Wireless Pers Commun (2009) 49:67–80
DOI 10.1007/s11277-008-9556-4

Investigation of Indoor Location Sensing via RFID Reader Network Utilizing Grid Covering Algorithm

Ahmed Wasif Reza · Tan Kim Geok

Abstract One of the biggest challenges in RFID (radio frequency identification) large scale deployment, such as in warehouse RFID deployment, is the positioning of RFID reader antennas to efficiently locate all the tagged objects distributed at RFID reader environment. This paper has investigated a novel location sensing system based on geometric grid covering algorithm that can use any passive or active RFID standard for positioning or tracking objects inside buildings. This study involves design of RFID reader antenna network which focuses on placing the reader antennas on a grid to cover all the tags distributed at two dimensional planes and position calculation using statistical averages algorithm. The statistical averages algorithm simply computes the location coordinates of the tagged object by statistical average of the reader antenna's location. The proposed grid of reader antennas can assist in minimizing the actual number of reader antennas required for RFID large scale deployment. The proposed prototype system is a simpler positioning system which presents the solution of placement pattern of RFID reader antennas, gives less complicated mathematical calculation, and is able to provide a high degree of accuracy. The obtained results show that the proposed location sensing system can achieve better positioning accuracy as compared to existing positioning system and in some cases accuracy improvement of about 50% can be reached.

Keywords Indoor positioning · Tracking · Location sensing · RFID reader network

1 Introduction

Over the years, there have been many systems and architectures dealing with the problem of automatic location sensing. Triangulation, scene analysis, and proximity are three major techniques for automatic location sensing [1]. Recent research trend have focused on RF (radio

---

A. W. Reza (✉) · T. K. Geok
Faculty of Engineering & Technology, Multimedia University, Jalan Ayer Keroh Lama, Bukit Beruang,
75450 Melaka, Malaysia
e-mail: awreza98@yahoo.com

frequency) technology as a basis for position determination which uses the techniques such as differential time of arrival or signal strength measurements. RADAR [2] is an RF based indoor positioning and tracking system that uses standard 802.11 network adapter. RADAR operates by recording and processing signal strength information at multiple base stations positioned to provide overlapping coverage in the area of interest. It combines empirical measurements with signal propagation modeling to determine user location and thereby enable location-aware services and applications. The major advantages of this system are that it is easy to setup, requires few base stations, and uses the same infrastructure that provides general wireless networking inside buildings. But down side of RADAR system includes poor tracking accuracy in most cases. The 50% error of the RADAR project is around 2.37–2.65 m and its 90% error is around 5.93–5.97 m. In Carnegie Mellon University, client-centric triangulation based remapped interpolated approach (CMU-TMI) is developed as an RF based indoor location sensing system [3]. This implementation is based on signal strength and access point information from the IEEE 802.11b WaveLAN wireless network. CMU-TMI requires less training efforts compared to RADAR system (i.e. training 1/8 of RADAR system) and generates 50% results accurate for 2 m but generates good results for errors greater than 2 m.

The proposed indoor location sensing system in this paper is motivated by RFID (radio frequency identification) technology. RFID is now becoming recognized and visible technology which had penetrated into almost all application fields including supply chain management, toll-payment, libraries, e-passports, shopping, and many other areas as an alternative to barcode based tracking [4]. One of the most important RFID applications is objects tracking and positioning due to its ability of high speed contactless identification in non-line of sight (NLOS) shared medium. Several RFID based positioning technologies have been developed for indoor. To create and analyze a fine-grained indoor location sensing system, a tagging technology known as SpotON [5] is developed using RFID for three dimensional (3D) location sensing based on radio signal strength. The researchers have designed and built hardware that serve as object location tags. SpotON tags use the received radio signal strength information as a sensor measurement for estimating inter-tag distance. However, a complete system has not been made yet. LANDMARC [6] on the other hand is an active RFID calibrated positioning system in which fixed RFID tags are used to serve as reference points. The LANDMARC approach does require signal strength information from each tag to readers, if it is within the detectable range. In this approach, each reader has a pre-determined power level, thus defining a certain range by which it can detect RFID tags. Based on the signal strength received by the RFID reader, the reader reports the power level of the tag detected. LANDMARC performs a preliminary measurement to know which power level corresponds to what distance. The accuracy of this approach is determined by the number of readers required, the placement of these readers, and the power level of each reader. It is seen that 50% error distance of LANDMARC is around 1m while the maximum error distances are less than 2 m. However, LANDMARC system suffers some problems such as: (i) standardization and (ii) there is no solution of actual placement pattern of readers and reference tags while the size of the area varies. Besides the RFID based positioning technologies discussed above, the most recent research work have been done in probe card management system for throughput improvement via tracking of probe cards [7] and in the field of food technology to create a safer food supply chain in order to provide a full traceability of food products [8].

