TAMPERE UNIVERSITY OF TECHNOLOGY

Hybrid WLAN-RFID Indoor Localization Solution Utilizing Textile Tag

Citation
Hasani, M., Talvitie, J., Lohan, E-S., Sydänheimo, L., & Ukkonen, L. (2015). Hybrid WLAN-RFID Indoor Localization Solution Utilizing Textile Tag. *IEEE Antennas and Wireless Propagation Letters*, *14*, 1358-1361. https://doi.org/10.1109/LAWP.2015.2406951

Year
2015

Version
Early version (pre-print)

Link to publication
TUTCRIS Portal (http://www.tut.fi/tutcris)

Published in
IEEE Antennas and Wireless Propagation Letters

DOI
10.1109/LAWP.2015.2406951

Copyright
©2015 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other users, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works for resale or redistribution to servers or lists, or reuse of any copyrighted components of this work in other works.

Take down policy
If you believe that this document breaches copyright, please contact cris.tau@tuni.fi, and we will remove access to the work immediately and investigate your claim.

Download date:20.04.2021

Hybrid WLAN-RFID Indoor Localization Solution Utilizing Textile Tag

Masoumeh Hasani, *Student Member, IEEE,* Jukka Talvitie, Lauri Sydänheimo, *Member, IEEE,* Elina-Simona Lohan, *Senior Member, IEEE,* Leena Ukkonen *Member, IEEE,*

***Abstract*—This paper presents a novel hybrid configuration for indoor positioning, utilizing the passive Radio Frequency Identification (RFID) and Wireless Local Area Network (WLAN). Our architecture is based on a mobile device with a WLAN receiver, a textile RFID tag and one or several RFID readers communicating with the mobile. The proposed passive textile RFID tag provides a very cost effective, power efficient and easy-implemented solution for human positioning and tracking applications. In addition, the joint utilization of two technologies increases the accuracy of the indoor positioning service. Our main contribution comes from the innovative RFID-WLAN hybrid architecture based on Received Signal Strengths and able to improve the localization accuracy compared to pure RFID and pure WLAN location solutions. The proposed algorithm is tested with real-field measurements.**

***Index Terms*— Backscattered power, fingerprinting, indoor positioning, RFID, Received Signal Strength (RSS), Wireless Local Area Networks (WLAN).**

I. Introduction

THE indoor localization with low complexity and high accuracy is one of the main challenges in today's wireless world. Most promising technologies to be used indoors are currently based on WLAN solutions [1][2][4][5][8][9]. Alternative solutions have been proposed based, for example, on infra-red light, ultra-wide-band (UWB) systems, Bluetooth, and RFID [6][7]. It is well understood that a low complexity can be achieved when using easily accessible information, such as Received Signal Strength (RSS) and many indoor localization solutions are based on RSS [4][6][7][8][9]. The main challenges remain in achieving the best possible accuracy with the available signals, and this is the part we investigate in here, assuming that the available signals are the WLAN and RFID signals. Indeed, the RFID technology has become increasingly popular over recent years for tracking and positioning applications in indoor environments, as a cost-effective and power efficient solution which can be installed easily on the different object or people.

The synergical use of WLAN and RFID positioning has been very scarcely addressed in the current literature so far. One example where this problem is tackled can be found in [1]. In [1], the mobile device was assumed to be equipped with both a WLAN receiver and an RFID reader and several passive RFID tags were placed inside a room. The RFID backscattered powers from the tags were only used as an indicator of the zone where the mobile was placed, and the position estimation was purely based on WLAN RSS fingerprinting, applied in the zone identified by the RFID tags. Pure RFID-based localization was not studied, neither included in the comparisons provided in [1].

The results published in [11] shows that the channel modeling based on the RFID measurements are very promising. Moreover, the standard deviation of shadowing even shows more stability of RFID measured data compared to the WLAN measurement. However, utilizing the pure RFID technology or pure WLAN has its own limitations [1]. In this work, we present a hybrid solution to increase the robustness and accuracy of indoor positioning systems especially in harsh propagation conditions. On one hand, using the textile RFID system provides high accuracy -within the limited distance- and easy-implemented solution for tracking people in indoor scenarios. On the other hand, a very good coverage can be achieved utilizing the WLAN. The novelty of our paper is two-fold: first, we propose a novel hybridization architecture based on RSS collected from RFID and WLAN systems; and secondly, we compare the performance of the hybrid approach with the pure WLAN and pure RFID localization solutions, based on measurement data performed in a university room.

