The use of RTOF and RSS for a one base station RFID system

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Summary
This paper describes a locating system based on one base station for RFID. The proposed method helps reduce average-distance errors, as well as installation cost and time. RTOF and RSS metrics are combined and used as inputs to the proposed-locating algorithm. A sub-area partitioning (called as iBox) is proposed to increase the accuracy of selecting direction of the target object. This also helps solving the indoor multipath problem. The tests described here used the UTD to simulate environments with the LOS and NLOS conditions. Our system reduces the average-distance error by one third compared to the simulated Landmarc algorithm.
Key words:
One BS, RFID, RTOF-RSS, UTD

1. Introduction

Since many wireless applications such as inventory management, health care, etc., require the physical location of objects, most systems employ an automatic locating system. One of the most well-known position location systems is the Global Positioning System (GPS). The GPS is widely used to track moving objects located outdoors. However, the GPS cannot determine precise locations of an indoor object, and sometimes cannot determine the position at all. Different indoor positioning approaches [1-14] have been proposed and tested for their effectiveness in locating the target objects inside buildings. Various technologies such as Ultrasonic, Infrared, IEEE 802.11, Bluetooth, and Radio Frequency Identification (RFID) [15] are applied to a locating system, each having its own strengths as well as limitations.

An overview of a typical locating system is illustrated in Fig. 1. The typical locating system consists of three major functional modules: location-sensing, positioning algorithm, and display. Input signals to the typical locating system are Radio Frequency (RF), Ultrasonic, Infrared, and other signals depending on available technologies. The location-sensing module generates location metrics such as Time of Arrival (TOA), Angle of Arrival (AOA), Round-trip Time of Flight (RTOF), and Received Signal Strength (RSS). These metrics are then fed into the positioning algorithm module. Proximity, scene analysis, and triangulation are the three principal techniques for the positioning algorithm module. At that stage, the coordinates of the target object are calculated and finally transformed to a readable format in the display module.

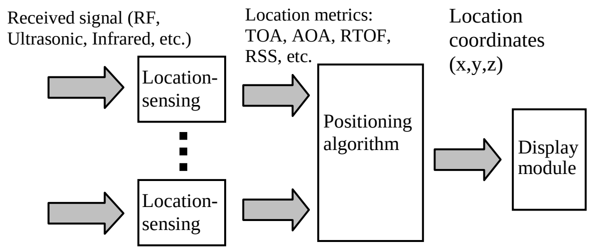

Fig. 1 Functional block diagram of a typical locating system

Most locating systems use three or more Base Stations (BSs), which are not only costly, but also take time to install. Moreover, the systems are prone to failure when a BS malfunctions. A search for an alternative approach with potentials for reductions in hardware costs and installation time, as well as improvement in accuracy is called for.

The [12] is an alternative system to approach such a challenge. Firstly, it uses the RSS metric to determine the radial distances of the reference points, and applies the RTOF metric to resolve the direction towards the target object. However, the RSS is prone to undue environmental influences. Several existing works with the use of the RSS include more BSs for the system accuracy improvement. In this paper, a one BS locating system with the conformable use of two metrics is suggested. The RTOF metric is less prone to environmental influences. Thus, the RTOF can provide accurate radial distances of the target objects. The signal signature of the RSS metric is applied as to appropriately identify the direction of target objects, based on the assumption that the signals of both the reference points and the target objects in the vicinity are approximately identical.

The proposed locating system employs the RFID technology for the location-sensing module. The RFID is not only a readily available technology but also a

Manuscript received July 5, 2010
Manuscript revised July 20, 2010

potentially cost effective product. It has been exploited in many wireless devices. The use of the RFID with the proposed system increases a chance for wide adoptions in many mobile commercial applications such as public transport, health care, animal identification, industrial automation, time attendance, access control, etc.

In the proposed locating system, a reader is utilized for a single BS, and passive tags are attached to the reference points as well as the target objects. The arrangement is similar to the use of one BS along with both fixed and moving Mobile Station (MS). The reference tags attached to the reference points are covered by the iBox placement. Their ID numbers and coordinates are stored in the main database for the pre-process. Their ID number, RSSs, and RTOFs are fed into the iBox matrix, once the proposed RTOF-RSS algorithm runs.

The iBox is proposed as a tool to partition a specific area into sub-areas, each represented by an individual iBox. The iBox is designed to circumscribe the target object locations based on two metrics, which are the RTOF and RSS. The combination of the two metrics improves accuracy and reliability of the proposed locating system.

This study aimed to: 1) analyze the signal behaviors appearance on the locating system; 2) evaluate the most appropriate system parameter called the shortest distance between the target tag and the reference tags; 3) to determine the efficient placement of reference tags and the effective number of adjacent reference tags within the iBox sub-area as to maximize the performance of the proposed system; 4) to establish the influence of the z axis on the accuracy in the locating system; 5) to assess the distance errors between the RTOF-RSS algorithm and the One-BS algorithm [12]; and 6) to compare the proposed system with other three approaches [11, 13-14].

Existing locating systems with RFID technology are described in Section 2. The proposed 3D model, a new method of the sub-area partitioning (iBox), and the RTOF-RSS algorithm are proposed in Section 3. The tests and results are described in Section 4, and the conclusion is in Section 5.

2. The locating systems with RFID Technology

In general, an RFID system [13] consists of a number of readers and tags that communicate with each other. Several positioning techniques with RFID [5-12] have been proposed. Most techniques rely on the RSS from at least four BS readers. The well-known triangulation technique [8, 10] relies on three BS readers. Two common locating systems which use the RFID technology are: SpotON [6] and Landmarc [11]. SpotON [6] locates objects by the employment of homogeneous sensor nodes without any central control. The inter-tag distance is determined by the RF signal strength information. However, a complete system has not been made available up to the present time. Landmarc [11] introduces the concept of the application of reference tags to reduce the number of deployed RFID readers, which potentially lowers the system cost. Reference tags are active tags of fixed settings as to assist the location calibration, and thus serve as reference points within the system. However, there is no need for an excessive number of expensive RFID readers is required, and hence is appropriate for environments constrained by hardware cost and installation time considerations. Table 1 summarizes the existing RFID-based locating system. The last row of Table 1 shows the One-BS system [12] which needs only one BS as well.