This paper refers to the development of a grid of reader antennas to cover all the tags distributed at two dimensional planes. There exist various researches based on coverage and connectivity issues in the context of wireless network [9–11]. As opposed to cover a given region, Booth [12] investigates the coverage and continuum percolation properties of the discs placed to cover a given set of points. This useful model suggests that grid covering algorithm can place circular reader antennas on the grid area that do not touch each other's centers and can cover all the tags on the two dimensional plane by using only grid reader antennas. This theorem is utilized effectively to develop the proposed low density grid reader antenna network, which can optimize the actual number of required reader antennas to make the proposed system viable and cost effective. The proposed method works well whenever connectivity radius ρ of a reader antenna is somewhat larger than the coverage radius r. The grid covering approach as well as analysis depends on the ratio $\frac{r}{\rho} \leq 1$ i.e. $r \leq \rho$. This network topology is designed and arranged in accordance with the circular radio coverage or interrogation zone of each RFID reader antenna [13]. It presents the solution of placement pattern of RFID reader antennas, therefore required number of RFID reader antennas and coverage can be achieved. Moreover, grid covering reader antenna network allows continuous position estimation in space and time. The continuous tracking technologies can be generated towards tracking items of high value such as emergency medical equipments or surgeon [14].

To improve read rate, positioning accuracy, and cover a number of distributed tags, several reader antennas are put together to form a grid reader antenna network in this study. For a RFID reader antenna deployment, such as in warehouse RFID deployment, where hundreds of reader antennas will be positioned in a building, the interference between all these readers must be studied carefully to avoid reader collisions [15]. Many applications now require several RFID readers to operate in close proximity of each other. In such a case, if several readers work simultaneously, the signal from one reader may interfere with the signal from others [16]. When two such readers are activate at the same time, the tags in the overlapped region can not differentiate between the two signals. If no additional anti-collision measures are implemented, reader collision may lead to misreading and thus can depress the improvement of read rate and correctness. This reader-to-reader collision can not be avoided by operating the interfered readers in different frequency channels. The only way the collision can be avoided is by ensuring that the interfering readers are active at different points in time [17]. There exist various multi-reader anti-collision algorithms [15–19] to solve this interference problem. However, in the proposed method, the reader to reader collision can be avoided since time multiplexing technique is implemented; where readers are activated sequentially and not simultaneously.

In this paper, a new tracking system is proposed. The proposed system is based on grid pattern reader network. The grid pattern topology can achieve higher efficiencies than randomly constructed topology reported in [20]. This demonstrates that for dense networks, the efficiency can be improved significantly if location information in available to each reader antenna of the grid network. To construct network of RFID reader antennas require that these reader antennas be low-sensing and homogenous. Reducing sensing radius of a reader and nicely formulated grid reader antenna network are two strategic moves to improve the accuracy in this study. The statistical averages algorithm [14] is proposed in this paper for position estimation through grid reader antenna network. This positioning algorithm computes the location coordinates of the tagged object by statistical average of the reader antenna's location when it detects any tag. In summary, the main contributions of the proposed method can be summarized as follows: (1) this study provides the solution of placement pattern of RFID reader antennas through grid of RFID antenna positioning, hence required number of RFID reader antennas and guaranteed coverage can be achieved (2) by designing of the proposed grid of antenna positioning, a RFID system can be optimized in a dense reader environment (3) the proposed grid reader antenna network together with statistical averages algorithm can achieve average positioning error as low as 0.5 m, which is about 50% better than the results obtained by a known positioning system (4) it can be compatible in any active or passive RFID standard and (5) it may be appropriate in a large warehouse or retail industry where tagged objects are heavily populated in a dense RFID reader deployment.

The organization of the remaining part of this paper is as follows: in Sect. 2, a more detailed discussion on grid covering reader antenna network and statistical averages algorithm is included. In Sect. 3, the position computation to determine the tracking accuracy of the proposed method is presented. The accuracy performance is evaluated for non-uniform distributed RFID tags. The results are compared with LANDMARC positioning system [6]. Lastly, Sect. 4 presents the conclusions of the proposed work.

2 Method of Investigation

The proposed tracking system can be implemented for different active or passive RFID standards which can operate at different frequency types. Circular radio coverage or interrogation zone is assumed for each RFID reader antenna. The proposed tracking method involves two phases: (1) setup of reader antenna network by utilizing grid covering algorithm which helps in finding the placement pattern of reader antennas, the number of required reader antennas, covering all the tags on the two dimensional plane, and creating reader intersecting zone for position calculation and (2) the statistical averages algorithm which computes the unknown tag's coordinates through the reader antenna network. The terms reader and tag are used interchangeably with RFID reader and RFID tag in this paper.

2.1 Setup of Reader Antenna Network

The layout of grid covering reader network is shown in Fig. 1. The bold dot denotes the grid points where reader antennas are installed, the straight line denotes the edge of the connectivity graph, and the circle denotes coverage of each reader antenna. The bold dot is defined by '1', if reader antenna is placed at grid point; otherwise '0' is assigned at grid point that creates number of null columns and null rows. Null columns and null rows are indicated by dotted arrow as shown in Fig. 1. This setup presents a solution of optimal number of required RFID reader antennas to cover a given set of tags in the area. The spacing between the grid lines is referred as L. Note that, for a $X \times Y$ rectangular region, the entire network system is designed by utilizing $r = \sqrt{2}L$ [12] which involves tiling of the plane through the reader antennas centered on the grid that do not touch each other's centers and guarantees to cover all the tags in the two dimensional area.

