Implementation of an RFID-Based Virtual Signal Mechanism for an Indoor Location Sensing System

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***Abstract*—** The variety in wireless technology and mobile computing devices has caused a growing application of location-sensing systems and correspondence services. The indoor location sensing system which applies radio frequency identification technology (RFID) is the most popular research topic in the area of location-sensing systems, and LANDMARC is the most representative one. However, LANDMARC suffers the drawback of inaccuracy in unstable signal intensity. A Virtual Signal Location System (VSLS) is designed and developed to overcome some drawbacks of LANDMARC. The concept of VSLS is based on additional setting of virtual signal tags as well as the normal distribution of signal strength, analysis of sampling rate and equalization to decrease signal intensity error. Comparisons were made with LANDMARC; these showed that VSLS effectively increased the sampling quality of the signal as well as the precision of positioning.

Keywords-LANDMARC, VSLS, RFID, location sensing, signal strength, virtual tag

I. INTRODUCTION

The variety in wireless technology and mobile computing devices has caused a growing application of location-sensing systems and correspondence services. In many industrial applications the physical location of objects needs to be known. Although the GPS outdoor location sensing system is mature [7], since it is satellite dependent it has an inherent problem in accurately locating objects inside buildings. For indoor location sensing systems, radio frequency identification technology (RFID) is one of the most popular techniques, whereas LANDMARC is the most representative [6]. LANDMARC is deployed in the interior space with a certain number of RFID readers and takes advantage of the large number of RFID tags for signal strength, thus it can provide guidelines. By examining the signal strength of the reference point, LANDMARC can obtain the tracking results. But LANDMARC has the drawback of inaccuracy in the case of unstable signal intensity. Moreover, the accuracy may drop rapidly due to enlargement of the tag deployment. How to overcome inaccuracy due to unstable signal strength and rapid drop due to enlargement of workspace motivated this research. In this paper, a Virtual Signal Location System (VSLS) [5] to overcome drawbacks of LANDMARC mentioned above is presented. The concept of VSLS is based on the additional setting of virtual signal tags as well as the normal distribution of their signal strength, analysis of sampling rate and equalization to decrease signal intensity error. The contribution of this research is in using VSLS to improve on LANDMARC. Some comparisons were made with LANDMARC; VSLS effectively increased the sampling quality of signal as well as the precision of positioning. In addition, the proposed mechanism also improved the tag deployment density along with accuracy; as a result, it reduced expenses.

RFID application has been getting increasingly popular over the last few years. It is being used in object identification in indoor environments because of the drawbacks of GPS, as mentioned earlier. RFID is used to store and retrieve data through electromagnetic transmission to a radio frequency (RF) compatible integrated circuit as a radical new means of enhancing data handling processes [4]. An RFID system has several components including a number of RFID readers, RFID electronic tags, and communication between these devices, and is shown in Figure 1. The communication mechanism is explained briefly in the following. If the application system needs to get product identification, the main computer sends a command to RFID readers. The readers send out radio frequency wave energy with an internal controller through the built-in RF transceiver. When the antenna of the electronic tag receives the radio wave, the internal transponder mechanism transforms the radio wave into power and a new radio wave is sent out to the main computer to do product identification and management [2].

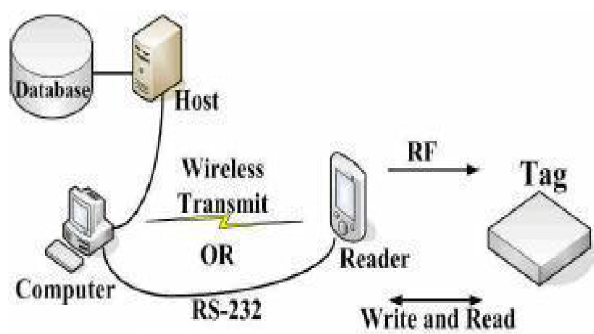

Figure 1. RFID architecture diagram

At present, there are a few well-known RFID indoor positioning technologies; for example, LANDMARC [6] and SpotON [1, 3]. LANDMARC uses extra fixed location reference tags with SSI (Signal Strength Indicator) and transmits power (Power Level) for location calibration. These reference tags serve as reference points in the system (like landmarks in our daily life). At the time LANDMARC was developed, RFID was not providing the frequency energy of tags to readers. Readers only reported the power detected within a range from level 1 to level 8 for determining the distance. The tag IDs received by readers are used to match with the existing reference tags, thus the range of their position can be estimated. The main advantage of this approach is that it is not expensive. The SpotON system [1] sets up a three-dimensional model based on the information received from Radio Frequency (RF) tags to determine product location. The positioning algorithm does not go through a central controller, but through the reference sensors with the same hardware architecture; sensors are scattered in the environment to collect and return the frequency energy information. The result is computed with distributed computation technology.

Based on the above, it can be concluded that applications of RFID-based technology provides both high positioning accuracy and low cost[8] making it the best option for indoor positioning.

II. SYSTEM STRUCTURE

Of the various positioning mechanisms, LANDMARC, developed by Ni *et al.*, is one of the most competitive mechanisms of all applications [9]. However, the accuracy of LANDMARC depends on the weight parameters generated by the signal strength between the reference tags and the tracking tag in estimating the position of an unknown signal. In fact, preliminary experimenting has shown that LANDMARC compares the signal strength of the tracking tag with some reference tags and takes the 4 nearby references tags to estimate weight numbers; results of the experiment are given in Figure 2. In Figure 2, “k” means the number of reference tags; “Ave” is the average distance error of all tracking tags, “Worst” is the worse performance of distance measuring of tracking tags. It shows that when k equals 4 LANDMARC performs the best. However, the distance between reference tags also plays an important role in the accuracy of positioning. Experiments were also run in an environment containing a reader, 4 reference tags and 10 tracking tags to test the positioning of the mechanism using LANDMARC. In Table 1, it is shown that when the distance between references tags was over 3 meters, the measuring error was larger. According to the above analysis of LANDMARC, the accuracy of positioning is proportional to the number of tags and inversely proportional to the distance between reference tags. The best performance of LANDMARC occurs when the distance between reference tags is 1-2 meters. This means that the best performance of LANDMARC depends on the number of references tags and the distance between them. In order to keep the same good performance in a larger workspace under restricted conditions and maintaining the same number of references tags, the distance between tags must be increased. However, then accuracy deteriorates.