Table 1: Related studies of RFID locating systems

Techniques [References]	BS	Metrics	Accuracy	Developed concepts
Improvement approach[5]	4	RSS	Unk.	4NN+Geometric+WCG
Random sampling [7]	≥ 5	RSS	1.5m	Monte Carlo algorithm
Statistical approach [9]	4 – 7	RSS	0.6m	Bayesian model
Landmarc [11]	≥ 4	RSS	1.6m	4NN + WCG
Designing [8]	≥ 4	RTOF	Unk.	Triangulation
Mechanism [10]	4	RSS + RTOF	0.71m	4NN+WCG+Triangulation
One-BS approach [12]	1	RSS + RTOF	0.73m	iBox + 4NN + WCG

BS = Number of base stations (readers). NN = Nearest Neighbor.
WCG = Weighted Center of Gravity. Unk. = unknown.

The One-BS approach [12] proposes a One-BS algorithm, which utilizes the vector format of the RSS-RTOF. It uses the first the RSS, and the RTOF subsequently. It extracts further information in regard to the quantitative data from the input profile sources. Its RSS profiles are generated from the path loss equation, in which 3D environment factors are not considered in the performed simulations. Its setting of the factors in the specific area is hardly defined in terms of MS shape, BS base, and reference tag base. The system lacks adaptation to the 3D world to prove its performance and robustness in respect to losses in severe multipath situations.

This paper describes an alternative locating system that a reader is used for one BS, and passive tags are attached to reference points as well as target tags. The additional contribution of the proposed system is on the development of iBox, which is suggested for accurate location estimation along with the RTOF-RSS algorithm. The algorithm utilizes the vector format of the RTOF-RSS. It differs from [12] in the use of the RTOF as well as the RSS. It necessitates the real material characteristics of 3D objects as parameters of a function that determines the outputs to achieve higher noise tolerances. Its details are described in the Section 3.

3. The Proposed System

The proposed locating system will be detailed as follows: 3.1) the proposed 3D model, 3.2) indoor signal propagation characteristics, 3.3) sub area-partitioning: iBox, and 3.4) the proposed RTOF-RSS algorithm, respectively.

3.1 The Proposed 3D Model

The proposed 3D platform is modeled as a room of size 12m × 10m × 2.5m as shown in Fig. 2. A BS reader and twenty reference tags are placed to conduct the tests at two levels: 0.77m and 2.48m of height. The reference tags are evenly deployed in a grid format. Each of the reference tags is located 2 meters apart on both x- and y- axis. The target tags are attached to the target objects as body models (BM). The system configuration is as follows:

I) The room contains 3D objects of various sizes. The characteristic of these materials on each object are shown in Table 2. Constant variables in each column of Table 2 have been sourced from references [16-19], within a 500 MHz to 4 GHz frequency range. All constant variables are adjustable except the Material Type (MT), because the particular characteristics of the MT are defined as part of its built-in application, the Numerical Electromagnetics Code–Basic Scattering Code (NEC-BSC) [20-21].

II) There is a single BS reader in the proposed 3D model. To determine if the system performance is affected by the reader's position, we conducted two tests, each with different coordinate. The first test places the reader at the center of the room (x, y, z) = (6m, 5m, 2.48m). The second places the reader in a corner of the room (x, y, z) = (0.8m, 0.8m, 2.48m).

III) A reader (BS) with an antenna is set up. It can support a UHF frequency, and is applied at 925 MHz in
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the experiment for a UHF range of 30-60cm. The RFID Standalone Reader ST800 of the Advance Corporation [22] is chosen for the system configuration, because of its robustness. It supports several kinds of tag protocols. Furthermore, as a multi-protocol UHF RFID reader, it is suitable for both outdoor and indoor use.

3.2 Indoor Signal Propagation Characteristics

Although extensive researches [5-7, 9-11] have been performed with respect to signal propagation characteristics, very little research relates those characteristics to the indoor positioning system. In the presented research, the characteristics of indoor signal propagation and the material characteristics are taken into account, because the locating systems utilizes wireless technologies

Reflection, diffraction and scattering are theoretically three propagation mechanisms that impact a mobile communication system [23-24]. Fig. 3a illustrates a signal strength pattern [25] around a single BS without environmental interferences. The signal strength pattern represents an ideal in a free space, where the RSS alone would indicate proximity to the source.

However, the BS in practice is prone to encounter environmental disturbances such as the walls and the material characteristics of nearby objects. These cause absorption, attenuation, reflection, or a combination of such the factors on the communication medium that may vary throughout the defined space accessible to the signal. Fig. 3b shows a distorted signal strength pattern around the BS caused by surrounding objects. This non-uniform distribution renders local position detection complex.

