Analysis of Indoor Positioning Approaches Based on Active RFID

Feng-juan Zhu, Zong-heng Wei, Bin-jie Hu
School of Electronic and Information Engineering
South China University of Technology
Guangzhou, China
Email: zfj030522@126.com

Jian-guang Chen, Zi-min Guo
The Radio Monitoring Centre of Guangdong Province
Guangzhou, China
Email:williamway2008@yahoo.cn

Abstract—**RFID technology is gaining much attention for indoor localization because of its advantages such as non-contact and non-line-of-sight nature. In this paper, we study two typical approaches using active RFID for indoor location sensing: LANDMARC and VIRE, and point out that the latter approach with a fixed threshold of Received Signal Strength Indication (RSSI) difference which determines the elimination of unlikely positions does not work well in complicated indoor environments with severe radio signal multi-path. Analysis of two important factors in VIRE directs us some improvements for adaptation to enhance the accuracy of indoor localization.**

Keywords: Indoor location; Positioning Algorithm; RFID

I. INTRODUCTION

With the large-scale deployment of the mobile computing device and the wireless network, more and more attentions have been paid to the location based service in indoor environments. Especially, it is useful for warehouse, hospital, fire fighting, police, or safety networks to locate the accurate position of objects. Several infrastructure-based systems are used for wireless indoor location [1]. Classical wireless technologies, like Global Positioning System (GPS), either unfeasible or too expensive, are unsuitable for use in indoor environments. Several solutions on the basis of RF technology, such as WLAN [2] [3], Bluetooth [4], GSM cellular network [5], and RFID [6] [7], are also well-known examples proposed for location estimation. One of the most common location metrics exploited by RF location approaches is the power of the RF signals exchanged among devices and antennas for their operation, generally referred to as Received Signal Strength Indication (RSSI). Due to several typical advantages with RFID location technology, i.e. no contact, non-line-of-sight nature, promising transmission range and cost-effectiveness, RFID systems are currently experiencing a fast growing interest in many application fields.

Our work aims at assessing the performance of location positioning approaches used in active RFID location systems based on RF power. Both the LANDMARC approach [6] and the VIRE approach [7] utilize the idea of having extra fixed reference tags to help location calibration. The LANDMARC approach uses an algorithm looking for the some nearest tags to calculate the coordinates of tracking tags, while the VIRE approach which employs the interpolation and the elimination algorithm can significantly improve the accuracy over the LANDMARC approach without additional cost. However, in complicated indoor environments the VIRE approach does not work well with a fixed threshold of RSSI difference, which determines the elimination of unlikely positions. This paper reviews the above two approaches and shows a comparison of them from system implementation and measurements. Then, we analyze the results of the VIRE approach and propose our new solutions.

II. REVIEW LANDMARC AND VIRE

A. LANDMARC

In detection range, both reference tags and tracking tags provide their ID to reader for identification. The readers are continuous reporting the tag's information that within the specified range. Suppose there are K readers along with m reference tags. Let S_i and θ_i denote the signal strength of the tracking tag and the signal strength of the reference tags received on the reader i , respectively, where $i \in (1, K)$, and $E_j = \sqrt{\sum_{i=1}^{K} (\theta_i - S_i)^2}$ indicates the location relationship between the reference tags and the tracking tag, where $j \in (1, m)$. When there are m reference tags in the detection range, the tracking tag has its $\vec{E}$ vector as $\vec{E} = (E_1, E_2, E_3, \cdots, E_m)$. Comparing the smaller $\vec{E}$ value, the nearest neighbors of the unknown tracking tag is found and the weighting factor of the neighboring reference tag is obtained. Therefore, the unknown tracking tag's coordinate will be found by using the nearest neighbor algorithm.

B. VIRE

It employs the concept of virtual reference tag based on the requirement of LANDMARC for a dense deployment of reference tags. The process of location estimation is divided into two steps below.