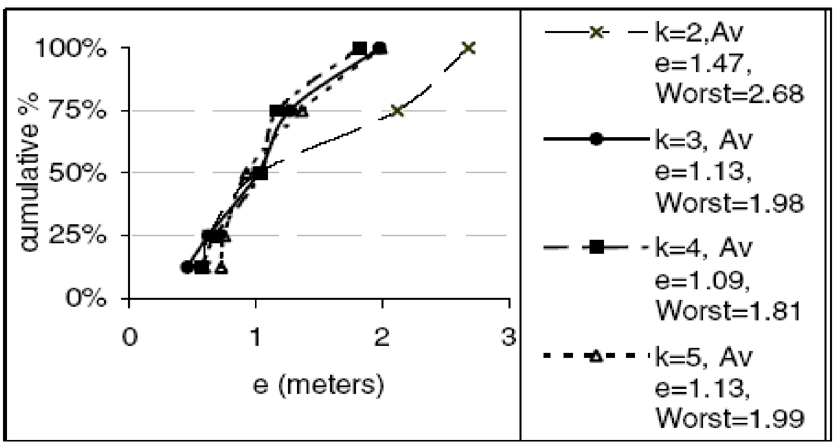

Figure 2. Experiments with LANDMARC showing k=4 as most accurate

Table 1. Simulation of positioning error in LANDMARC

Dist	1m	2m	3m	4m	5m
Tracking tag	Distance of error （unit：meters）				
t1	1.25	1.57	1.84	2.15	2.68
t2	1.31	1.65	1.68	2.31	2.95
t3	1.29	1.61	1.7	2.26	3.02
t4	1.32	1.55	1.66	2.25	2.74
t5	1.24	1.64	1.83	2.19	2.81
t6	1.22	1.62	1.74	2.32	2.69
t7	1.30	1.59	1.72	2.17	2.95
t8	1.28	1.63	1.69	2.28	2.73
t9	1.27	1.55	1.77	2.21	2.91
t10	1.23	1.57	1.81	2.29	2.82

As a result, the implementation of LANDMARC is limited in real world applications due to the lack of workspaces of 1 square meter. More reference tags have to be added in a large environment for accuracy, however, that increases the cost. Since, the number of reference tags in a real environment is limited, when the distance between tags is increased, LANDMARC does not have the best accuracy.

In this study, VSLS was designed and developed to compensate for the two problems of cost and a large workspace. The limited number of reference tags was reinforced by setting up extra virtual signals derived from virtual tags. The virtual tag was not actually hardware but was the signal strength derived from real active tags in an autopilot car. The sampling position spots were measured in advance and the signal strength was noted beforehand. That produced the off-line table which will be explained in more detail in the next section. As a result, the tag numbers of these two systems were quite different. A comparison was done of the number of tags in a 25 square meter room with both LANDMARC and VSLS; the reference tags had to be set up within 1 meter from each other. As a result, 50 tags had to be used in LANDMARC, but with VSLS only 10. Therefore, numbers of settings saved up to 5 times on the tags used in LANDMARC, making the application of RFID in a real environment possible.

In the following sections, the system structure of VLSL is briefly introduced by means of a simple diagram as given in Figure 3. This mechanism was designed using several processes and components. The process consisted of virtual signals sampling, a Middleware program to purify the signal strength, a database to store and access information, and the positioning mechanism of LANDMARC to compute the weight of the tracking tag relative to reference tags for computing the position of the tracking tags.

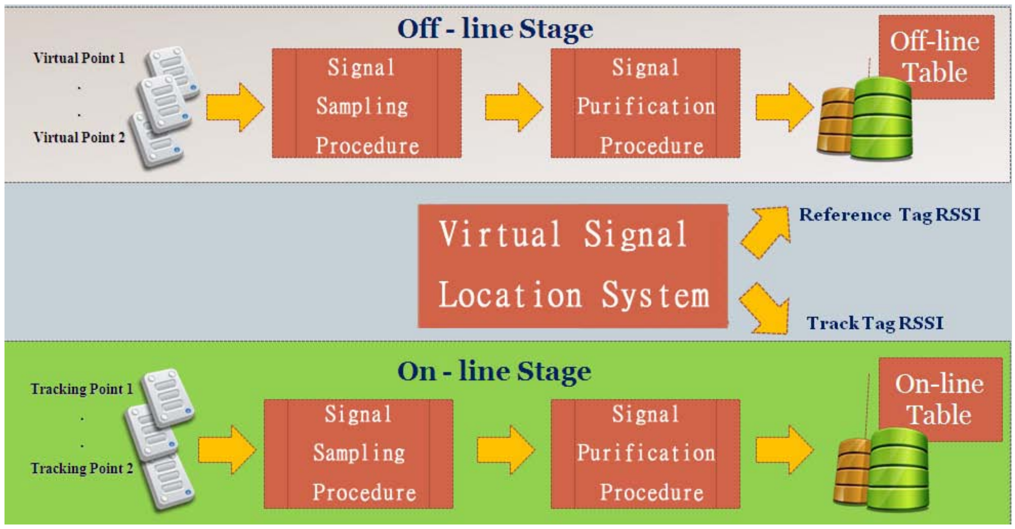

Figure 3. VSLS system structure

For a clearer picture of the VSLS virtual signal location system structure as given in Figure 3, Figure 4 is given to demonstrate the relationship between different components. It consists of several processes, including “Virtual signal receiving element”, “Signal purification element”, “Database element”, and “Positioning element”. We will give some description of the function of each element in the following paragraph.