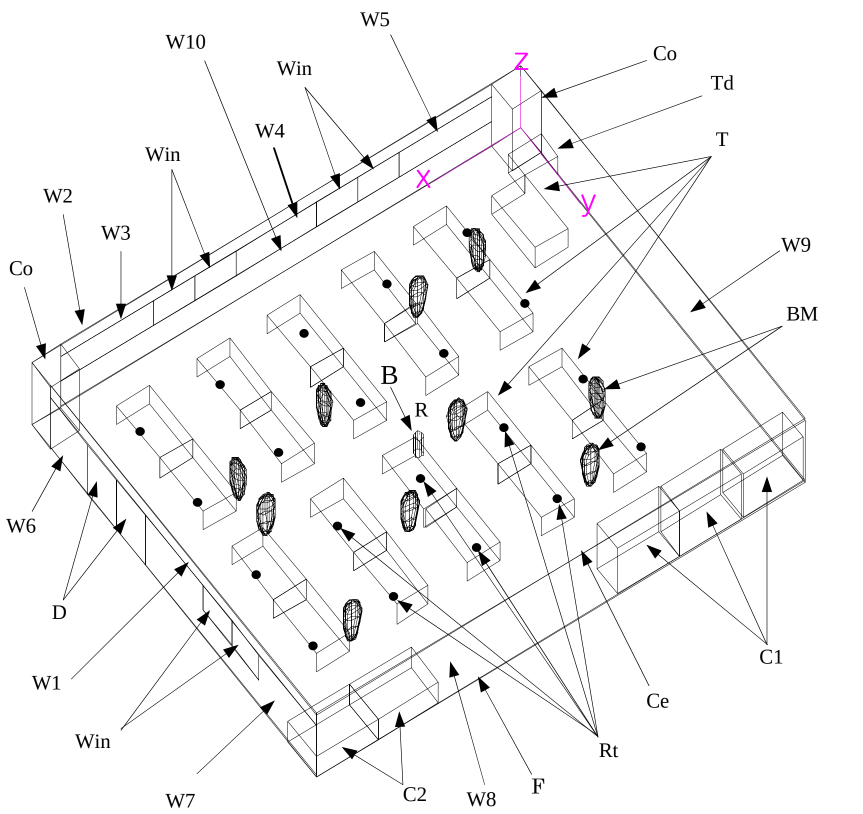

Fig. 2 The proposed 3D model (R = reader, Rt = reference tags, other abbreviations as per Table 2)

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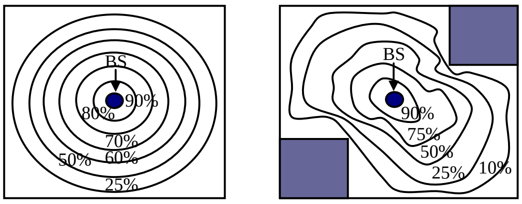
Table 2: Details of material characteristics at 500MHz-4GHz frequency range

Type Lists	MT	Size W×L×H(m)	RP1	DLT	RP2	Th(m)
One front up glass wall (W1)	1	0×9.3×0.5	7.4564	0.0108	1	0.005
One left and front up glass wall (W2)	1	10.6×0×0.5	7.4564	0.0108	1	0.005
One left and front and middle glass wall no.1 (W3)	1	2.3×0×1	7.4564	0.0108	1	0.005
One left and front and middle glass wall no.2 (W4)	1	2×0×1	7.4564	0.0108	1	0.005
One left and front and middle glass wall no.3 (W5)	1	2.3×0×1	7.4564	0.0108	1	0.005
Six glass windows (Win)	1	(1×0×1),(0×1×1)	7.4564	0.0108	1	0.005
Two front glass doors (D)	1	0×1×2	7.4564	0.0108	1	0.005
20 plaster body models (BM)	1	0.42×0.28×1.6	2.3	0.001745	1.5	0.28
One front and down gypsum-board wall no.1 (W6)	-2	0×1.3×2	2.908	0.0205	1	0.01
One front and down gypsum-board wall no.2 (W7)	-2	0×6×2	2.908	0.0205	1	0.01
One right and front gypsum-board wall (W8)	-2	12×0×2.5	2.9084	0.0205	1	0.01
One back gypsum-board wall (W9)	-2	0×9.3×2.5	2.9084	0.0205	1	0.01
Three tall wooden cabinets (C1)	-2	1.5×0.7×1.8	3.4199	0.0362	1	0.03
Two short wooden cabinets (C2)	-2	1.5×1×0.8	3.4199	0.0362	1	0.03
21 wooden tables (T)	-2	0.8×1.5×0.76	3.4199	0.0362	1	0.03
One wooden desk (Td)	-2	0.8×0.6×0.75	3.4199	0.0362	1	0.03
One pole for a settled reader (B)	-2	0.2×0.2×0.69	4	0.0043	1	0.25
Two concrete columns (Co)	-4	0.7×0.7×2.5	4	0.0043	1	0.35
One left and front and down concrete wall (W10)	-4	10.6×0×1	4	0.0043	1	0.35
One gypsum-board ceiling (Ce)	-4	12×10×0	2.908	0.0205	1	0.02
One Floor (F)	0	12×10×0	-	-	-	-

* RP1 = Relative Permittivity. DLT = Dielectric Loss Tangent.
RP2 = Relative Permeability. Th = Thickness. MT = Material Type:
1 = Transparent thin material slab, -2 = Double-sided coated material plate,
-4 = Single-sided coated material plate, 0 = Perfect electric conductor.