1) Virtual Grid coordinateDetermination: When the real reference tags are properly placed, a map of 2D regular virtual grids is easily set up by dividing each physical grid cell

This work was supported by the Guangdong Province Science and Technology Project (Grant No.2007A05100024) and the National Natural Science Foundation of China (Grant No.60671023).

covered by 4 real reference tags into $n \times n$ equal sized virtual grid cells with each virtual grid cell covered by 4 virtual reference tags, and hence the number of virtual reference tags equally placed between two adjacent real reference tags is $n-1$. Clearly, the coordinates of the virtual reference tags can be easily calculated. And the RSSI values of virtual reference tags to each reader are calculated by the linear interpolation algorithm. For the horizontal lines and the vertical lines, the RSSI values of virtual reference tags are interpolated by using (1) and (2) below, respectively.

$$S_h(T_{p,b}) = S_h(T_{a,b}) + p \times \frac{S_h(T_{a+n,b}) - S_h(T_{a,b})}{n} = \frac{p \times S_h(T_{a+n,b}) + (n-p) \times S_h(T_{a,b})}{n} \tag{1}$$

$$S_h(T_{a,q}) = S_h(T_{a,b}) + q \times \frac{S_h(T_{a,b+n}) - S_h(T_{a,b})}{n} = \frac{q \times S_h(T_{a,b+n}) + (n-q) \times S_h(T_{a,b})}{n} \tag{2}$$

where $S_h(T_{i,j})$ denotes the RSSI value of the virtual reference tag located at the coordinate (i, j) for the *h*-th reader. The values of parameters are $a = \lfloor i/n \rfloor$, $b = \lfloor j/n \rfloor$, $0 \le p(= i \bmod n) \le n-1$ and $0 \le q(= j \bmod n) \le n-1$

2) Elimination of Unlikely Positions: On the basis of virtual reference grids and the RSSI value of a tracking tag, a proximity map covering the whole sensing area can be established for each reader, and is divided into a number of regions, those of which are marked as '1' if the difference of RSSI values between the region and the tracking tag is smaller than a threshold. After obtaining K proximity maps from the K readers, an intersection function is applied to indicate the most probable regions from the K readers. An algorithm in [7] which can adaptively reduce the threshold will give the smallest area formed by the smallest threshold available.

When the interpolation and elimination processes are finished, the calculation of the coordinate of the tracking tag is related to two weighting factors W_{1i} and W_{2i} as follows:

$$W_{1i} = \sum_{h=1}^{K} \frac{|S_h(T_i) - \theta_h(R)|}{K \times S_h(T_i)} \tag{3}$$

where $S_h(T_i)$ and $\theta_h(R)$ denote the RSSI value of the *i*-th selected virtual reference tag and the RSSI value of the tracking tag perceived on reader *h,* respectively.

$$W_{2i} = \frac{p_i}{\sum_{i=1}^{n_a} p_i} = \frac{n_{ci}}{\sum_{i=1}^{n_a} n_{ci}} \tag{4}$$

where p_i denotes the ratio of conjunctive possible regions to the whole sensing area, n_{ci} is the number of conjunctive regions, and n_a is the number of total regions in the whole sensing area. The calculated coordinate of a tracking tag is given by

$$(x, y) = \sum_{i=1}^{n_a} w_i (x_i, y_i) \tag{5}$$

where $w_i = w_{1i} \times w_{2i}$.

III. SYSTEM IMPLEMENTATION AND EVALUATION

A. Experimental Setup

For comparing above two positioning approaches, we design experiments that work in two different environments: Env1 and Env2. Env1 is a council-chamber (Length, Width, and Height to be 6m×6m×2.55m), in which there is a council board being in the center, three cabinets and tens of office chairs against the walls. Env2 is a training room (Length, Width, and Height to be 13.8m×6.6m×2.55m), which is filled with office chairs and desks which are used for personnel training; especially there are two large concrete pillars and many desks heaped at the back of the room.

In the location model, the reference tags are properly placed to form a map of 2D regular grid and each physical grid cell is covered by 4 real reference tags. In Env1, we deploy 16 reference tags and 9 tracking tags according to the placement in Fig.1, and the *Spacing* between two adjacent tags is 1.2m. In Env2, we deploy 15 reference tags and 8 tracking tags according to the placement in Fig.2, and the *Spacing* between two adjacent tags is 2m. For both locales, we use 4 readers and they are placed in the four corners of the sensing area.