II. Measurement Setup

To prepare the database for the fingerprinting, the RSS measurements were carried out in one university room in Tampere, utilizing the RFID system and WLAN system. The RFID experiment has been done using wearable passive UHF RFID tag installed on the human arm. The measurement procedures are explained below in more detail.

A. Tag Fabrication

The wearable tag is easy to be integrated with clothing due to its flexible conductive materials (electro-textile). Thus it is a great solution for monitoring human movement and tracking. In addition, it can provide a reliable and efficient wireless communication link between the body-worn electronics and surrounding environment. The utilized sample for the measurement is a simple dipole UHF passive RFID tag

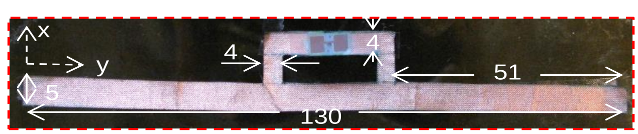


Fig. 1. The textile passive UHF RFID tag.

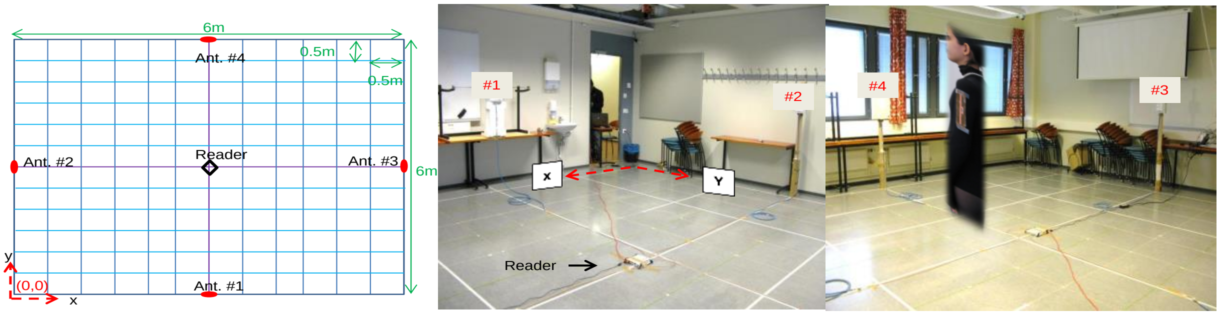


Fig. 3. The lef picture shows the schematic of the measurement region. The deployed experiments showed in the right pictures.

fabricated by electro-textile. As it is shown in Fig. 1, the dipole is a copper fabric which is applied on top of a polyimide based thin substrate. The commercial NXP G2iL chip is glued to the fabric using conductive epoxy.The tag has been designed for the frequency 850 – 690 MHz and the read range of the tag in free air measurement is about 8 meters. More detail about the electrical properties of the copper fabric and the tag design is available on [10].

B. Data Collection Using RFID Tag

The RSS measurements were performed in an indoor area. As it is illustrated in Fig. 2, a square region (6 m × 6 m) has been divided to 144 smaller areas (0.5 m × 0.5 m). The x and y coordinate including 13 measurement points, respectively, are marked in the picture. To have a good coverage in the room, four readear antennas were placed in each center edges of the square area. The antenna placement was done following an optimization process, while trying to maximize the overall coverage of all readers. The antennas are connected to an RFID Speedway Impinj reader that is placed in the center of the square. The Impinj reader, including four antenna ports, is capable of communicating with all four antennas simultaneously. The reader is adjusted to the ETSI frequency. In addition, the redear is connected to the computer through the LAN connection for storing the scanned data. The maximum transmitted power of the Impinj reader is about 30 dBm. To not exceed the EIRP (equivalent isotropically radiated power), the transmitted power for the measurement is adjusted to the 28 dBm with respect to the loss of the cables and gain of the antennas. The copper fabric tag has been installed on the human arm in vertical polarization since the reader anteenas are vertical polarized.