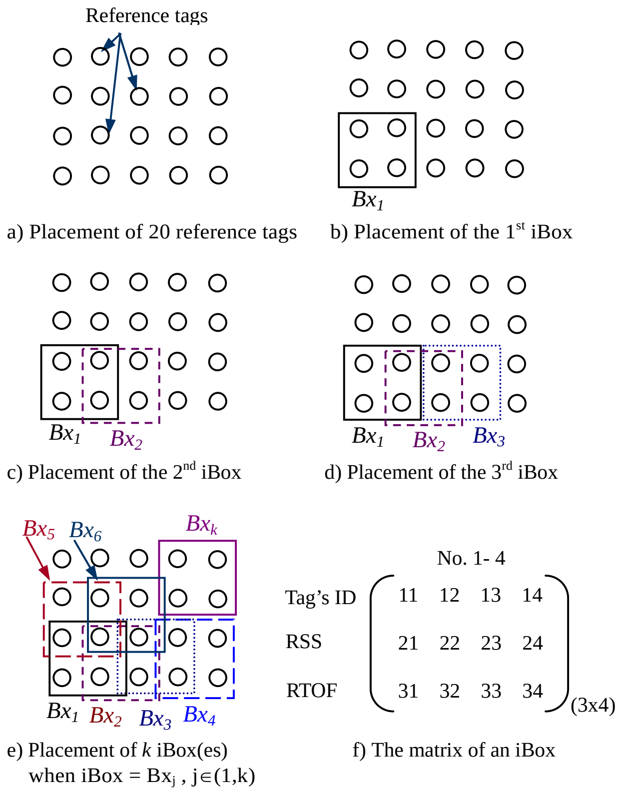


a) With no interference b) With interference

Fig. 3 Signal strength pattern from one BS in a free space

As to study the behavior and propagation characteristics of signals in each position within the proposed system in which various types of material characteristics are settled, a simulation application [20-21] was run to generate the primary data of signals related to the suggested 3D model. Primary data such as the numerical electromagnetic fields and the scattering based on the ray tracing of the UTD (the Uniform Geometrical Theory of Diffraction) was consequentially collected. The simulation was performed under 3D real-world conditions, in order to offer a more reliable system validation. The application [20-21] also aimed to: 1) generate the primary data compatible with the studied variables; 2) clarify the facts of a 3D world; 3) complete the data collection to enable analysis; 4) update information on the platform environment; and 5) provide a valid and reliable research instrument.

The analysis of the behavior of signals and their propagation characteristics in the application revealed a fluctuation of the signals which was caused by the instability of severe multipath conditions. The RTOF metric is considered in our system because it is less sensitive to environmental changes and yields accurate radial distances, which renders an apposite template for the design of the iBox concept.



a) Placement of 20 reference tags b) Placement of the 1st iBox
c) Placement of the 2nd iBox d) Placement of the 3rd iBox
e) Placement of *k* iBox(es) when iBox = Bx_j , j∈(1,k) f) The matrix of an iBox

Fig. 4 Placement and generated pattern of the iBox

3.3 Sub-Area Partitioning: iBox

The intersection Box (iBox) is the sub-area partitioning. It is an array which stores the information of four neighboring reference tags. It is designed to determine if it circumscribes a particular target tag location. Once the reference tags are deployed as a grid format sized 4×5 as showed in Fig. 4a, every iBox contains four reference tags, and at least its two reference tags must belong to another iBox as illustrated in Fig. 4b-4e. The iBox(es) are virtually placed in the pre-specified area. Therefore, the sub-sections defined by the iBox(es) overlapped each other. Based on a grid placement of the reference tags of any quantity, the first placement of an iBox is shown in Fig. 4b. Fig. 4c and 4d display the second and the third placements of the next iBox(es). Fig. 4e illustrates the complete k iBox(es), which covers all reference tags, and k is u–1 times v–1 when reference tags are deployed as a grid of $u \times v$.

The data structure of each iBox is represented as a 3×4 array as shown in Fig. 4f. Each column of the array contains the information of each reference tag in the iBox. The index of the column is the same as the tag's ID. Each row represents the information which is composed of: the ID number, the RSS, and the RTOF.

3.4 The Proposed RTOF-RSS Algorithm

An innovative locating algorithm (also referred to as the RTOF-RSS algorithm) improves the system accuracy in comparison to earlier performances [12]. It is based on the conformable use of the RTOF and RSS metrics (RTOF-RSS). Once the One-BS algorithm [12] exploits the RSS-RTOF, it applies the RSS to search for the candidate radial distance of the reference tags. In comparison with the RSS, since the RTOF signal is less sensitive to environmental interferences such as the multipath problem and signal fluctuation, the RTOF yields a more accurate candidate radial distance than the RSS. Subsequently, the RSS value is exploited for the determination of the target tag direction. Within the candidate radial distance, the position of the target tag is searched for the best match between the RSS of the target tag and the average RSS value of the iBox as the provided RSS are analogous in its vicinity.

In the proposed system, a reader and tags use a defined RF and protocol to transmit and receive data. There are one reader, n reference tags and m target tags. It is assumed that the reader can receive the information relevant to the RTOF and RSS of the tags. The RTOF [8] is derived from the reader. Its readout indicates the radial distance from the BS reader to the tags (referred to as MS), reliant on time-stamped records. The radial distance is derived from Eq. (1):

$$dist_{BS-MS} = \frac{(t_s + t_r - t_{proc-R}) \times c}{2} \quad (1)$$

where $dist_{BS-MS}$ is the distance between a BS and an MS; t_s is the sending time; t_r is the receiving time; t_{proc-R} is the fixed time delays of the BS circuitry and the MS circuitry based on Roll-Call Polling protocol; and c is the velocity of light.

The applicable algorithm is as follows:

- Step 1: The RTOF vectors of reference tags are defined as $\overline{R} = (R_1, R_2,\ldots, R_n)$, $j \in (1,n)$, and target tags as $\overline{T} = (T_1, T_2,\ldots, T_m)$, $i \in (1,m)$. The distance vector is formulated as $\overline{E^i} = (E^i_1, E^i_2,\ldots,E^i_n)$, in accordance to the distances between all reference tags and the i^{th} target tag. A distance value between the i^{th} target tag and the j^{th} reference tag is computed with the use of Eq. (2):

$$\overline{E^i_j} = (T_i - R_j), \quad j \in (1,n). \quad (2)$$

- Step 2: Each reference tag ID in correlation with the six shortest distance values in the vector $\overline{E^i}$ is kept as the matching information. The k iBox(es) are generated. Each reference tag ID obtained previously is matched against the reference tag IDs in each iBox. Each iBox which contains at least two reference tags within the six shortest distance values is selected as a potential iBox.

Step 3 to 5 give details of how to pinpoint the target iBox among the obtained potential iBox(es).