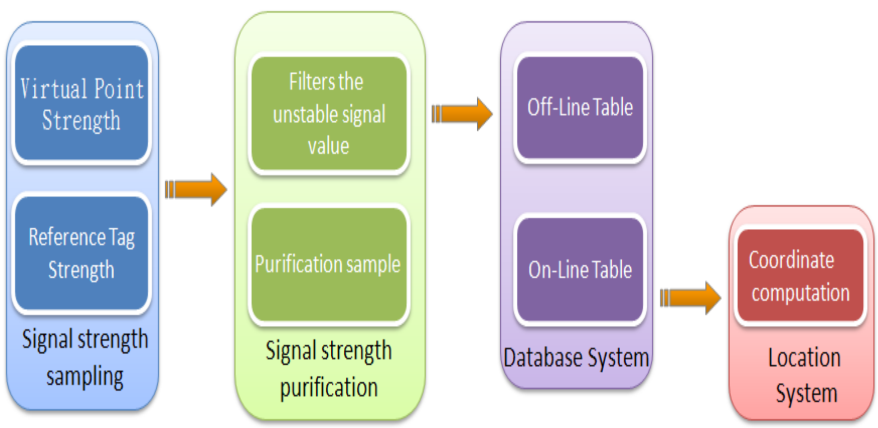

Figure 4. VSLS Position-Sensing system flow chart

A. Virtual Signal Receiving Element

The use of virtual tags may have less strong signal strength in a large room, thus the setting of tags includes both real reference tags and virtual tags. The reason for virtual tags based on those of an autopilot car is that these are different from the signals sent from fixed real tags. As is shown in Figure 5, V1~V8 were virtual signal tags and A ~ D were real signal tags. The function of real signal tags is to allow for the error caused by using a virtual signal due to overly strong or relatively weak signals and as well as environmental obstacles causing large errors in positioning. Signal purification can fix the signal strength error as given below.

B. *Signal Purification Element*

During the experiment, the quality of signal strength received from a reference tag was unstable due to the signal being derived from a moving object, that is the autopilot car in the experiment when entering or leaving the reference point determined in advance. At this stage, two signals were received, one sent by the reference tag, and the other by the virtual reference tag. In the purification process, a multi-sampling error analysis was performed and averaged. From Table 2, all sampling points for real tags and virtual positions for virtual tags can be seen. A 1.2 signal per second and 100 samples of signal were sent out. The speed of receiving was the same. The strongest and weakest 15 samples were deleted and only 70 samples were kept. An acceptable signal strength $RSSI_{\Phi}$ was obtained by averaging the signal strength (x_i) using the following formula [6].

$$RSSI_{\Phi} = \sum_{i=1}^{m} \frac{x_i}{m}. \tag{1}$$

Purification greatly reduced signal strength error caused by interference of exterior equipment reducing accuracy in subsequent positioning. The results after purification are shown in Table 3 and Table 4 for real reference tags and virtual reference tags, respectively. For real reference tags, the purification improved by 12% ~ 24% and for the virtual reference tags 4% ~ 9%. The signal strength after the averaging process by equation (1) greatly increased the accuracy of positioning during the experiment caused by some external interference of low signal strength.

Table 2. Tags arrangement in the experiment

Tag par. \ Tag dis.	1m	2m	3m	4m	5m
Reference Tags (unit: piece)	10	10	10	10	10
Virtual Tags (unit :piece)	0	10	20	30	40
Sending frequency (unit: sec/per sending)	1.2	1.2	1.2	1.2	1.2
Sampling signals (unit : piece)	100	100	100	100	100

Table 3. Signal strength improvement for the reference tags

Type	Tag	Before Purify	After Purify	Improvement in signal strength
RSSI	A	217	193	12.44%
	B	229	197	16.24%
	C	237	195	21.54%
	D	249	201	23.88%

Table 4. Signal strength improvement for the virtual reference tags

Type	Tag	Before Purify	After Purify	Improvement in signal strength
RSSI	T1	189	175	8.00%
	T2	180	173	4.05%
	T3	250	234	6.84%
	T4	263	241	9.13%

C. *Data Base Element*

A Microsoft SQL Server 2005 was used to set up a Database Management System (DBMS) which operated and managed signal data received from RFID tags. It consisted of the off-line and the on-line data sets which contained information including signal strength, coordinates, and battery power. In the following paragraph, these two databases are described.

1) The Off-line Table

The off-line table contains information collected from designated reference points sent from an autopilot car. The information included several items, such as tag number (Tag), quality of connection (LQI), signal strength (RSSI), reader number (Reader Name), battery power status (DI), x-coordinate (T1), y-coordinate (T2), and time of receiving (Show Time). Some signal strengths after purification were not be saved in the DBMS off-line table when the strength was lower than 100 RSS (low electric power). During the off-line stage, a function designed by Middleware which is called “prohibit all personel entering area” prevented signals or disturbance sent from any active tag.

2) The On-line Tabl**e**

When an unknown signal (the blue dot points in Figure 5) entered the area of the VSLS system, the RFID Middleware identified this signals as tracking tags, and put the data in the DBMS. In Figure 5, a simulation floor plan is given. When R1 (reader 1) reads the signal sent from the tracking tags, Middleware took data collected from the off-line table of the neighboring reference and virtual tags and compared them. Several formulas were used and their variables were the same as those of LANDMARC. This is discussed in Section III [6], including Eqs. 2 and 3;

$$E_j = \sqrt{\sum_{i=1}^{n} (\Theta_i - S_i)^2}, \tag{2}$$

$$w_j = \frac{\frac{1}{E_i^2}}{\sum_{i=1}^{t} E_i^2}. \tag{3}$$

Equation 2 was used to calculate the signal strength of the tracking tags relative to the reference and virtual tags; Equation 3 was used to calculate the weight of the tracking tag with respect to neighboring reference and virtual tags.