The required number of reader antennas in each row along x-axis can be determined from the following equation.

$$\frac{\mathrm{Int}(n_c + 1)}{2} = m_{c1}, m_{c2};\ \text{where } \frac{X}{L} = n_c \tag{1}$$

where m_{c1} and m_{c2} are integer numbers. If n_c is an integer number and $\mathrm{Int}(n_c + 1)$ is an odd integer then m_{c1} must be less than m_{c2}; otherwise m_{c1} is equal to m_{c2}, where m_{c1} is the required number of reader antennas in each row. In a situation, when n_c is a fraction number [$\mathrm{Rem}(n_c)$ must be greater than 0.41] and $\mathrm{Int}(n_c + 1)$ is an odd integer then [$\mathrm{Int}(n_c + 1) + 1$] is assigned to $\mathrm{Int}(n_c + 1)$ and m_{c1} is equal to m_{c2}, which is the required number of reader antennas at each row. The Int is the integer operation and the function $\mathrm{Int}(x)$ equals the integer part of x. The Rem denotes a remainder operation and $\mathrm{Rem}(x) = x - \mathrm{Int}(x)$. Hence, the total number of grid points in each row is $(m_{c1} + m_{c2})$.

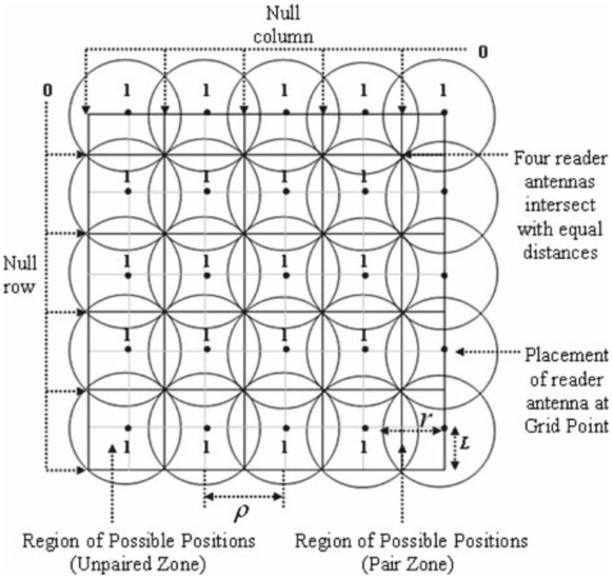

Fig. 1 Layout of grid covering RFID reader antenna network

Similarly, the required number of rows can be calculated from the equation as follows.

$$\frac{\mathrm{Int}(n_r+1)}{2} = m_{r1}, m_{r2}; \quad \text{where } \frac{Y}{L} = n_r \tag{2}$$

where m_{r1} and m_{r2} are integer numbers. If $\mathrm{Int}(n_r+1)$ is an odd integer then m_{r1} must be less than m_{r2}; otherwise m_{r1} is equal to m_{r2}, where m_{r2} is the required number of rows.

If k and l are odd integers then the center of the kth row $(1 \le k \le u)$ and lth column $(1 \le l \le v)$ reader antenna is at,

$$\left[x_c^{(k-1)l}, y_c^{(k-1)l}\right] = [L \times l, L \times (k-1)], \text{ if } \mathrm{Int}(n_r+1) \text{ is an odd integer} \tag{3}$$

$$\left[x_c^{kl}, y_c^{kl}\right] = [L \times l, L \times k], \quad \text{if } \mathrm{Int}(n_r+1) \text{ is an even integer} \tag{4}$$

where,

$$u = (m_{r1} + m_{r2}) \tag{5}$$

$$v = \begin{cases} (m_{c1} + m_{c2}) - 1, & \text{if } \mathrm{Int}(n_c+1) \text{is an odd integer} \\ (m_{c1} + m_{c2}), & \text{if } \mathrm{Int}(n_c+1) \text{is an even integer} \end{cases} \tag{6}$$

As a result, the number of required reader antennas to cover a given set of tags in the area of dimension $X \times Y$ is,

$$N \quad = m_{c1} \times m_{r2} \tag{7}$$

According to Eqs. 1 and 2, for an example, to cover all the tags in an area of 5 m × 10 m with reader antennas of interrogation range, $r = 1.41$ m and $L = 1$ m, the required number of reader antennas in each row is 3 and the required number of rows is 6. Therefore, the Eq. 7 indicates that the optimal number of required reader antennas is $3 \times 6 = 18$. Whereas, to cover all the tags in an area of dimension 15 m × 15 m area, this will be shoot up to 64. The actual number of required RFID reader can be less than N by using RF multiplexer and this reduces the overall cost of the proposed positioning or tracking system.