- Step 3: The RSS information of the i^{th} target tag is denoted as S_i. Then the RSS average (called as S_{avg}) of all reference tags in each potential iBox is computed. The absolute of the different value between the S_i and the S_{avg} of every potential iBox(es) is subtracted. An iBox that gives the minimum absolute value is selected as the target iBox.
- Step 4: If there exist multiple RSS minimum absolute values, RTOF average value of each iBox is to be used to reduce the number of iBox(es). Absolute difference values of the RTOF of the i^{th} target tag and the average RTOF in the potential iBox(es) are computed. The iBox with the RTOF minimum absolute difference value circumscribes the i^{th} target tag location.
- Step 5: Nevertheless, if there exist multiple RTOF minimum absolute values, the RTOF value of every reference tag in those iBox(es) is subtracted from the RTOF of the i^{th} target tag. Its magnitude is then sorted. The minimum value in the sorting list will identify the target iBox with the assumption that the obtained target iBox has the highest probability to enclose the i^{th} target tag.
- Step 6: The computed coordinate (x, y, z) of the i^{th} target tag is obtained by the use of Eq. (3):

$$(x,y,z) = \sum_{p=1}^{4} w_p(x_p, y_p, z_p), \quad (3)$$

where w_p is the weight value of the p^{th} reference tag based on RTOF in the target iBox. The weight value of the i^{th} target tag is defined by the weighted center of gravity defined by Eq. (4):

$$w_p = \left(\frac{1}{(E_p^i)^2} \right) \Big/ \left(\sum_{q=1}^{4} \frac{1}{(E_q^i)^2} \right), \qquad p,q \in (1,4). \quad (4)$$

The performance (distance error) of the algorithm is evaluated by the estimation of an error as the linear distance between the actual coordinates (x_0, y_0, z_0) of the target tag and the computed coordinates (x, y, z), as Eq. (5):

$$distance \;\; error = \sqrt{(x - x_0)^2 + (y - y_0)^2 + (z - z_0)^2}. \quad (5)$$

4. Tests and Results

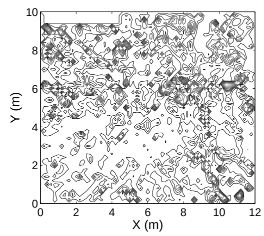
The discussion of both the tests and the results are arranged as follows: 1) an illustration of the performed simulations; 2) an analysis of the signals measured in the suggested system; 3) a determination of the suitable shortest distances between the target tag and reference tags as to improve the proposed system accuracy; 4) the pattern of placement of reference tags and the number of adjacent reference tags within the iBox defined sub-area as to maximize the proposed system performance; 5) a study of the influence of the z axis on the system accuracy; 6) the distance errors from the RTOF-RSS algorithm and the One-BS are assessed; 7) a comparison and evaluation of the proposed system and other three approaches: the Landmarc [11], the UltrasonicReflections [13], and the Wi-FiAccessPoint [14].

First, the proposed 3D model was run to set up the test. In the tests, the primary data for the input signal profiles of the algorithms are generated under the condition of the NEC-BSC [20-21] with the option of the Friis power [23]. The antenna movement of the BS is determined by the option of a fixed-source and a move-receiver (field point). The volumetric near-zone-pattern-cut command was used to observe field signal. The obtained power in watts (W) was calculated by means of Eq. (6). MATLAB was applied to facilitate the calculation.

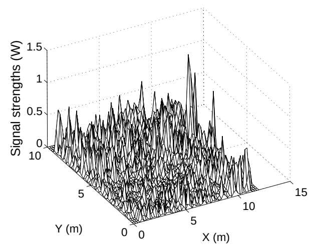
$$power = 10^{\left(\frac{dB}{10}\right)} \quad (6)$$

The target tags or MS are placed within the 120-square-meters area of the proposed 3D model with fixed-reference-tag positions as shown in Fig. 2.

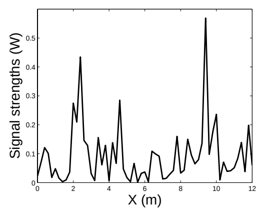
Second, to study the signal behavior, each tested pattern consisted of 10 MS' coordinates placed in the proposed 3D model. The signal strength (RSS) of each MS is measured when the remaining nine MS is placed randomly, for 10 times with one fixed MS position. This gives 91 tested patterns. The tests were performed by placement of the BS at the center and in the corner of the room. The obtained signal profiles are graphed in Fig. 5-7. Fig. 5a illustrates a contour plot of signal profiles in the test room. Fig. 5b shows an amplitude plot of signal profiles in the same model. Fig. 5c displays how fluctuation of the signals measured along one horizon line across the proposed 3D model is. Fig. 6a and b displays the variance and the average of the RSS of each MS obtained 91 tested patterns, respectively. Fig. 7 shows the cumulative distribution function (CDF) of 10 signals of a single MS obtained from 910 MS. The obtained propagation characteristics unveil a fluctuation of the signals which is caused by the instability of severe multipath conditions. Since the RTOF metric is less sensitive to environmental changes, it provides better accurate radial distances than the RSS. Thus, the RTOF paves an appropriate template for the design of the iBox concept.