As is shown in Figure 5, the last four (k) reference tags C, D, V3, and V4 were the closest tags corresponding to the tracking tag detected by reader R1. A positioning formula $(x,y)=\sum_{i=1}^{k} w_i(x_i,y_i)$ was used to calculate the coordinate of the tracking tag, and the position information was written in the on-line table, which contained the information of several items, such as the tag number (Tag), signal strength (RSSI), x-coordinate (T1), y-coordinate (T2), reference tags number (P1-P4), entering time (ShowTime), and reader number (Reader Name). VSLS tracked and recorded the location of each tracking tag and saved these data for subsequent positioning analysis.

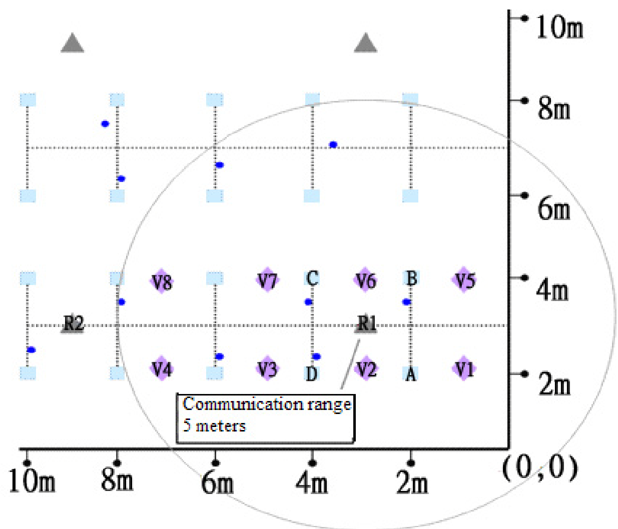

Figure 5. Experimental Floor Plan

In this research, components in the system were all related to each other; the signal receiving element determined the virtual signals using the autopilot car; the signal purification was done with Middleware in both the off-line and on-line stages; and a database was established which contained information of the location of reference tags, virtual tags, the weight of tracking tags compared to reference tags, and a mechanism for positioning analysis in order to choose the closest reference or virtual tags as the parameters in the calculation of positioning. The problems of LANDMARC can be resolved by using a virtual signal sampling process. In the next section, simulation experiments for testing the use of signals in VSLS and comparing the performance with LANDMARC are presented. In addition, experiments with the number of tags used in the positioning systems are compared showing that the number of reference tags can be greatly reduced, making for hardware expense being lower in the VSLS system.

III. EXPERIMENT SIMULATION

A. *Experimental Environment*

A 10 meters by 10 meters floor plan was designed to execute the experiment. Different simulations could be carried out by enlarging the distance between reference tags. The environment excluded the inference of wireless base settlement and man-made obstacles, as is shown in Figure 5. In the experiment area, readers, reference tags, tracking tags, and virtual tags were set. The effective range of the receiving signals from tags was set to be 5 meters, and different readers were 5 meters, 10 meters, and 15 meters apart in different simulations to prevent inter-connection between different readers degrading the stability of signal reception. The frequency of reference tags was set to be the same as that of the readers, which was 2.4 GHz. The sending frequency was 1.2 signals per second, and the placement of the tags was adjustable. In order to do a comparison with LANDMARC, the distance between tags was set to be 1 meter in the beginning, and different simulations were carried out by increasing the distance from 1 meter to 5 meters apart with increments of 1 meter per simulation. The virtual tags were not functional when the distance between various tags was 1 meter. When the distance was 2 meters, then the virtual tags V1 to V6 were set in the neighborhood of B, C, A, D reference tags as shown in Figure 6. The reader in this experiment was Syris SYRD245-1N (2.4 GHz), the reference tag was Syris Active Tag (2.45 GHz), and the autopilot car was Surveyor Corporation SRV-1.

B. *Simulation*

In order to test the functioning of virtual tags and to compare with LANDMARC, several simulations were carried out, and the experiments differed according to the distance between reference tags. In the simulation, both VSLS and LANDMARC used 10 reference tags, 10 tracking tags, the sending frequency for all was 1.2 signal/sec, and 100 samples were received for each position. The main purpose of real reference tags being used was to do some adjustment when there were changes like displacement, regular adjustments, and virtual tag signal adjustments.

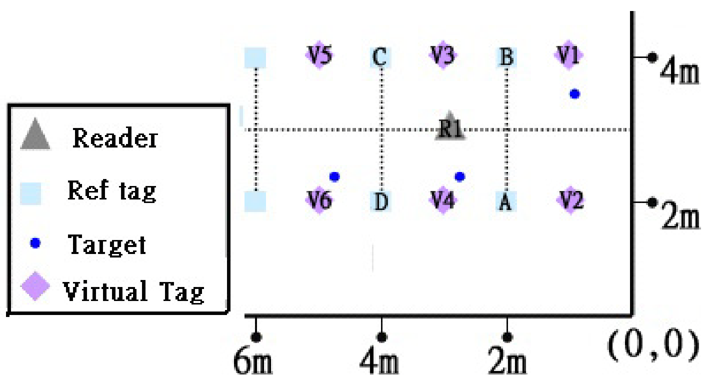

Figure 6. Virtual tags are included when reference tags are more than two meters apart

C. *Pre-positioning Stage*

The off-line stage: An autopilot car followed a designated route along the virtual tags and moved at 2.5 meter/sec, when it entered a position assigned for a virtual tag, it stayed for 120 seconds to let the tag in the car send a signal back to the RFID Middleware and also to the off-line database. For every 100 signals only 70 were kept in the DBMS because of the/for purification.