However, for a practical implementation of our proposed hybrid solution, we would need a WLAN connection from the reader to the mobile device. In here, we prove that an RFID-WLAN localization solution with wearable tags is fully feasible, but we do not offer the full commercial architecture. The recommended architecture is shown later in Fig. 5 (b).

The tag backscattered power measurement is performed by moving the person between all 169 measurement positions. This measurement has been repeated 4 times facing one specific antenna each time to be able to compare the results with similar orientations in the training and estimation phases and with different antenna orientations in these phases (the latter case being the most likely one in a commercial implementation). The same type of measurements in 42 random coordinates is also conducted for the estimation phase, several times. The block diagram of the pure RFID location solution is shown in Fig. 3 (a).

C. WLAN Data Collection

The data collection for the WLAN was done similarly with [2][3]. In the same measurement room as above, the WLAN data have been collected utilizing a Nexus tablet with HERE maps. The tablet had software capable of reading the destination map and converting it to the Cartesian coordinates. During the data collection, the position on the map is manually added and the RSS values from multiple Access Points (AP) at that point are read. The measurements were taken at the same coordinates as for RFID to enable the hybridization. The pure WLAN positioning solution shown in Fig 3 (a) is based on traditional fingerprinting with Gaussian likelihood function [2][5].

III. Proposed Hybridization Algorithm

Our proposed hybridization architecture is shown in Fig. 3 (b). It has two stages: a training stage shown in the upper part, and an estimation phase, where the actual hybridization is done. In the *training (off-line) phase*, received signal strengths from WLAN AP or backscattered powers from RFID readers are collected and stored in $(x_i, y_{j,} F_{i,j}^{(ap)}, F_{i,j}^{(rf)})$ vectors, where $x_i, y_{j,}$ are the x and y coordinates of the grid point where the measurements were done, $F_{i,j}^{(ap)}$ is the RSS from the *ap*-th AP in $x_i, y_{j,}$ point, $ap = 1,...,N_1$, N_1 is the total number of AP heard in the training phase, $F_{i,j}^{(rf)}$ is the backscattered power heard by the *rf*-th RFID reader in $x_i, y_{j,}$ point, $rf = N_1 + 1,..., N_1 + N_2$, and N_2 is the total number of RFID readers (in our case, $N_2 = 4$). Our convention is that the last N_2 RSS values belong to the RFID signals, so that we can tackle jointly the WLAN and RFID measurements. Also, if an AP is not heard in a certain point, the convention is that $F_{i,j}^{(ap)}$ has a dumb (NaN) value.

Table 1 illustrates the characteristics of the measured environment, in terms of the mean and maximum ranges at which a transmitter is heard, the minimum, maximum and average number of heard transmitters in each measured point inside the room, and the estimated shadowing standard deviation, based on the training data. The shadowing standard

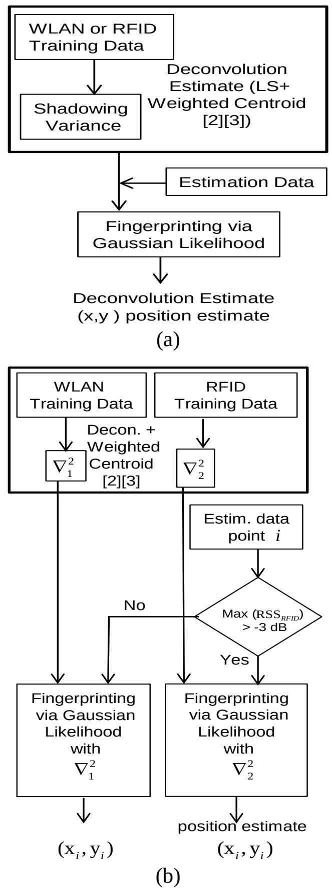


Fig. 3.(a) Pure RFID/Pure WLAN location. (b) Proposed Hybrid RFID-WLAN positioning algorithm.

deviation is computed via path-loss modeling with deconvolution estimation, based on [2].