a) Contour plot of signal profiles

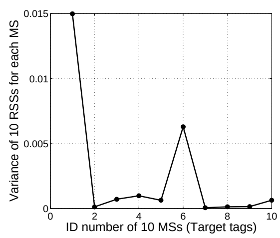


b) Amplitude plot of signal profiles

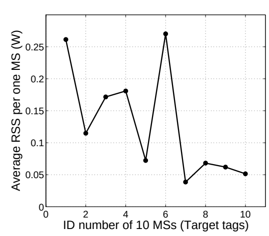


c) Fluctuation signals on a path

Fig. 5 Signal profiles in the proposed 3D model



a) Variance of 10 RSS of each MS



b) average of all signals of 10 MS

Fig. 6 Average signal strength (in Watts) of each MS

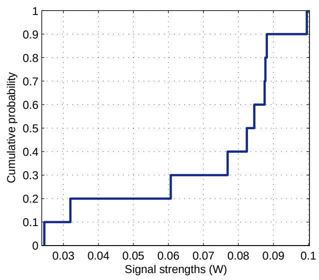


Fig. 7 The CDF of the 10 signals of a single MS

Third, an appropriate number of the shortest distances between the target tag and twenty reference tags within the iBox(es) were established. The tests were performed at 10 tested patterns with random coordinates of the 100 target tags. From Step1 to Step 2 of Section 3.4, the iBox stored the information of four reference tags. The analogous information was obtained from the distance value of Eq. (2). An increase in the number of the shortest distances improved the system performance but tended to saturate when the number of the shortest distances was exceeded. Table 3 summarizes the calculated results of the localization of the MS positions on the RTOF-RSS algorithm based on the proposed 3D model with the BS sited on z=0.77m at either the center or alternatively in the corner of the room. The results indicate that for the proposed 3D model with 10 MS, at least five shortest distance quantities are required in order to achieve all the positions of the 10 MS. The use of an excessive number of the shortest distances results in undue computation time. Thus, six shortest distance quantities between the reference tags and the target tag in candidate radial distances were considered for the iBox(es) involved with the relevant reference tags. The proposed algorithm default is optimal and shown in Table 3.

Table 3: Relation between the number of shortest distance quantities and the number of correctly located MS along with computation time values.

Shortest distance quantities	Number of MS correctly located (10 MS total)		Computational Time (seconds)
	Center BS	Corner BS	
2	6	5	5
3	6	8	5.5
4	9	10	6
5	10	10	6.5
*6	10	10	7
7	10	10	7.5

*: Optimal to determine all target tags.
Center BS: the BS located in at the center of the room.
Corner BS: the BS located in the corner of the room.

Fourth, the four different patterns of the reference tag placement and the two quantities of nearest neighbors within the iBox were simulated, as to monitor accuracy over the system. The four patterns: A, B, C and D are shown in Fig. 8. The pattern A and B are asymmetric patterns; the pattern C is a semi-symmetric grid; and the pattern D is a symmetric grid. The simulations were run with 20 reference tags with 2m apart and with two BS placements which are the center as well as the corner of the room, located at the height of 0.77m. There are 5 tests under the NLOS condition. For each test, 10 target tags are randomly positioned. The nearest neighbors of 3 and 4 (3NN and 4NN) within the iBox are analyzed simultaneously in these simulations. The 5NN was not considered as for it employs more than 20 reference tags used in the proposed system. The results of the RTOF-RSS algorithm are summarized in Table 4. As evident in Table 4, the pattern D and the 4NN was chosen as the default for the system, as this pattern not only reduces the necessary number of iBox(es), but also computational time; the pattern D offers the additional benefit of easy placement of the reference tags for actual installation.

As a grid of 2 meters allows for the placement of 20 reference tags for the purpose of evaluation of the system, the use of a distance of 1 meter consequentially allows the placement of 63 reference tags in the same room. Based on the pattern D and the 4NN with the LOS and NLOS conditions, the 5 tests of the 10 target tags with random positions were simulated. The results are summarized in Table 5; the average distance error with NLOS and the BS in the corner was reduced by 58% compared to the results listed in Table 4, though more reference tags were necessitated by the system. Under NLOS conditions, the average variance of distance errors in Table 5 was increased by 100% as compared to the values in Table 4 for the pattern D and the 4NN and the BS placed at the center of the room. An arrangement of a system with a grid pattern of reference tags 2 meters apart was elected, because the reliability of the obtained variance of errors and the less reference tag usage were to be considered.

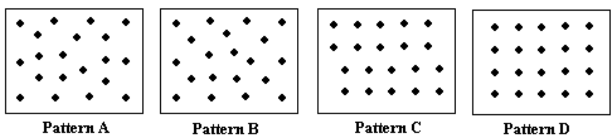


Fig. 8 Placement patterns of the 20 reference tags

Table 4: Comparison of the placement patterns for the RTOF-RSS algorithm under NLOS condition

NN	**Placement types**	**No. of iBox(es)**	**Average distance errors**		**Average variance of distance errors**	
			Cen. BS	**Cor. BS**	**Cen. BS**	**Cor. BS**
3NN	A	27	3.413	2.396	3.494	2.392
	B	26	3.236	3.079	3.289	2.028
	C	24	3.735	2.112	3.773	1.760
	D	24	3.513	2.211	3.328	1.976
4NN	A	15	3.464	2.717	3.608	2.563
	B	15	2.955	2.813	2.743	2.383
	C	12	3.454	2.700	4.723	3.334
	D	12	3.383	2.583	3.468	1.555

NN = Nearest Neighbors, Cen. = Center, Cor. = Corner

Table 5: Comparison with one meter grid placement of 63 reference tags

Conditions	**Evaluation**	**Average distance errors**	
		Center BS	**Corner BS**
LOS	Average distance error	2.9068	0.9266
	Average variance of error	3.9934	0.4036
NLOS	Average distance error	3.2354	1.4954
	Average variance of error	6.9938	1.2199

Fifth, the suitability of level placement of tags and the BS reader in height was analyzed. The placement of reference tags and the BS reader at heights of 2.48m and 0.77m as shown in Table 6, was applied. Under those conditions, the BS reader was sited at the center and in the corner of the room (the proposed 3D model). The target tags are placed at 7 different height levels, as listed in Table 6. For each height level, there are 70 randomly positioned target tags in (x,y) coordinates. As provided by the RTOF-RSS algorithm, the results of the locating system indicate that the z axis influences the distance errors and affects the system accuracy. The simulations reveal that the suitable level placement of tags and the BS reader in height should be at the same level as shown shaded fields in Table 6. As thus future study involves a full 3D locating system evaluation.