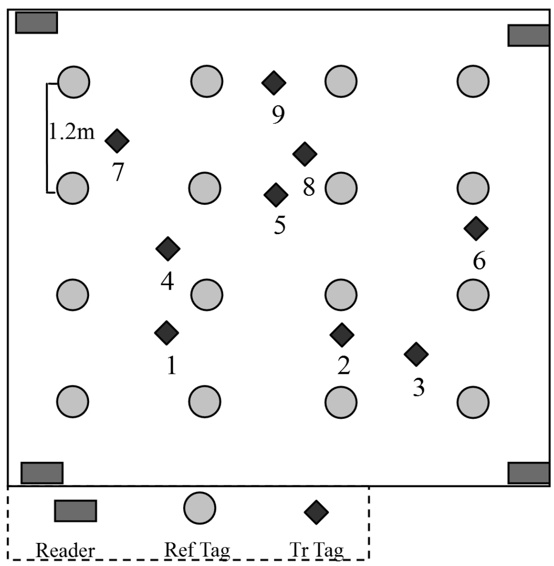

Figure 1. Placement of the tags and the readers in Environment1

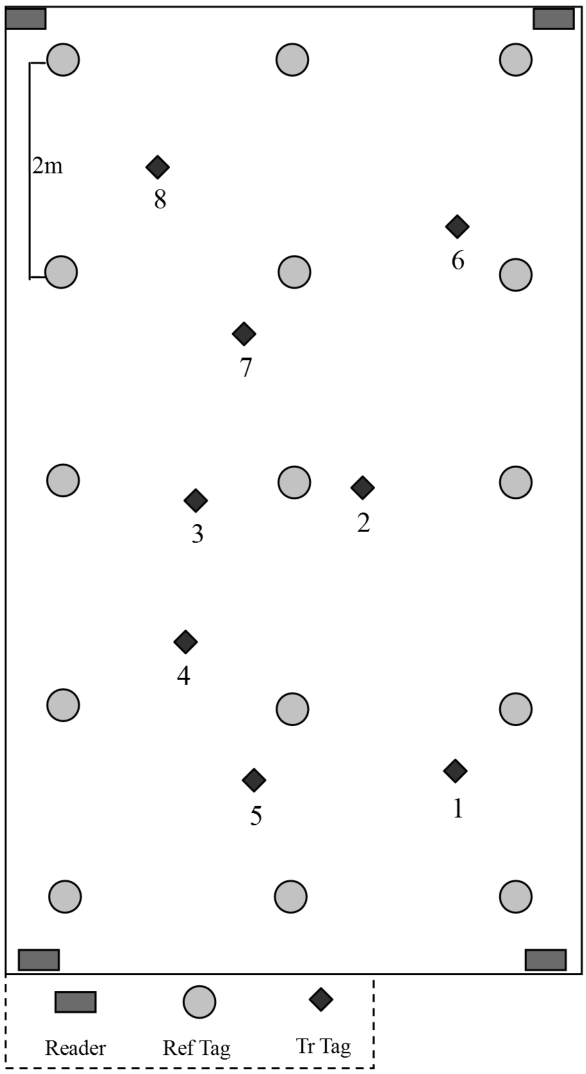

Figure 2. Placement of the tags and the readers in Environment2

B. Location Estimation

When implementing the LANDMARC, the parameter *k* (the number of the nearest tags) is chosen as *k*=4. In VIRE, the optimal values of parameters are chosen as in TABLE Ⅰ.

TABLE I. THE OPTIMAL CHOICES OF THE PARAMETERS IN VIRE

parameter	**Env1(Spacing=1.2m)**	**Env2(Spacing=2m)**
n	3	5
threshold	8	8

Fig.3 shows the relationship between the average estimation error of 8 tracking tags and the threshold for the case of Env2 with n=5. When the threshold is near 8, the estimation error is lowest. Fig.4 and Fig.5 show the location estimation error of the tracking tags in the two environments.