In the *estimation (on-line) phase*, the following values are measured: $(R^{(ap)}, R^{(rf)}),\ ap = 1,...,N_1,\ rf = N_1+1,...,N_1+N_2$ where $R^{(ap)}$ is the RSS measured from the *ap*-th AP, and the $R^{(rf)}$ is the backscattered power measured at the *rf*-th reader. Again, a transmitter which is not heard is signaled by a NaN value. The mobile position is computed based on the following Gaussian probabilities:

$$p_{i,j}^{(1)}(R^{(ap)}) = \sqrt{\frac{1}{2\pi\sigma_1^2}} \exp\left(-\frac{\left(R^{(ap)} - F_{i,j}^{(ap)}\right)^2}{2\sigma_1^2}\right), ap = 1,...,N_1 \quad (1)$$

$$p_{i,j}^{(2)}(R^{(rf)}) = \sqrt{\frac{1}{2\pi\sigma_2^2}} \exp\left(-\frac{\left(R^{(rf)} - F_{i,j}^{(rf)}\right)^2}{2\sigma_2^2}\right), rf = N_1+1,...,N_1+N_2. \quad (2)$$

Above, $p_{i,j}^{(1)}(R^{(ap)})$ is the probability to be in $x_i, y_{j,}$ point if the RSS value $R^{(ap)}$ was heard from the *ap*-th AP, σ_1^2 is the WLAN shadowing variance, obtained from the training data, $p_{i,j}^{(2)}(R^{(rf)})$ is the probability to be in $x_i, y_{j,}$ point if the value $R^{(rf)}$ was heard at the *rf*-th reader, and σ_2^2 is the RFID shadowing variance, obtained from the training data. A decision is taken based on the joint cost function $\Upsilon_{i,j}$, via: $(\hat{x}_i\ \hat{y}_i) = \max_{x_i, y_j} \Upsilon_{i,j}$, with:

TABLE 1. ENVIRONMENT STATISTICS, BASED ON MEASURED DATA.

	Max range [m]	***Mean range [m]***	***Min Nr. of heard APs/ Readers per point inside the room***	***Max Nr. of heard APs/ Readers per point inside the room***	***Mean Nr of heard APs/ Readers per point inside the room***	***Shadowing standard deviation [dB]***
RFID(1)	6.70	3.85	0 (42.31% cases)	3	1.17	1.94
WLAN(2)	74.4	10.96	16	26	21.71	2.31

(1) The RFID statistics are room-based and using the true Reader positions (known)

(2) The WLAN statistics are building-based and using the estimated AP positions via the weighted centroid approach [3].

$$\Upsilon_{i,j} = w_1 \sum_{ap=1}^{N_1} p_{i,j}^{(1)}(R^{(ap)}) + (1 - w_1) \sum_{rf=N_1+1}^{N_1+N_2} p_{i,j}^{(2)}(R^{(rf)}) \quad (3)$$

and the weights defined adaptively as:

$$w_1 = \begin{cases} 1 & \max\limits_{ap=1}^{N_1}\left(R^{(ap)}\right) - a > \max\limits_{rf=N_1+1}^{N_1+N_2}\left(R^{(rf)}\right) \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

a is an optimization parameter, which selects the threshold between using RFID or WLAN-based estimates. The optimization of a is illustrated in Fig. 4, based on the distance Root Mean Square Error (RMSE) as the optimization criterion. The optimization of a was done with a different set of estimation data than that one used in Fig. 5 and Table 2. It was found that $a = 2$ dB gives the best results, meaning that we trust the RFID positioning as long as the RFID signal strength is higher than the WLAN signal strength with a 2 dB margin.

