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Adaptive Rfid Positioning System Using Signal Level Matrix

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***Abstract*—**In this paper, we present a method named Signal Level Matrix (SLM) which can improve the accuracy and stability of active RFID indoor positioning system. Considering the accuracy and cost, we use uniform distribution mode to set up and separate the overlapped signal covering areas, in order to achieve preliminary location setting. Then, based on the proposed SLM concept and the characteristic of the signal strength value that attenuates as the distance increases, this system cross-examines the distribution of adjacent signals to locate the users more accurately. The experimental results indicate that the adaptive positioning method proposed in this paper could improve the accuracy and stability of the positioning system effectively and satisfyingly.

***Keywords*—**RFID positioning, localization, indoor, location-aware.

I. Introduction

RADIO Frequency Identification (RFID) is a technology that identifies the target object and obtains related data automatically based on radio frequency signals. The RFID contains Readers and Tags. In fact, the RFID has been widely used in daily life, such as access card, electronic wallet, and EasyCard in Taiwan. This paper focuses on the application to indoor location by using the active RFID.

Location-based service (LBS) has been extensively studied in recent years. The most representative example is GPS (Global Positioning System), which has been developed into various applications, including navigational tools, such as PAPAGO and Navi, and online maps, such as Google Map and Yahoo Map. However, the GPS cannot overcome the interference of indoor objects, thus researches related to indoor positioning have emerged and developed rapidly [1-12]. According to the comparison on common indoor positioning systems, such as RFID, Bluetooth, WIFI, Ultrasounds and WIMAX, RFID is the best tool for indoor positioning, in terms of accuracy and cost [13].

Three key points are usually evaluated for the RFID-based Real Time Location System (RTLS) [14]: 1) deployment mode: how to arrange Tag and Reader indoors to achieve the most efficient coverage; 2) cost: although the RFID technology has reduced the cost greatly, as compared with other technologies, a lower system setup cost is more helpful to the prevalence and related applications of the system; 3) positioning accuracy: for a RFID positioning system, the most direct indicator of positioning accuracy is how to reduce the positioning error.

At present, four major technologies use RFID in research of positioning, which are Time of Arrival (TOA), Time Difference of Arrival (TDOA), Received Signal Strength (RSS) and Angle of Arrival (AOA). TOA and TDOA are positioning techniques using time as the basis of measurement, and they require accurate synchronization and frequency. TDOA measures the distance by using the relative time of the measured signal, whereas TOA uses the absolute time to measure the distance. As compared to the basis of time, RSS uses the signal strength as the basis of measurement, but this method is likely to be interfered by multi-path and objects, resulting in measurement errors. AOA uses antenna arrays or directional antennae in LOS (Line-of-sight) signal transmission environment for accurate results. RSS is the most suitable positioning mode for indoor environment at present, considering cost and accuracy.

This paper proposes a low cost and accurate RFID positioning method in an efficient deployment mode based on the characteristic of the signal strength and the concept of Signal Level Matrix. The remainder of this paper is organized as follows: Section 2 introduces and analyzes related studies of RFID positioning; Section 3 presents the system architecture, positioning mode and positioning process; Section 4 discusses the concept of the Signal Level Matrix and the fault-tolerant positioning mechanism; Section 5 analyzes and compares the experimental results; Section 6 gives the conclusions.

II. Related works

As the RFID indoor positioning system develops rapidly, many RFID positioning systems have been released, such as SpotON [1], LANDMARK [2], VIRE [3], LEASE [4]. These positioning systems have become the basis of subsequent researches on RFID positioning, as well as successful indoor positioning systems [5-12].

The SpotON system proposed by J. Hightower et al. (2000) is the pioneer of active RFID positioning research. The system uses RFID Reader and many active RFID Tags to construct a wireless sensor environment covering the whole indoor area. It also proposes a signal strength regression model by using the signals between active RFID Tag and RFID Reader, which

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receives radio wave through RFID, and determines the distance between the sending end and the receiving end according to the signal strength.

L. Ni et al. proposed another well-known active RFID positioning system, LANDMARK [2]. It is based on the algorithm for converting received signal strength indication into distance used by J. Hightower et al. in the SpotON system. The LANDMARK system adds a Reference Tag in its location environment to help positioning and resolving obstacles in the environment, and uses K-nearest neighbor algorithm to screen the reference point and improve the execution efficiency. Appling the active RFID to positioning systems was proven to be feasible, but some problems were yet to be solved, such as unstable performance of Tag in signal strength, and the RSSI values of the time were simply separated by 8 levels. Thus, using only the signal strength value for location seemed to be deficient.

Y. Zhao et al. proposed another positioning system, VIRE [3], which incorporates the concept of Reference Tag as in LANDMARK. VIRE carries out linear interpolation according to signal strength by using the concept of four solid Tags enclosing a Grid, the Grid is cut into N x N Virtual Grids. Thus, the concept of Virtual Reference Tag is incorporated in positioning assistance. VIRE requires lower cost, and improves the resistance to environmental noise. More accurate positioning value than LANDMARK can be obtained after the specific threshold filtering procedure.