Table 6: Average distance errors when placing the 70 target tags on different levels

Levels of Rt.& BS	Site of the BS	Levels of the 70 target tags in height						
		2.48m	2m	1.7m	1.3m	0.77m	0.3m	0.1m
2.48m	Center	3.218	3.267	3.343	3.488	4.143	4.390	4.695
	Corner	2.786	2.992	3.141	3.301	4.612	4.846	4.088
0.77m	Center	4.396	4.194	4.093	3.879	3.370	3.697	3.980
	Corner	4.079	3.855	3.741	3.196	2.588	2.883	3.660

Levels of Rt. & BS = Levels of 20 reference tags and a BS in height

Sixth, we do the comparison between the proposed RTOF-RSS algorithm and the One-BS algorithm under the same platform setup environment. There are 910 random MS' placements, in which the BS reader is sited at the center and in the corner of the room. The BS and the tags are placed at a height of 0.77m. Fig. 9 shows the average values of the obtained distance errors of each MS. The signal agent of each MS is represented by the average value of the eight received signals. Each of the received signals is computed with the use of Eq. (6), and then fed into the algorithms. The distance errors of the MS' positions are computed with the use of Eq. (5). The distance errors are averaged and displayed into two forms: graphic and numerical. The graphical form is illustrated in Fig. 9, whereas the numerical form is reported in Table 7. It is noteworthy that the RTOF-RSS algorithm causes an error deduction in excess of 60% as compared to the One-BS algorithm. However, slight improvements occur when the BS is placed in a corner.

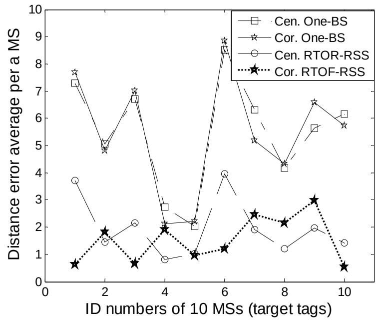


Fig. 9 Distance error averages for each MS

Table 7: Comparison in the accuracy averages for all MS on the One-BS algorithm and the RTOF-RSS algorithm

Algorithms based on input profiles	Location of the BS reader	Averaging eight signals around each MS	
		Average distance error (m)	SD
One-BS	Center	5.42	1.97
	Corner	5.44	2.20
RTOF-RSS	Center	2.03	1.17
	Corner	1.50	0.86

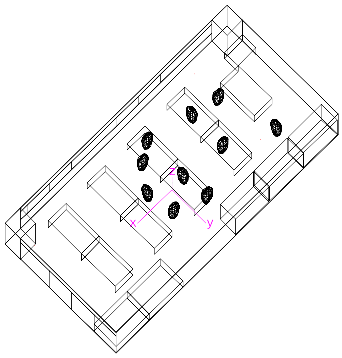
Seventh, the final simulations are the comparisons between our proposed system and the Landmarc system [11]. Two simulations are drawn for different 3D models, based on a computer system with Window XP on a 930 MHz Intel Pentium III processor, with 256 of RAM.

The first model is our proposed 3D model as described in Section 3.1. The BS and the tags are at a height of 0.77m. Comparisons among the proposed method and the Landmarc algorithm are studied under LOS and NLOS conditions. The average distance errors and their variances are summarized in Table 8. The RTOF-RSS algorithm significantly reduces the distance errors by approximate 30% compared to the Landmarc. The results also indicate the nature of the one BS locating system. At the center position, variances of the proposed system are larger than those of the system with the BS corner placement. This is due to the corner placement which eliminates the back side radiations, and thus improves the reliability of the system in determining the directions of the target tags.

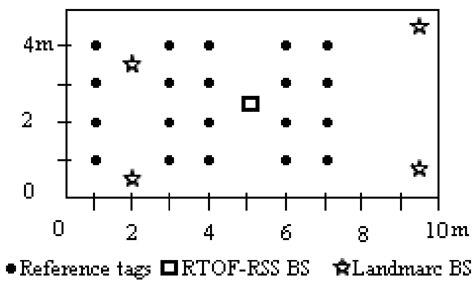
Table 8: Comparison of the RTOF-RSS algorithm and Landmarc algorithm based on the proposed 3D model

Condition	**Evaluation**	**RTOF-RSS algorithm**		**Landmarc algorithm**
		Center BS	**Corner BS**	**Four BS sites**
LOS	Average distance error	1.5490	1.6809	3.6357
	Average variance of error	1.2779	0.6904	1.9725
NLOS	Average distance error	3.3832	2.5832	3.8485
	Average variance of error	4.3682	1.5545	2.3938

The second model is the Landmarc 3D model [11], as shown in Fig. 10a. The Landmarc pattern is not a square grid as suggested in our proposed pattern. The Landmarc pattern places the 20 reference tags intermittently at the distance of 1m and 2m. The placement of the 20 reference tags is illustrated in Fig. 10b. This model is set up in the room sized 10m in width, 5m in length, and 2.5m in height. The BS and the tags are placed at the height of 0.77m. The components and material characteristics used in this simulation are listed in Table 2 with the UTD. The Landmarc model is run to generate signals which are subsequently fed into both the RTOF-RSS algorithm and the Landmarc algorithm.



a) The Landmarc 3D model of the Set 1 placement



b) Placement of the 20 reference tags and the BS readers

Fig. 10 The Landmarc model and placement of readers and reference tags

The coordinates of the four BS readers of the Landmarc system are shown in Fig. 10b, whereas a single BS reader of the proposed system is placed at the center and in the corner of the room. The BS reader placements of both the Landmarc and our proposed system are detailed in Table 9. The tests with the five different placement sets of the 10 target tag's coordinates, as listed in Table 10, are run.

The simulation results (distance errors) are calculated by means of Eq. (5). For each set, those distance errors are averaged and recorded in Table 11. The totalAVG, as listed in the bottom of this table, is an average value of the obtained values of the five sets. The totalAVG of the average distance errors (ADE) of the proposed system in both the centered BS and the cornered BS provides superior accuracy to the Landmarc system. Once the BS is in the corner of the room, the totalAVG of the average variance of errors (AVE) reduces two folds, compared to the Landmarc system. This is resultant from the cornered BS which radiates signals to the tags in the focused directions, while the centered BS radiates signals in omni-direction. The totalAVG of the average computed time (ACT) of the proposed system is somewhat worse in all cases because of the computational time of the iBox. As the proposed system causes a reduction of the system cost and the installation time, the cornered BS ought to be considered for the real installation as to achieve better accuracy and reliability.