The results of the hybridization algorithm (Fig.3), compared with pure WLAN and pure RFID positioning are shown in Fig. 5 and in terms of the cumulative distribution function of the distance error and of the percentage of estimated track points with a distance error below 2 m, respectively. In Fig.5 we show what happens when only N out of the four RFID readers are used, N=1,…4. Clearly, more RFID readers are available, the better the accuracy of the location solution. The pure RFID solution is unable to offer a position estimate in 40 to 80% of the cases (depending whether we use 4 or less RFID readers), and this is because the reader range is limited, and there are many points inside the room where no backscatter power reaches the readers. On the other hand, a pure WLAN positioning solution can always offer a position estimate. Pure RFID solutions are indeed slightly better at very low distance errors (lower than 1m), but this kind of small errors are achieved with a low probability. Table 2 illustrates the probabilities (given as percentages) of achiving a distance error less than 2 m with any of the considered algorithms.Hyrid RFID-WLAN solutions are clearly the best, even with only one RFID reader. The results clearly show the benefits of a hybrid RFID-WLAN architecture, benefits which can be incorporated in a commercial architecture as illustrated in Fig 5 (b).

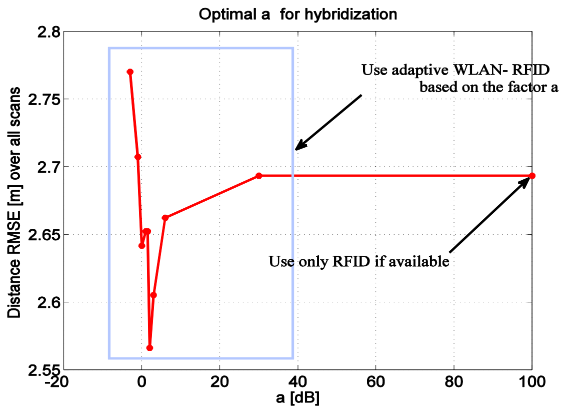


Fig. 4. Optimization of the hybridization parameter *a*.

IV. Conclusion

In this paper, we have introduced a novel hybrid WLAN-RFID indoor localization solution. The hybrid solution is suitable for the indoor positioning in environments where both RFID and WLAN signals are available, since it takes advantage of both types signals. The textile passive RFID tag proposes very cost effective, easy implemented and efficient configuration for human tracking in harsh environments and it can be deployed for other purpose such as access control or patient tracking in health care applications. The presented configuration based on the hybrid model can be expanded for larger indoor area utilizing more RFID tag and readers, as illustrated in our design recommendation in Fig. 5 (b).

Our experimental results show that our hybrid solution can enhance the probability to get errors below 2 meters with several percents even if only one RFID reader is available, and that RSS coming from two different systems can be successfully combined towards a joint hybridization solution.

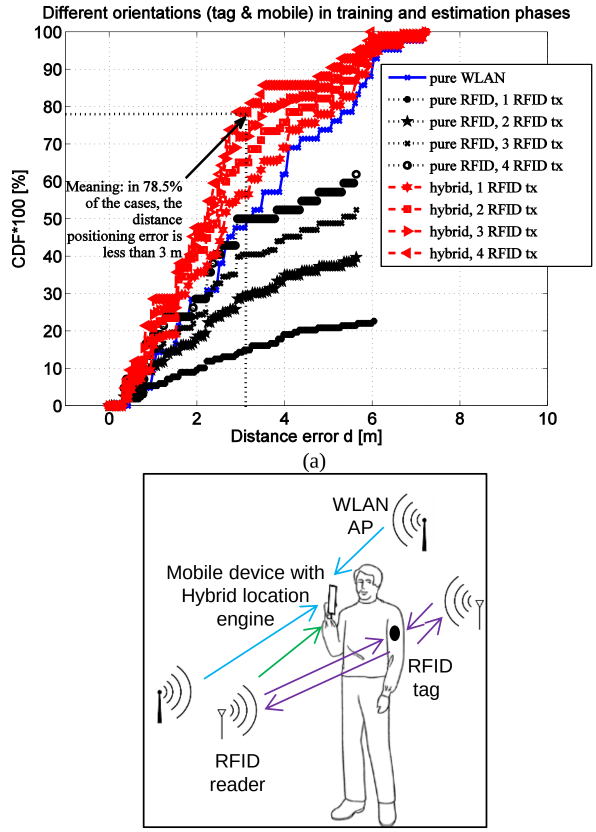
References

[1] S. C. Spinella, A. Iera, and A. Molinaro (2010, Mar.) On potentials and limitations of a hybrid WLAN-RFID indoor positioning technique, *International Journal of Navigation and Observation, Hindawi*,