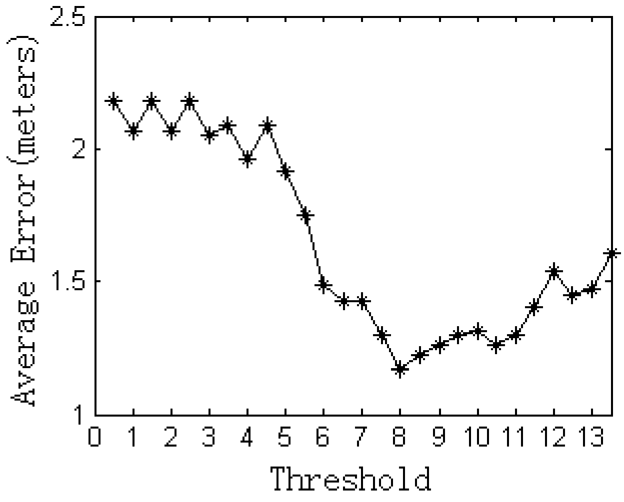

Figure 3. the Threshold vs. Accuracy in VIRE

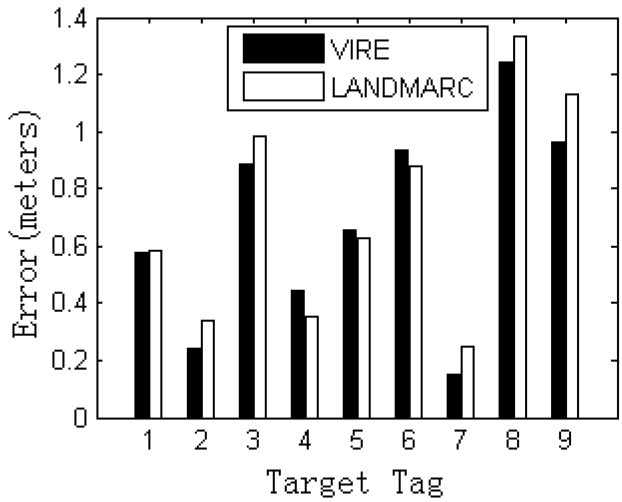

Figure 4. Estimation error of the tracking tags in Env1

Clearly the estimation error in VIRE for each tracking tag is not always less than the error in LANDMARC. In Env2, Tracking Tag 1, Tracking Tag 2 and Tracking Tag 7's estimation errors in VIRE are even worse than the estimation errors in LANDMARC. Even if we had adjusted the parameters *n* and *threshold*, no improvement could be achieved. The most possible reason for the problem will be analyzed in the following section.

IV. ANALYSIS

As we know from the VIRE approach, there are two important factors: the density of virtual reference tags and the threshold of RSSI difference in the elimination algorithm, which influence the location errors. It is easy to find out the appropriate value of the density of virtual reference tags, because when it exceeds a certain value the location error will nearly decrease to the minimum and no further improvement

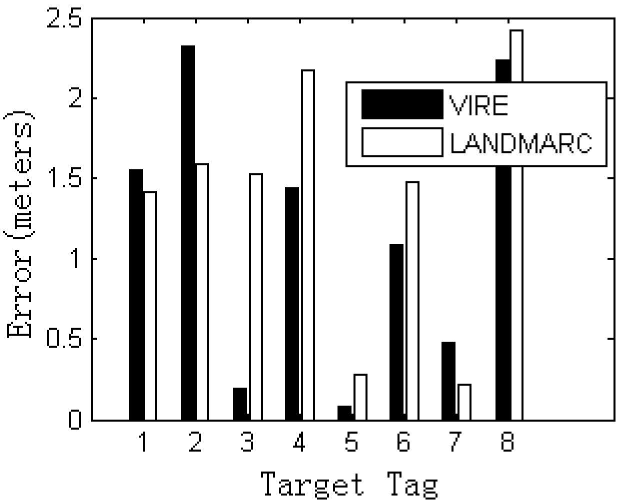

Figure 5. Estimation error of the tracking tags in Env2

can be achieved. However, it is difficult to search for the appropriate threshold. Actually, if the threshold is too big, many noisy virtual reference tags will be selected. Consequently, the average estimation error of the VIRE approach will increase. On the contrary, if the threshold is too small, the real positions may be swept and the average error will also increase.