Table 9: Coordinates of the BS readers at z = 0.77m

RTOF-RSS approach				**Landmarc approach**							
Center BS1		Corner BS1		BS1		BS2		BS3		BS4	
x	y	x	y	x	y	x	y	x	y	x	y
2.5	5.0	0.8	0.8	2.0	0.5	2.0	3.5	9.5	0.85	9.5	4.5

Table 10: Coordinates of 10 target tags in each set and at z = 0.77m

Target tags' ID	Set 1		Set 2		Set 3		Set 4		Set 5	
	x	y	x	y	x	y	x	y	x	y
1	4.5	3.6	4.8	3.8	5.8	3.8	4.4	3.6	4.8	3.2
2	5.6	3.2	5.6	3.6	4.6	3.6	5.6	3.0	4.2	2.2
3	4.6	2.6	5.0	2.2	5.0	3.6	4.4	2.6	5.0	1.6
4	5.8	2.2	4.4	1.0	5.0	2.2	5.8	2.0	6.0	1.0
5	5.2	1.4	1.4	3.6	4.2	2.0	5.0	1.6	4.6	1.0
6	4.6	1.0	2.0	2.4	4.8	1.6	4.6	1.0	2.0	3.0
7	3.0	2.8	2.0	1.4	5.4	1.6	3.0	2.8	2.0	2.0
8	3.0	1.4	2.2	1.0	4.2	1.0	3.0	1.2	8.6	1.0
9	1.4	3.6	6.2	2.8	5.6	3.4	3.6	3.6	6.8	3.8
10	2.0	1.6	6.4	1.6	5.6	2.6	1.6	3.4	6.2	2.4

Table 11: Comparison of the RTOF-RSS algorithm and Landmarc algorithm based on the Landmarc 3D model

Tested sets	**RTOF-RSS algorithm**						**Landmarc algorithm**		
	Center BS			Corner BS					
	ADE	AVE	ACT	ADE	AVE	ACT	ADE	AVE	ACT
Set 1	1.913	1.143	7.0	1.507	0.366	6.8	1.907	0.442	6.0
Set 2	1.584	0.516	6.7	1.312	0.448	6.2	1.889	0.452	5.6
Set 3	0.915	0.286	6.8	1.758	0.339	6.5	2.208	1.321	5.9
Set 4	1.614	1.384	7.0	1.251	0.366	6.6	2.398	0.348	6.0
Set 5	1.719	0.771	7.1	1.423	0.209	7.0	1.438	0.776	6.4
TotalAVG	**1.549**	**0.812**	**6.92**	**1.451**	**0.346**	**6.62**	**1.968**	**0.668**	**5.98**

ADE = Average Distance Errors, AVE = Average Variance of errors
ACT = Average Computed Time(sec.), TotalAVG = Averages in column

Finally, the comparisons over other two approaches are conducted. The UltrasonicReflections [13] proposed the 3D locating system based on a single BS with the use of ultrasonic reflections, and the TOA metric. The experiment was performed in an empty office room without room details, however, our proposed system was studied with the room-size and 3D objects in details. It applied the signature matching method which is a different from ours. The BS was fixed at a wall and the receiver was placed at 20 different positions. The least error was obtained with 20cm range. The worst scenario was obtained with 1.2m.

The Wi-FiAccessPoint [14] exploited a RSS metric, a single Wi-Fi access point, and a ray tracing technique. Its location estimates was computed using Bayesian filtering on sample sets derived by Monte Carlo sampling. The experiment was simulated under the environment of a 150 square meter floor-plan house, whereas our proposed system was estimated using the iBox method and the metric characteristics of both the RTOF and the RSS. The result showed that the filter was successful at estimating the node's location with an error of 1 meter range.

5. Conclusions

An innovative idea of the RTOF-RSS metric of one BS locating system with the application of RFID technology is presented. The proposed system applies the 3D simulation of the NEC-BSC application, and combines both the RTOF and RSS metrics with the iBox method to circumscribe the target tag location. The RTOF are first calculated by the RTOF-RSS algorithm through the iBox(es) as to obtain the radial distances of all tags placed on the radius of the BS. The six shortest distances, in the radial distances, between the target tag and the reference tags stored in the iBox(es) are considered. Subsequently, the RSS are computed by means of the proposed algorithm based on the candidate iBox(es) as to determine the direction of the target tag, based on the signal signature.

The analysis of the behavior of signals and their propagation characteristics reveal a fluctuation of the signals which is caused by the instability of severe multipath conditions. Thus, the RTOF metric is considered less sensitive to environmental changes and yields accurate radial distances, which renders a suitable template for the design of the iBox concept. The six shortest distances are selected, as they aid the reduction of computation time. The effective placement of reference tags is a symmetric grid layout with the segregation of 2 meters between the reference tags. The use of four reference tags within an iBox is appropriate, as it allows a system of only 12 iBox(es) and thus reduces the computational time. The computed tests proved an increased performance. The distance error of the proposed system under NLOS condition is reduced by 60% in comparison to the One-BS algorithm. Under LOS and NLOS conditions, the distance error of the proposed model is reduced by 33% compared to the Landmarc model. Since just one BS reader is used, the cost of the related hardware and installation time is greatly reduced.

Further studies are suggested on the use of smart antenna which controls the signal direction. This potentially improves the precision of the system as it reduces uncertainty of the signal strength. The extended work of the proposed system to a 3D real world environment should be investigated.

Acknowledgment

The author would like to thank Dr. Danai Torrungrueng, Asian University for his useful discussions and help with the simulation program. In addition, this research was supported by the graduate school, Kasetsart University.

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