2.2 Statistical Averages Algorithm

Statistical averages algorithm computes the coordinates of tagged entity as statistical average of the reader antenna's location when it detects the tag. The region of possible positions is defined as the intersection of the areas of several circles as shown in Fig. 1. Grid covering reader antenna network forms only two types of reader intersecting zone i.e. unpaired zone and pair zone (indicated by dotted arrow as shown in Fig. 1). Here the 'zone' defines the range of a reader within which it is able to perform its operation. In case of two intersecting circles, the region of possible positions can be depicted as a pair zone. Unpaired zone is created by non-overlapped portion of intersecting circles. Moreover, four reader antennas intersect with equal antenna-tag distances at null row and null column position of grid covering network. Thus, statistical averages algorithm performs simple mathematical computation through two types of reader intersecting zone.

Let $R_i(x, y)$ denotes the coordinates of reader antennas and T denotes the tag position. The position of a tag can be calculated if and only if it is covered by one of the following reader antennas.

$$T \in R_1(x, y) \cap R_2(x, y) \cdots\cdots\cdots \cap R_k(x, y) \tag{8}$$

where k denotes the number of reader antennas involved in estimating the position of the tag. To compute the coordinates of the tracking tags, different k values can be as $k = 1, 2,$ and 4. The tag's estimated coordinates $(x_{\mathrm{est}}, y_{\mathrm{est}})$ is calculated through the following equation.

$$(x_{\mathrm{est}}, y_{\mathrm{est}}) = \left(\frac{R_1 x + \cdots + R_k x}{k}, \frac{R_1 y + \cdots\cdots\cdots + R_k y}{k}\right) \tag{9}$$

The precision of statistical averages algorithm greatly depends on the reported location information of reader antenna. Therefore, proper positioning of the antenna is essential for good tracking accuracy. The accuracy also depends on distribution of reader antennas around the tagged entity. Nearer tags to the reader antenna and tags within smaller intersecting zone can give better positioning accuracy for the proposed system. The proposed grid reader antenna network together with statistical averages algorithm can also be applied to 3D coordinate location sensing system.

3 Results and Performance Evaluation

The results discussion can be divided into three parts. The first part discusses position calculation for non-uniformly distributed tags. The second part illustrates the effect of reader-tag distance and the number of readers on estimated tracking or positioning accuracy. In the last part of discussion, accuracy comparison with LANDMARC [6] is included to evaluate the performance of the proposed location sensing system. The term accuracy is used interchangeably with error distance or error in this paper, which is the parameter for performance comparison.

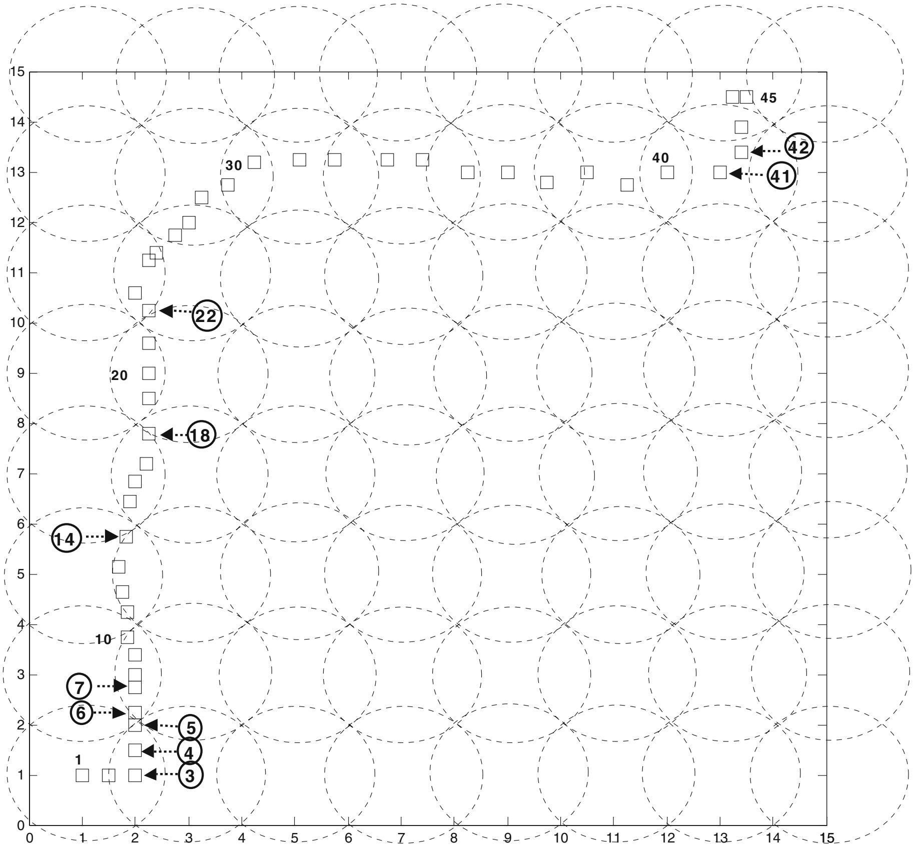

Fig. 2 Non-uniform placement of tags in 15 m ×15 m area

3.1 Position Calculation for Non-uniformly Distributed Tags

In the first part, area of 15 m ×15 m is chosen and 64 reader antennas are installed at grid points using Eq. 4 as shown in Fig. 2. In this setup, 45 tags are distributed in the grid antenna network area. After distributing the tags non-uniformly, it is observed that 35.55% of tags placed in unpaired zone and 64.45% of tags are in pair zone. The accuracy, E is examined by using the equation as follows.