D. *Positioning Process*

The on-line stage: When the tracking tags entered the area of a reader (for example R1), the tracking tags sent about 25 signals per meter. The purification process deleted the strongest 5 and the weakest 5 signal data and only 15 signals were taken to find an average value as the signal strength of the tracking tag, and then delivered to the positioning process.

The positioning process was similar to that of LANDMARC, signal strengths were the same as with [6]. Suppose there are n RFID readers along with m tags as reference tags and u tracking tags as objects being tracked. The Signal Strength Vector of a tracking/moving tag is defined as $S = (S_1, S_2, \ldots, S_n)$ where S_i denotes the signal strength of the tracking tag perceived on reader i, where i $\in (1, n)$. For the reference tags, the corresponding Signal Strength Vector is $\theta = (\theta_1, \theta_2, ..., \theta_n)$ where θ_i denotes the signal strength. We introduce the Euclidean distance in signal strengths, for each individual tracking tag p, where p $\in (1, u)$. Define $E_j = \sqrt{\sum_{i=1}^{n} (\theta_i - S_i)^2}$, where j $\in (1, m)$, as the Euclidean distance in signal strength between a tracking tag and a reference tag r_j. Let E denote the location relationship between the reference tags and the tracking tag, i.e., the nearest reference tag to the tracking tag is supposed to have the smallest E value. When there are m reference tags, a tracking tag has its E vector as $E = (E_1, E_2, \ldots, E_m)$. Same weight function as Equation 2 is used to calculate the weight to the nearest reference tags. An error between the real location and the tracking location is calculated by $e = \sqrt{(x - x_0)^2 + (y - y_0)^2}$ where (x, y) are the coordinates of the calculated tracking tag and (x_0, y_0) is the true location of the tracking tag.

E. Positioning Analysis

For comparison between VSLS and LANDMARC, 10 tracking tags were used for both systems, and errors of these 10 tracking tags from the positioning process were calculated. The same process was repeated 1000 times, an average error and the largest error of each tracking tag was obtained. The average error was the average of the distance error of each tracking tag in 1000 trials; and the largest error was the average of the largest distance errors. The relative error of the average error and the relative error of the largest error are defined as follows:

1. SAvg.Dist:= $\frac{\text{LANDMARC SAvg.Dist-VSLS } SAvg.Dist}{\text{LANDMARC } SAvg.Dist} * 100\%,$

2. SMax.Dist: $\frac{\text{LANDMARC SMax.Dist-VSLS } SMax.Dist}{\text{LANDMARC } SMax.Dist} * 100\%.$

F. Different Simulation Scenarios

CASE 1: One meter between neighboring reference tags.

In this case, even though the virtual tags were not functioning yet, purification had an effect in gaining an accuracy advantage of 0.65% in the average error and 24.33% in the largest error, respectively, when VSLS was compared with LANDMARC. The red square-dot line represents the performance of VLSL and the blue diamond-dot line the performance of LANDMARC. From Figs. 7 and 8 it can be seen that the red square-dot line generally stayed below the blue diamond-dot line meaning that the performance of VSLS was a little better in case 1, especially in the Maximum error performance at the tag t_3.

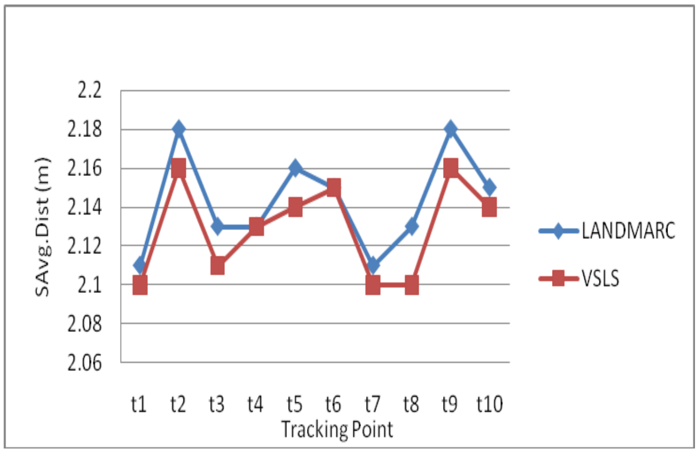

Figure 7. Average error of 10 tracking tags of VLSL and LANDMARC in case 1

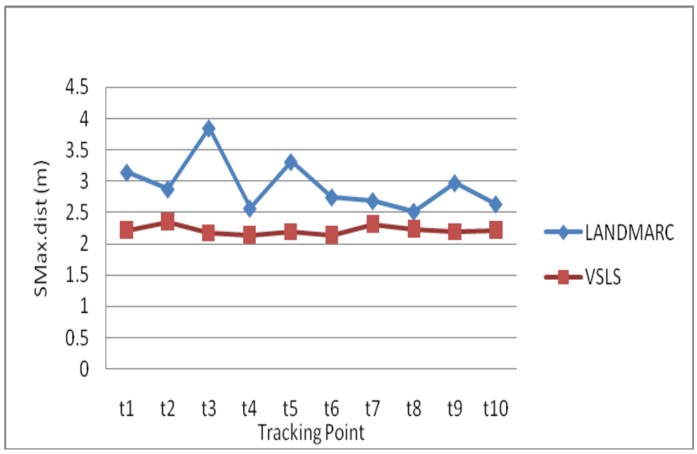

Figure 8. Largest error of 10 tracking tags of VLSL and LANDMARC in case 1

CASE 2. Two meters between neighboring reference tags.