The LEASE positioning system proposed by P. Krishnan et al. included reference point in the system, and compared the changes in RSS value for positioning [4]. Jin et al. added the screening mechanism of Reference Tag in the LANDMARK system to improve the positioning effect [5]. Shih determined the distance weight based on the signal strength in the system, and displayed the position of the object through triangulation method [6]. Yang used two-phase cluster algorithm to solve the problem in identifying Reference Tag [7]. Jian used TOA–AOA location algorithm to determine the time difference of received RFID signal and the incidence of signal, so as to improve the positioning accuracy [8].

Many new active RFID positioning systems have been proposed in recent years. Jiang et al. published an article on LANDMARK system in 2009 [9], which suggests to conduct re-positioning by exchanging the Reference Tag with the closest Tracking Tag after the first positioning by the LANDMARK system. The results showed an improvement of the positioning accuracy. Huang et al. also used the concept of LANDMARK, but changed the corner positioning of LANDMARK system to triangulation method, so as to improve the positioning accuracy [10]. Other studies also proposed different methods. For example, Chang et al. combined ultrasonic to assist in positioning, so as to reduce the error values of location [11].

Based on the above, the main cause for positioning system errors is instable RSSI of Tag signal, and it is likely to be interfered by environmental factors. Thus, using only signal strength for location often results in large errors in location [1-12]. Therefore, this paper did not use the signal strength value for positioning directly. Since the signal strength of Tag would decrease as the distance increased, and considering the differences of environment and Tag, it first classified signal levels for different Tags at multiple distances, and then used the matrix formed by these signal levels and the fault-tolerance mechanism for accurate and stable positioning.

III. System Architecture

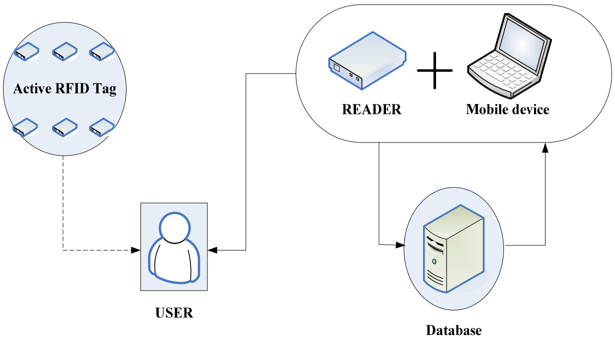

Fig. 1 Schematic diagram of positioning mode

Figure 1 is the schematic diagram of the positioning mode proposed by this paper. The active tags are set in the localization environment equally in intervals of 2m at upper, lower, left and right side. The suitable signal strength threshold for specific Tag is analyzed and stored in the database. When users move in the indoor space with mobile device combined with RFID Reader, the positioning system compares the received Tag signal values with the positioning data in the database timely, in order to determine the location of the users.

The positioning process of this system is shown in Figure 2. First, the localization environment is arranged before positioning, and the signal strength reference values of specific Tag at different distances are analyzed and set. Then, the SLM of all sensing areas are set up and stored in the database according to the signal strength reference values. During real-time positioning, the Reader converts the received signal level into SLM timely, and searches the database for identical SLM. If an identical SLM is found, the corresponding sensing area is displayed directly to finish positioning; if no identical SLM is found, the fault-tolerance mechanism is used for searching similar SLM to complete positioning; if no similar SLM is found, the system returns to the step of analyzing signals for re-collection of signals and repositioning.

As compared with other RFID positioning systems, this system only requires one RFID Reader and several Tags to complete positioning, and it can reduce the construction cost of positioning system effectively. Furthermore, in the proposed positioning method, the user carries a RFID Reader, which allows the system administrator to know about the user's location, and the user can know his location timely. Thus, this system can indicate the position of the user timely, and can be applied in guides of exhibition halls, museums, airports or campuses.