A concept of adaptive threshold of RSSI difference mentioned in [7] can help us to find out the appropriate threshold for a tracking tag. However, the threshold chosen for one tracking tag is not always applied for the other tracking tags. Due to radio signal multi-path effects, the effect of each tag is different from another one, especially in Env2, where there are two large concrete pillars and lots of desks. The difference of RSSI values between two discretional real tags gets more diverse, and so in the corresponding proximity map, the difference of RSSI values between a virtual tag and a tracking tag also gets more diverse. Consequently, a tracking tag's appropriate threshold may be extremely different from another one's.

In the results of the VIRE approach, we find out that the number of the selected virtual reference tags ultimately makes a great difference for some tracking tags. In our method, we attempt to search for the appropriate threshold for each tracking tag with an improvement of the reduction algorithm of threshold. The crucial is making sure the number of the selected virtual reference tags after the interpolation and elimination processes be in a right range with respect to *n*, so that it enables us to obtain sufficient information from the selected virtual reference tags. Therefore, each tracking tag can find out its appropriate threshold. In addition, an adjustment of the reduction step in the algorithm can be implemented to expedite the processe. Then, to improve the accuracy, we consider several methods to describe the weight of possible position, e.g. using the Euclidian distance and the weight of possible position mentioned in [6], comparing with W_{1i} in VIRE.

TABLE II. THE ESTIMATION ERROR OF THREE APPOROACHES

Approach	AVERAGE		WORST	
	Env1	*Env2*	*Env1*	*Env2*
Proposed	0.53m	0.75m	1.16m	2.06m
VIRE	0.68m	1.17m	1.25m	2.24m
LANDMARC	0.72m	1.38m	1.33m	2.42m

With the two environments shown in Fig.1 and Fig.2, we examine the performance of the proposed approach. The worst estimation error and the average estimation error in each approach are presented in TABLE Ⅱ, respectively. Clearly, our method works best. The values of the final appropriate thresholds of 8 tracking tags in Env2 with the proposed approach are 9.1, 12.2, 7.0, 11.2, 8.1, 5.4, 7.7, and 7.2 in turn, which are nearly in the optimal range of threshold given by VIRE as shown in Fig.3. Hence, the accuracy is improved.

V. CONCLUSIONS

In this paper, we assessed the performance of positioning algorithms in active RFID systems, namely the well-known LANDMARC approach and the VIRE approach. Then, we analyzed the latter approach with a fixed threshold of RSSI difference in the elimination algorithm which influence the location errors, and introduced our method: improvement of the reduction algorithm of threshold for each tracking tag and improvement on the calculation of possible position's weight with Euclidian distance to reach higher location accuracy. The experiment results show the advantage of the proposed approach, and the feasibility is verrified.

REFERENCES

[1] H. Liu, H. Darabi, P. Banerjee, and J. Liu, "Survey of Wireless Indoor Positioning Techniques and Systems", IEEE Trans. Sys. Man. Cyber.- Part C: Appl. Review, vol. 37, pp.1067-1080, Nov., 2007.

[2] P. Bahl and V. N. Padmanabhan, "RADAR: An In-Building RF-Based User Location and Tracking System," in Proc. IEEE INFOCOM, March 2000, vol.2, pp.775-784

[3] M. Youssef and A. Agrawala, "The Horus WLAN location determination system," in Proc. Mobile Systems, Applications And Services, June 2005, pp. 205–218

[4] U. Bandara, M. Hasegawa, M. Inoue, H. Morikawa and T. Aoyama, "Design and implementation of a Bluetooth signal strength based location sensing system," in Proc. IEEE Radio and Wireless Conference, Sept.2004, pp. 319-322.

[5] V. Otsason, A. Varshavsky, A. LaMarca, and E. de Lara, "Accurate GSM indoor localization," UbiComp 2005, Lecture Notes Computer Science, Springer-Varlag, vol. 3660, pp. 141–158, 2005.

[6] L. M. Ni, Yunhao Liu, Yiu Cho Lau, Yiu Cho Lau and Abhishek P.Patil. "LANDMARC: indoor location sensing using active RFID," in Proc. First Int.Conf. Pervasive Computing and Communications, March 2003, pp.407-415.

[7] Yiyang Zhao, Yunhao Liu, lionel M.Ni, "VIRE: Active RFID-based Localization Using Virtual Reference Elimination," in Proc. Parallel Processing, Sept. 2007, pp 5-12.