From Figure 9, the SAvg.Dist of LANDMARC ranged from 2.2 to 2.3 meters compared with 2.12 to 2.18 meters when the distance between neighboring reference tags was 1 meter; this means that the accuracy of the system was reduced by increasing the distance between reference tags, nevertheless, the average error of VSLS stayed between 2.07 and 2.16 meters. VSLS had about 6.05% improvement in the average error and 26.3% improvement in the largest error compared with LANDMARC as shown in Figures 9 and 10, respectively.

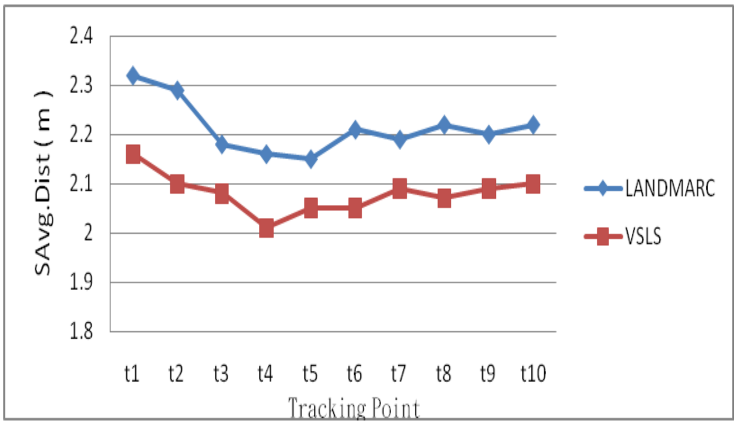

Figure 9. Average error of 10 tracking tags of VLSL and LANDMARC in case 2

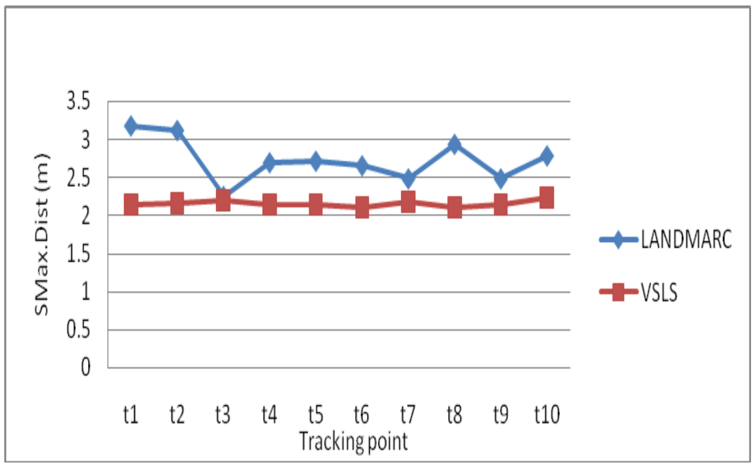

Figure 10. Largest error of 10 tracking tags of VLSL and LANDMARC in case 2

<u>CASE 3. Three meters between neighboring reference tags.</u>

From Figure 11, the average of LANDMARC was getting large in ranges from 2.25 to 2.4 meters compared with 2.12 meters to 2.18 meters when the distance between neighboring reference tags was 1 meter; this means that the accuracy of the system was even more reduced by increasing the distance between reference tags from 1 to 3 meters, but the average error of VSLS stayed between 2.05 and 2.17 meters. VSLS had about 8.47% improvement in the average error and 26.73% improvement in the largest error compared with LANDMARC as shown in Figures 11 and 12, respectively.

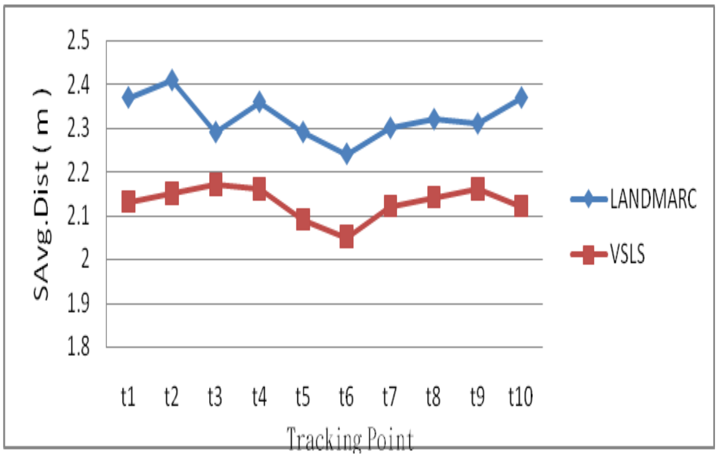

Figure 11. Average error of 10 tracking tags of VLSL and LANDMARC in case 3

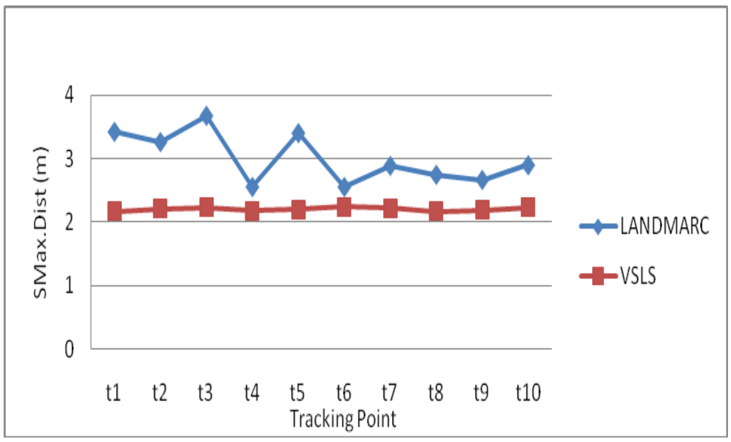

Figure 12. Largest error of 10 tracking tags of VLSL and LANDMARC in case 3

CASE 4. Four meters between neighboring reference tags.