[2] S. Shrestha, J. Talvitie, E. S. Lohan, "Deconvolution-based indoor localization with WLAN signals and unknown access point locations" in

Table 2. Percentage of estimated points with accuracy below 2 m

% of points with accuracy below 2 m	Same orientation of the mobile device in training and estimation	Different orientation of the mobile device in training and estimation
PureWLAN	48.25%	28.57%
Pure RFID with 1 RFID tx	13.49%	9.52%
Pure RFID with 2 RFID tx	25.00%	17.85%
Pure RFID with 3 RFID tx	33.53%	23.80%
Pure RFID with 4 RFID tx	41.26%	28.57%
Hybrid RFID-WLAN with 1 RFID tx	48.31%	39.45%
Hybrid RFID-WLAN with 2 RFID tx	52.44%	45.06%
Hybrid RFID-WLAN with 3 RFID tx	57.14%	49.48%
Hybrid RFID-WLAN with 4 RFID tx	61.50%	53.06%



(b)

Fig. 5. (a) Percentage of points where we attain an error smaller than a threshold, via pure WLAN, pure RFID and hybrid estimates. (b) Proposed hybrid RFID-WLAN architecture with passive RFID tags.

Proc. *IEEE International Conference on Localization and GNSS (ICL-GNSS)*, June 2013, Torino, Italy.

[3] E. S. Lohan, K. Koski, J. Talvitie, and L. Ukkonen "WLAN and RFID Propagation Channels for Hybrid Indoor Positioning" in Proc. *IEEE International Conference on Localization and GNSS (ICL-GNSS)*, June 2014, Helsinki, Finland.

[4] V. Honkavira, T. Perala, S. Ali-Loytty, and R. Piche, "A comparative survey of WLAN fingerprint methods," in Proc. 6th Workshop Position., Navigat., Commun. 2009 (WPNC'09), pp. 243–251.

[5] N. Le Dortz, F. Gain, and P. Zetterberg, "Wifi fingerprint indoor positioning system using probability distribution comparison," in Proc. IEEE Int. Conf. Acoust., Speech, Signal Process. (ICASSP), Mar. 2012, pp. 2301–2304.

[6] G. Yanying, A. Lo, I. Niemegeers, "A survey of indoor positioning systems for wireless personal networks," Communications Surveys & Tutorials, IEEE , vol.11, no.1, pp.13,32, First Quarter 2009, doi: 10.1109/SURV.2009.090103

[7] L. Hongbo, Y. Jie, S. Sidhom, W. Yan, C. Yingying, Y. Fan, "Accurate WiFi Based Localization for Smartphones Using Peer Assistance," Mobile Computing, IEEE Transactions on , vol.13, no.10, pp.2199,2214, Oct. 2014

[8] B. Wang, S. Zhou, W. Liu,Y. Mo, "Indoor Localization based on Curve Fitting and Location Search using Received Signal Strength," Industrial Electronics, IEEE Transactions on , vol.PP, no.99, pp.1,1, doi: 10.1109/TIE.2014.2327595, doi: 10.1109/TMC.2013.140

[9] S. Guoli, C. Jie, G. Wei, K. Liu, "Signal processing techniques in network-aided positioning: a survey of state-of-the-art positioning designs," Signal Processing Magazine, IEEE , vol.22, no.4, pp.12,23, July 2005, doi: 10.1109/MSP.2005.1458273

[10] K. Koski, E. Moradi, A. Vena, T. Bjorninen, L. Sydanheimo, L. Ukkonen, and Y. Rahmat-Samii "Characterization of Electro-textiles Using Wireless Reflectometry for Optimization of Wearable UHF RFID Tags", *PIERS Proceedings*, Aug. 2013.

[11] M. Hasani, E. S. Lohan, L.Sydanheimo, L.Ukkonen, "Path-Loss Model of Embroidered Passive RFID Tag on Human Body for Indoor Positioning Applications", *IEEE RFID-TA*, Sep. 2014.