$$E = \sqrt{(x - x_{\text{est}})^2 + (y - y_{\text{est}})^2} \tag{10}$$

where (x, y) is the actual tag's coordinates and $(x_{\text{est}}, y_{\text{est}})$ is the calculated or estimated tag's coordinates. The estimated tag's coordinates is calculated from Eq. 9. Figure 3 shows the tracking results with statistical averages algorithm run. Detailed analysis in Fig. 4 shows error distance with respect to each sample tag. Figure 5 shows that the tags located in pair zone can achieve the lowest error distance of about 0.35 m while unpaired zone offers positioning estimation with the highest error close to 0.48 m. The worst error improves from 1 to 0.75 m by pair zone. The obtained results show that the average error distance of the proposed positioning system is about 0.4 m.

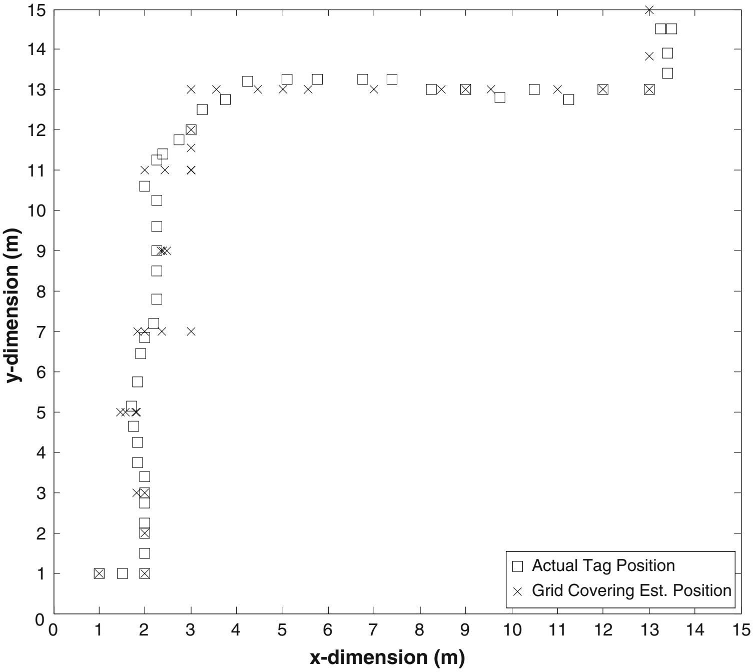

Fig. 3 Tracking results with statistical averages algorithm run

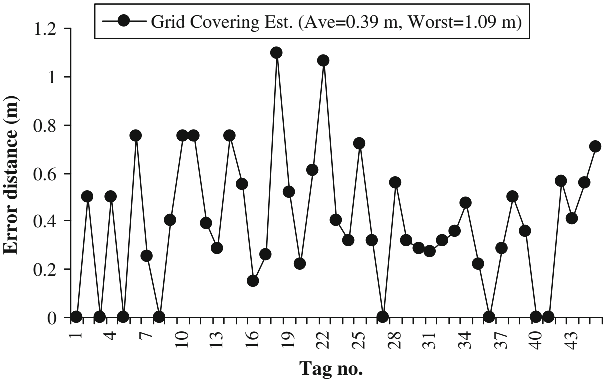

Fig. 4 Error distance with respect to each sample tag

3.2 Effect of the Reader-Tag Distance and the Number of Reader Antennas

In this part, the results analysis reveals that the obtained accuracy fluctuates by different reader to tag distances and less reader-tag distance within smaller intersecting zone gives low error. For example (shown in Fig. 2), the proposed system provides 100% accuracy for tag 3 and tag 41, positioned at the middle of pair zone and unpaired zone, respectively along horizontal and vertical grid lines in grid network area. Figure 6 illustrates the effect of reader to tag distance along with the size of intersecting zone on the estimated tracking accuracy. Only tag 5 is detected by four reader antennas ($k = 4$) with equal reader to tag distances

