and A. Patil, “Landmarc: indoor location sensing using active rfid,” *Wireless networks*, vol. 10, no. 6, pp. 701–710, 2004.

[8] C. Lu, C. Liao, C. Wu, and L. Fu, “Real-time fine-grained multiple-target tracking on an extensible virtual fab architecture using multi-agents,” *International Journal of Electronic Business*, vol. 5, no. 1, pp. 37–47, 2007.

[9] T. Sarkar, Z. Ji, K. Kim, A. Medouri, and M. Salazar-Palma, “A survey of various propagation models for mobile communication,” *Antennas and Propagation Magazine, IEEE*, vol. 45, no. 3, pp. 51–82, 2003.

[10] C. Oestges, B. Clerckx, L. Raynaud, and D. Vanhoenacker-Janvier, “Deterministic channel modeling and performance simulation of microcellular wide-band communication systems,” *Vehicular Technology, IEEE Transactions on*, vol. 51, no. 6, pp. 1422–1430, 2002.

[11] L. Ni, D. Zhang, and M. Souryal, “Rfid-based localization and tracking technologies,” *Wireless Communications, IEEE*, vol. 18, no. 2, pp. 45–51, 2011.

[12] C. Laoudias, P. Kemppi, and C. Panayiotou, “Localization using radial basis function networks and signal strength fingerprints in wlan,” in *Global Telecommunications Conference, 2009. GLOBECOM 2009. IEEE*. IEEE, 2009, pp. 1–6.

[13] R. Van Der Merwe, A. Doucet, and N. De Freitas, “The unscented particle filter,” *Advances in Neural Information Processing Systems*, pp. 584–590, 2001.

[14] H. Simon, *Neural networks: a comprehensive foundation*. Prentice Hall, 1999.