From Figure 13, the average of LANDMARC was getting large in ranges from 2.53 to 2.55 meters compared with 2.12 to 2.18 meters when the distance between neighboring reference tags was the initial distance 1 meter apart; this means that the accuracy of the system was greatly reduced by increasing the distance between reference tags from 1 meter to 4 meters, but the average error of VSLS stayed in the range of 2.09 to 2.34 meters. VSLS had about 18.38% improvement in the average error and 31.49% improvement in the largest error compared with LANDMARC as shown in Figures 13 and 14.

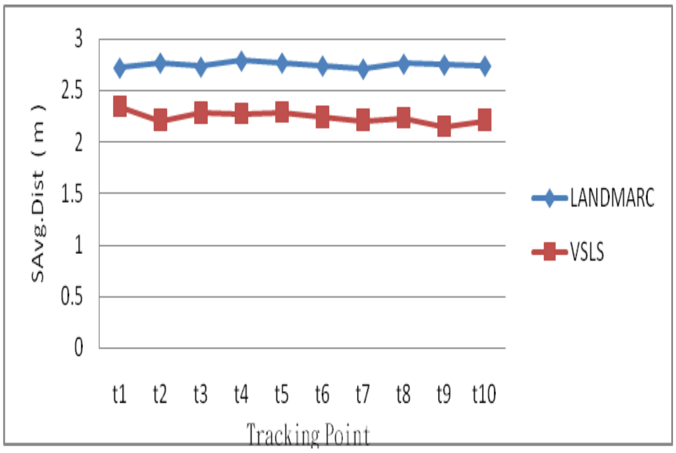

Figure 13. Average error of 10 tracking tags of VLSL and LANDMARC in case 4

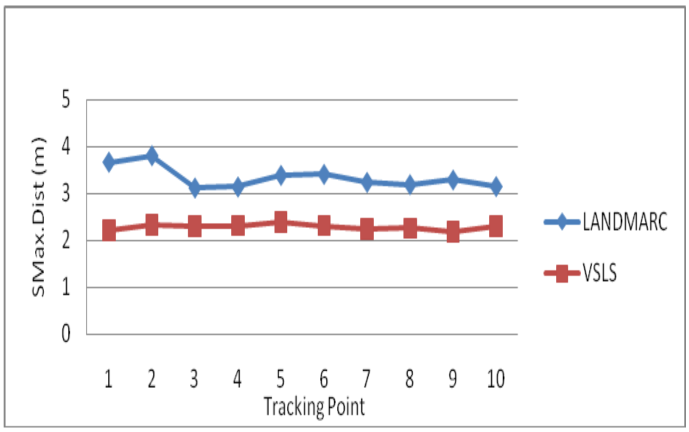

Figure 14. Largest error of 10 tracking tags of VLSL and LANDMARC in case 4

<u>CASE 5. Five meters between neighboring reference tags</u>.

From Figure 15, the average of LANDMARC was getting even larger in ranges from 2.58 to 3 meters compared with 2.12 to 2.18 meters when the distance between neighboring reference tags was 1 meter; this means that the accuracy of the system was greatly reduced by increasing the distance between reference tags, but the average error of VSLS stayed in the range of 2.34 to 2.67 meters. VSLS had about 189.64% improvement in the average error and 36.29% improvement in the largest error compared with LANDMARC as shown in Figures 15 and 16, respectively.

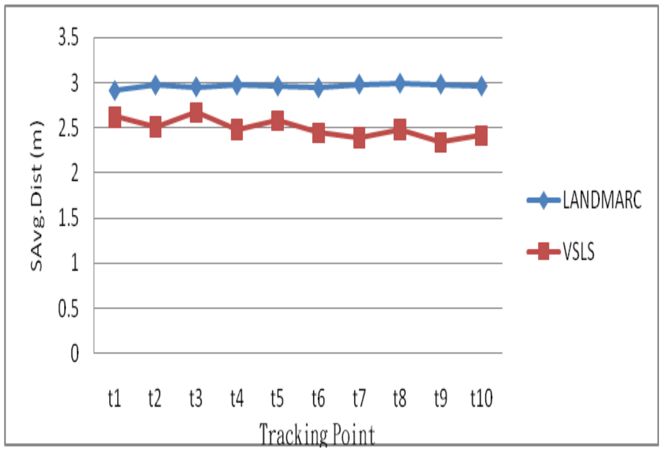

Figure 15. Average error of 10 tracking tags of VLSL and LANDMARC in case 5

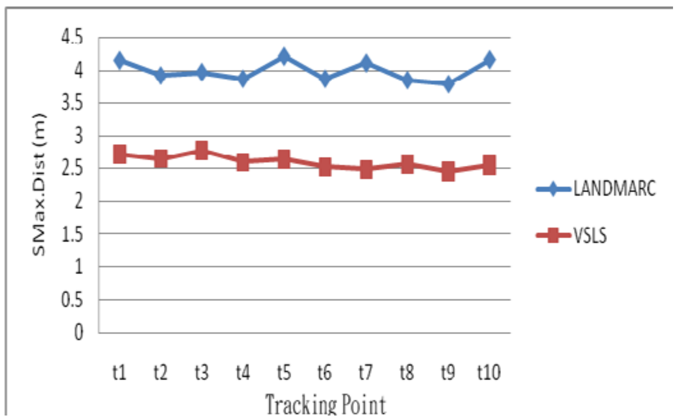

Figure 16. Largest error of 10 tracking tags of VLSL and LANDMARC in case 5

Tables 5 and 6 are given to show the comparison between VSLS and LANDMARC in these 5 simulations and to determine the accuracy of the two positioning systems. The results were evaluated by executing 1000 positioning simulations for each case, and the average error and the largest error were evaluated by taking the mean of the sum of the average error and the largest error of these 1000 simulations, respectively. It shows that VLSL outperformed LANDMARC by the percentage given in the last row of each table.