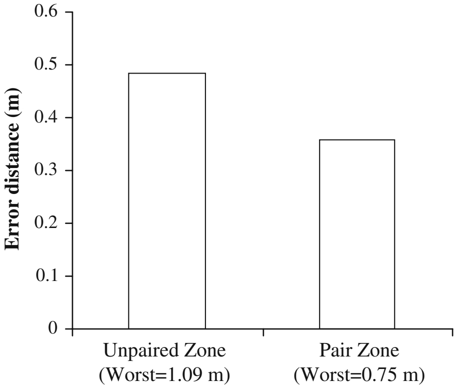

Fig. 5 Average error distance for each zone

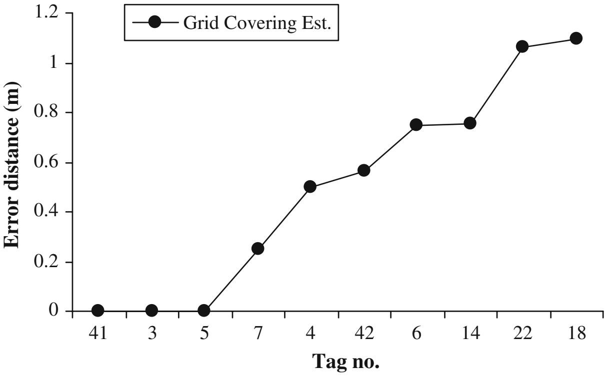

Fig. 6 Effect of the reader-tag distance and the number of the readers

and thus, gives 0 m error. The obtained error distances for tag 7, tag 6, tag 4, and tag 3 fairly fluctuate by different reader to tag distances in pair zone. The variation of error distances for tag 41, tag 42, tag 22, and tag 18 at unpaired zone is also included in this analysis as an example. The remaining tags included in this study vary in a similar way by different reader to tag distances and size of intersecting zone. Based on the statistics shown in Fig. 7, it can be seen that the maximum error distances (i.e. approximately 80%) of the proposed location sensing system are in the range of 0 to 0.5 m, which is very promising.

3.3 Accuracy Comparison with LANDMARC System

In the last part of results analysis, the positioning accuracy of the proposed method is compared with LANDMARC positioning system [6]. LANDMARC system involves tracking of tagged objects with four RFID readers and 16 reference tags as reported in [6]. With the placement of the reference tags and the tracking tags, the system keeps collecting data of power levels from four readers continuously. The physical distance is computed directly by using power level. Therefore, LANDMARC develops an algorithm to reflect the relations of signal strengths by power level and thus, estimates the position of the tag. LANDMARC system obtains two sets of positioning results from two sets of non-uniformly distributed

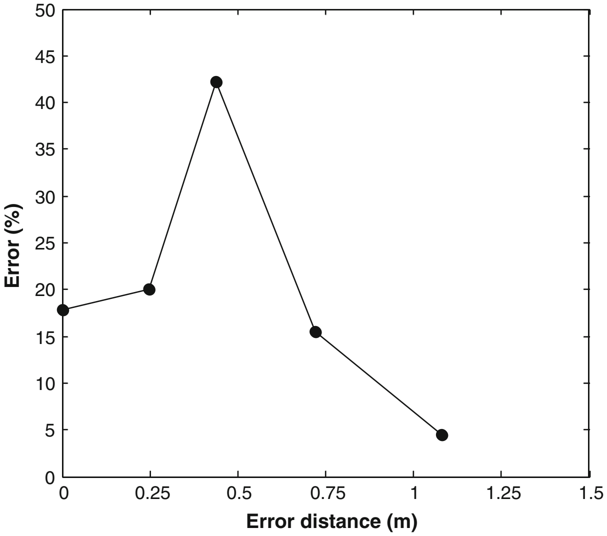

Fig. 7 Percentage of error distance for the proposed system

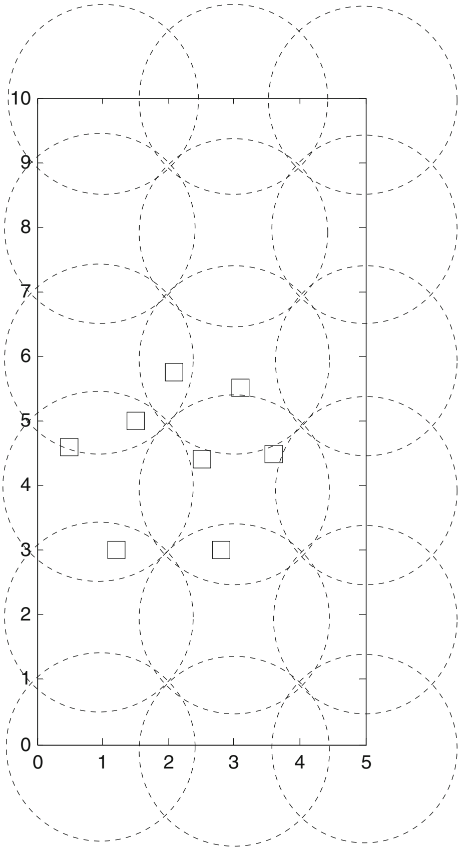

Fig. 8 Placement of RFID reader antennas and tags (original setup)