Table 5. Average error in VSLS and LANDMARC

Average error					
Case / System	Case 1 SAvg.Dist(m)	Case 2 SAvg.Dist(m)	Case 3 SAvg.Dist(m)	Case 4 SAvg.Dist(m)	Case 5 SAvg.Dist(m)
LANDMARC	2.143	2.214	2.326	2.748	3.101
VSLS	2.129	2.08	2.129	2.243	2.492
Comparison	0.65 %	6.05 %	8.47 %	18.38 %	19.64 %

Table 6. Largest error in NSLS and LANDMARC

The Largest Error					
Case / System	Case 1 SMax.Dist(m)	Case 2 SMax.Dist(m)	Case 3 SMax.Dist(m)	Case 4 SMax.Dist (m)	Case 5 SMax.Dist(m)
LANDMARC	2.926	2.928	3.008	3.341	3.99
VSLS	2.214	2.158	2.204	2.289	2.542
Comparison	24.33 %	26.30 %	26.73 %	31.49 %	36.29 %

G. Discussion

The results of these simulations showed that the virtual tags filled the gap by improving accuracy of position-sensing due to the enlargement of the distance between neighboring reference tags and that the VSLS system outperformed and gave better accuracy compared with LANMARC under similar settings. The reason was that the signals depicted from real tags in the autopilot car were kept stable, and these signals were received in the off-line stage. This means that there was low interference, no obstacles, and that the signal strengths remained stable due to the additional purification process. The reason why LANDMARC was less accurate when the distance between reference tags increased, was due to the best performance currently in LANDMARC for a 2D environment needing 4 reference tags, and the enlargement of the distance causing the signal strengths to be lower, and that would cause the accuracy of position-sensing getting weaker. From Tables 5 and 6, it is shown that the refinement of each case was 0.65%, 6.05%, 8.47%, 18.38%, up to 19.64%; and the refinement in the largest error for each case was 24.33%, 26.30%, 26.73%, 31.49%, and up to 36.29% respectively. VSLS did make up for reduced accuracy due to the enlargement of distance between reference tags in LANDMARC.

Another perspective of this research is the arrangement of hardware in the floor plan. VSLS used signal strengths from virtual tags to replace signal strengths from real reference tags. Applying the off-line stage to produce virtual signal sources was one of the key factors to avoid over-usage of reference tags in order to maintain accuracy. In Table 7, a comparison between LANDMARC and VSLS positioning mechanisms was made. The experiment was designed to let these systems maintain a fixed distance between tags, that is, 1 meter. In LANDMARC, the number of real tags had to be increased; while in VSLS, virtual signals were implemented and deployed instead. In VSLS, 10 reference tags (S) were used, and they were used in the off-line stage to adjust the virtual signals (θ), under the restriction $RSSI_{S_n} < RSSI_{\theta} < RSSI_{S_{n+1}}$. When the signal strength $RSSI_{\theta}$ was larger than $RSSI_{S_{n+1}}$ or $RSSI_{\theta}$ was smaller than $RSSI_{S_n}$ then this signal had to be rebuilt in order to avoid bias and maintain accuracy.

Table 7. Comparison between LANDMARC and VSLS under the same number of reference tags

Positioning accuracy under the same number of reference tags between LANDMARC and VSLS					
Scenarios / **Systems**	**1 m**	**2 m**	**3 m**	**4 m**	**5 m**
VSLS	10	10	10	10	10
LANDMARC	10	20	30	40	50
SAvg.dist (%)	0.3	0.21	0.33	0.37	0.29
SMax.dist (%)	23.79	27.14	29.37	32.06	38.1

From Table 7, under the same requirement of 1 meter between reference tags (or virtual tags), VSLS improved in the average error from case1 to case 5 about 0.3%, 0.21%, 0.33%, 0.37%, 0.29%, respectively. In the maximum error, VSLS improved from 23.79%, 27.14%, 29.37%, 32.06% to 38.1%, respectively. The number of real reference tags saved up to 2 to 5 times compared with LANDMARC. The VSLS system saved on the hardware for the position-sensing system, and VSLS also gained budget efficiency in the real environment.

IV. Some Concluding Remarks

a. A new position-sensing system, VSLS, is developed and designed. It used similar principles and rules as LANDMARC. The accuracy of positioning was improved compared with LANDMARC whose accuracy can be degraded due to distance enlargement between reference tags. By applying the concept of virtual tags whose signal was derived from a real tag in an autopilot car, and by the normal distribution of signal strength, samples adoption and signal purification signal strength error was reduced. The purified signals were saved in DBMS. When the tracking tags entered the search area, the signal strength saved in DBMS was used to match and do positioning analysis, and the positioning error was greatly reduced, and it was not affected by change in another search environment such as the enlarging of distance between neighboring reference tags.

b. Different simulated cases were studied by enlarging distance between reference tags. From Tables 8 and 9, it can be seen that the refinement of these cases was 0.65%, 6.05%, 8.47%, 18.38%, up to 19.64%, respectively; and the refinement of the largest error in these cases was 24.33%, 26.30%, 26.73%, 31.49%, and up to 36.29%, respectively. VSLS did make up for degraded accuracy due to the enlargement of distance between reference tags in LANDMARC.

c. With the placement of reference tags, VSLS was more applicable in the real positioning-sensing environment, since according to the simulation when the distance was from 1 meter to 5 meters, virtual tags were used instead of real reference tags, the number of reference tags was thus greatly reduced and hardware expense was lower. The accuracy of average error maintained a level within 2.5 meters, and the largest error was maintained within 3 meters, even when the distance between reference tags was up to 5 meters. As a result, VSLS position-sensing system was proven to be more suitable for the real environment than LANDMARC.

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