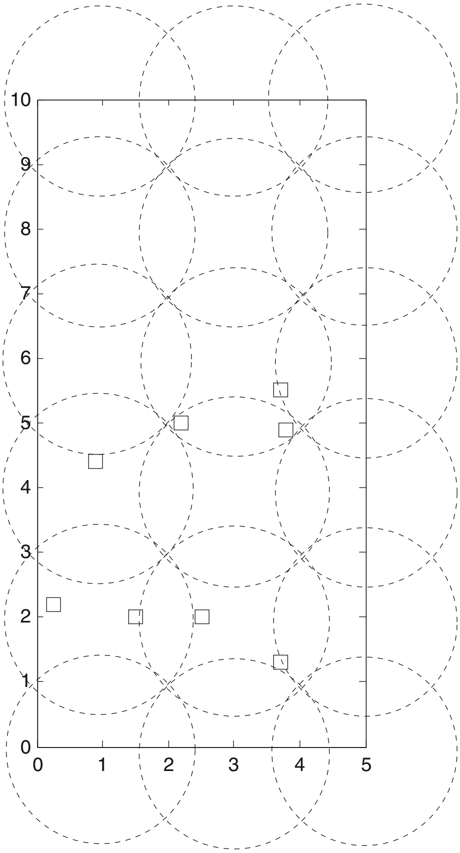

Fig. 9 Placement of RFID reader antennas and tags (change track tag)

tags. The first set is the original setup of RFID readers, reference tags, and tracking tags while in the second set, the placement of tracking tags is changed.

The positioning estimation is repeated by using the proposed grid covering reader antenna network approach. Therefore, the reader antennas are perfectly installed at grid points using Eq. 3, to cover all the tags in the area of 5 m ×10 m, shown in Figs. 8 and 9. For original setup, it is observed that 50% of tags placed in unpaired zone and the remaining 50% of tags positioned at pair zone. It is seen that unpaired zone provides error of about 0.68 m while pair zone gives the lowest error of about 0.29 m. After changing of track tags, it is obtained that the average error distance through unpaired zone and pair zone is almost similar (where 37.5% of tags placed in pair zone and 62.5% of tags in unpaired zone). In the second set, the obtained error distance is similar due to irregular placement of the tags at worse position of pair zone. Figure 10 shows performance comparison of both LANDMARC positioning system and the proposed grid covering based positioning system with one to five error levels, where level 1 indicates minimum error distance and level 5 indicates the worst error. Finally, the obtained results are summarized in Table 1.

The obtained results indicate that the proposed method can achieve average positioning error as low as 0.5 m, which is about 50% improvement on accuracy provided by LANDMARC

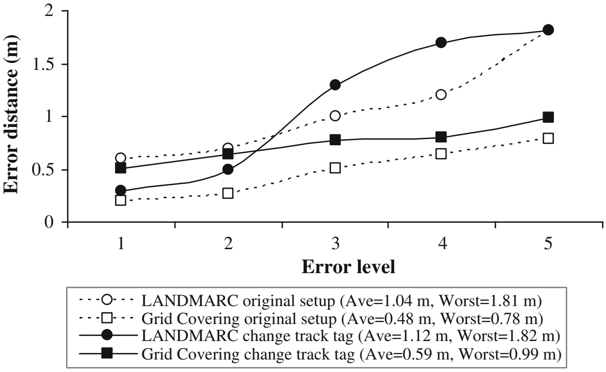

Fig. 10 Performance comparison of both the methods

Table 1 Positioning error comparison between LANDMARC system and the proposed grid covering based positioning system

Experiment sets	LANDMARC		Grid covering		Improvement over LANDMARC	
	Average error (m)	Worst error (m)	Average error (m)	Worst error (m)	Accuracy improvement (%)	Worst Error Improvement (%)
Original setup	1.042	1.81	0.4781	0.7810	54.12	56.85
Change track tag	1.124	1.82	0.5898	0.9899	48.63	45.61

[6]. With respect to the worst error, the proposed method also obtains improvement of about 50%. Table 1 shows the significant contribution of this study.

4 Conclusions

This paper refers to the development of a grid of reader antennas for the localization of a number of distributed tags by employing the RFID technique. The positioning algorithm presented in this paper calculates the tag position by statistical average of the reader's location. The proposed prototype system is a simpler positioning system which involves less complicated mathematical computation. The proposed reader antenna network guarantees to cover all the tags on the grid area and provides position estimates continuous in space and time. This represents a new point in the taxonomy. Additionally, the proposed grid network can minimize the required number of reader antennas to cover a given set of tags at indoor space and thus, can decrease the overall cost for the system setup. The obtained results indicate that the proposed positioning method is consistently more accurate than LANDMARC positioning system and can achieve positioning with error as low as 0.5 m.

The proposed positioning or tracking technique can be implemented for any RFID standard depending on the system design requirement such as size of the area to be tracked. The technique presented in this paper will be very useful in the development of an in-building location sensing system for RFID large scale deployment, such as in warehouse.

References

1. Hightower, J., & Borriello, G. (2001). A survey and taxonomy of location sensing systems for ubiquitous computing. Technical Report CSE 01-08-03, University of Washington, Seattle, WA, August 2001.
2. Bahl, P., & Padmanabhan, V. N. (2000). RADAR: An in building RF-based user location and tracking system. In *Proceedings of the IEEE Conference on Computer Communications (INFOCOM)*, Vol. 2, pp. 775–784, 2000.
3. Smailagic, A., & Kogan, D. (2002). Location sensing and privacy in a context—aware computing environment. *IEEE Wireless Communication*, *9*(5), 10–17.
4. Finkenzeller, K. (2003). *RFID handbook: Fundamentals and applications in contactless smart cards and identification*. Chichester: John Wiley, Leipzig, dritte edition.
5. Hightower, J., Want, R., & Borriello, G. (2000). SpotON: An indoor 3D location sensing technology based on RF signal strength. In: Technical Report UW CSE 2000–02–02, University of Washington, February 2000.
6. Ni, L. M., Liu, Y., Lau, Y. C., & Patil, A. P. (2004). LANDMARC: Indoor location sensing using active RFID. *Journal of Wireless Networks, 10*(6), 701–710.
7. Ingamells, M., & Kober, J. (2005). Improving final test throughput via RFID tracking of probe cards. In *Proceedings of the International Symposium on Semiconductor Manufacturing (ISSM)*, San Jose, California, pp. 80–83, September 2005.
8. Jones, P. (2006). Networked RFID for use in the food chain. In *Proceedings of the IEEE International Conference on Emerging Technologies and Factory Automation (ETFA)*, Czech Republic, pp. 1119–1124, September 2006.
9. Gupta, P., & Kumar, P. R. (1998). Critical power for asymptotic connectivity in wireless networks. In W. M. McEneany, G. Yin, & Q. Zhang (Eds.), *Stochastic analysis, control, optimization and applications: A volume in honor of W. H. Fleming* (pp. 547–566). Boston: Birkhauseo.
10. Kershner, R. (1939). The number of circles covering a set. *American Journal of Mathematics, 61*, 665.
11. Hall, P. (1988). *Introduction to the theory of coverage processes*. J Wiley.
12. Booth, L., Bruck, J., Franceschetti, M., & Meester, R. (2003). Covering algorithms, continuum percolation, and the geometry of wireless networks. *Annals of Applied Probability, 13*(2), 722–741.
13. Li, L. W., Lim, C. P., & Leong, M. S. (2001). Near field of electrically small thin square and rectangular loop antennas. *Progress in Electromagnetics Research*, PIER 31, pp. 181–193, 2001.
14. Patil, A., Munson, J., Wood, D., & Cole, A. (2005). BlueBot: Asset tracking via robotic location crawling. Tech Report RC23510, IBM T.J. Watson Research Center, Hawthorne, NY, February 2005.
15. Leong, K. S., Ng, M. L., Grasso, A. R., & Cole, P.H. (2006). Synchronization of RFID readers for dense RFID reader environment. In *Proceedings of IEEE International Symposium on Applications and the Internet Workshops*, Phoenix, Arizona, pp. 48–51, January 2006.
16. Wang, D., Wang, J., & Zhao, Y. (2006). A novel solution to the reader collision problem in RFID system. In *Proceedings of IEEE International Conference on Wireless Communications, Networking and Mobile Computing (WICOM)*, Montreal, Canada, pp. 1–4, September 2006.
17. Zhou, S., Luo, Z., Wong, E., Tan, C. J., & Luo, J. (2007). Interconnected RFID Reader collision model and its application in reader anti-collision. In *IEEE International Conference on RFID*, Grapevine, Texas, USA, pp. 212–219, 2007.
18. Waldrop, J., Engels, D. W., & Sanna, S. E. (2003). Colorwave: A MAC for RFID reader networks. In *IEEE Wireless Communications and Networking Conference (WCNC)*, New Orleans, Louisiana, USA, pp. 1701–1704, 2003.
19. Engels, D. W., & Sarma, S. E. (2002). The reader collision problem. In *Proceedings of IEEE International Conference on Systems, Man and Cybernetics*, Hammamet, Tunisia, Vol. 3, pp. 6, October 2002.
20. Iyengar, R., Kar, K., & Banerjee, S. (2005). Low-coordination topologies for redundancy in sensor networks. In *Proceedings of the 6th ACM international symposium on Mobile ad hoc networking and computing*, Urbana-Champaign, Illinois, USA, pp. 332–342, May 2005.

Author Biographies

Ahmed Wasif Reza received the B.Sc (Hons.) degree in computer science and engineering from Khulna University, Bangladesh in 2002. He is currently proceeding towards his Master of Engineering Science (MEngSc.) and also working as a research officer in Multimedia University, Malaysia. He worked as a lecturer in University of Science and Technology Chittagong, Bangladesh until 2004. He is also a member of Centre for Image Processing and Telemedicine (CIPTEM), Multimedia University, Malaysia. His research area includes radio frequency identification (RFID), smart items and sensor network, wireless and mobile communication, and biomedical image processing.

Tan Kim Geok received the B.E., M.E., and PhD. degrees all in electrical engineering from University of Technology Malaysia, in 1995, 1997, and 2000, respectively. He has been Senior R&D engineer in EPCOS Singapore in 2000. In 2001–2003, he joined DoCoMo Euro-Labs in Munich, Germany. He is currently academic staff in Multimedia University. His research interests include radio propagation for outdoor and indoor, RFID, multi-user detection technique for multi-carrier technologies, and A-GPS.