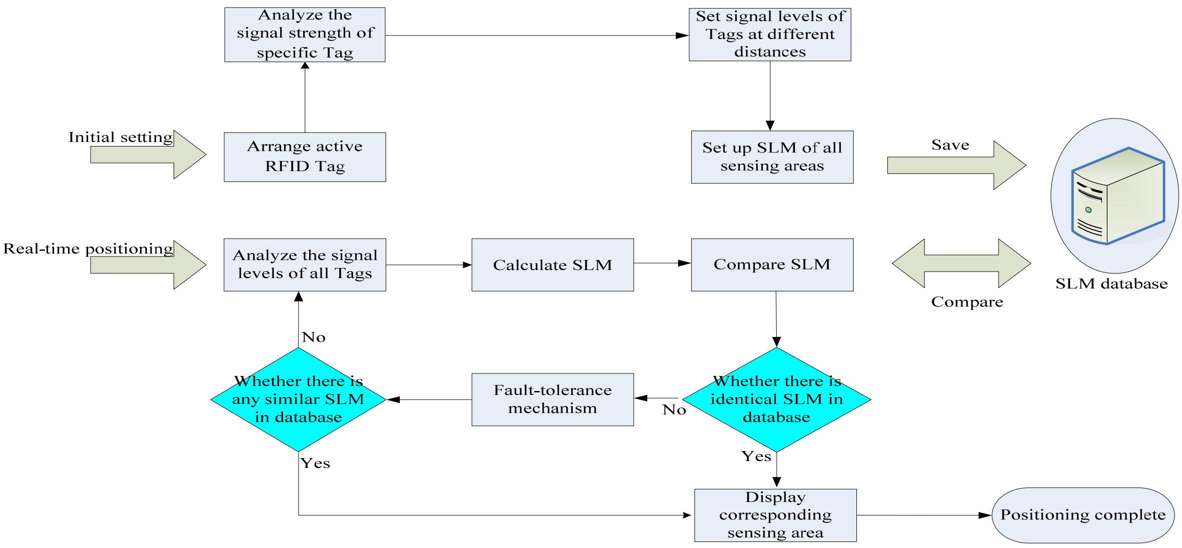

Fig. 2 Schematic diagram of positioning flow

IV. Fault-Tolerant Positioning Mechanism

Most of RFID positioning methods use the signal strength directly as the basis of positioning, but these methods sometimes neglect the differences in Tag signal strength. The proposed method can set proper signal strength reference values respectively according to the individual differences of environment and Tag, and then analyze the variance in signal strength, so as to improve the accuracy of positioning. The construction of the adaptive RFID location mechanism in this paper contains three steps: analysis of sensing overlap area, analysis and comparison of Signal Level Matrix, fault-tolerance mechanism. The details are described below.

A. Analysis of Sensing Overlap Area

As shown in Figure 3, an active RFID Tag is arranged at an interval of 2 meters in the location space, and each Tag is coded (T11, T12, …Tmn) according to the line coordinates (m, n). Two round sensing ranges with radii of 1 meter and 2 meters are specified centering on the position of Tag, and the intersection of these sensing ranges divides the location space into several smaller independent sensing overlap areas. These sensing overlap areas can be divided into three types according to the distance between the user and the Tag: 1) the Reader is very close to a Tag (less than 0.5 meter); 2) the distance between the Reader and a Tag is over 0.5 meter and less than 1 meter; 3) the distance between the Reader and all tags is over 1 meter.

As shown in Figure 3, using the area of Tag11 to Tag33 as an example, in the first situation, if the Reader is very close to Tag22 (less than 0.5 meter), it can be located at Tag22 directly (this location is named A22). In the second situation, taking Tag22 as an example, if the distance between Reader and Tag22 is over 0.5 meter and less than 1 meter, the range of 1 meter around Tag22 is divided into 8 blocks, and the blocks are named according to their positions relative to Tag22 (Up, Down, Left, Right), which are A22U, A22D, A22L, A22R, A22UL, A22UR, A22DL and A22DR.

In the third situation, if the distance between Reader and all Tags is over 1 meter, namely, the Reader is just located among 4 tags, the plane among four Tags can be divided into 4 smaller and more accurate location blocks based on the signal strength of other remote Tags. The blocks are named by adding X to the end of the name of the adjacent second kind of block, for example, the third kind of blocks among Tag22, Tag23, Tag32 and Tag33 are named A22DRX, A23DLX, A32URX and A33ULX. Take the third kind of blocks around Tag22 as examples, they are named A22ULX, A22URX, A22DLX and A22DRX.

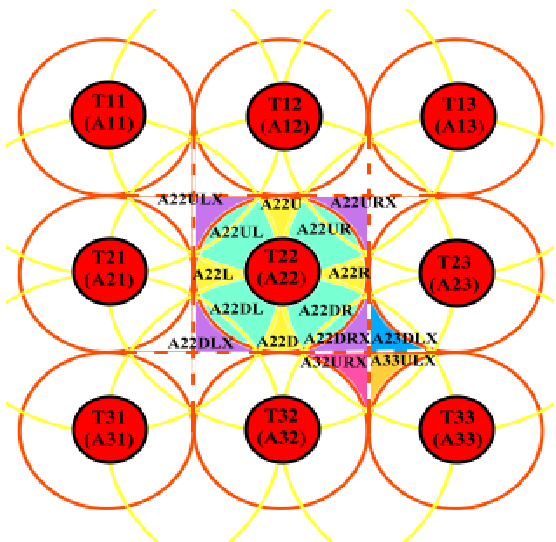

Fig. 3 Schematic diagram of block naming method

B. Signal Level Matrix

Based on the sensing overlap area and the classification of signal level, this paper proposed the concept of Signal Level Matrix (SLM). First, the signal strength is classified into six levels according to the distance between Reader and Tag (as shown in Table 1), and then the Signal Level Matrix of the area of Reader is set up according to the signal levels of the Tags around the Reader.

For example, taking the area shown in Figure 3 as an example, the type 1 Signal Level Matrix is set up corresponding to the type 1 blocks of Tag22, the main characteristic is that it senses Tag22's signal level S22 = L0 (as example shown in Figure 4). Eight kinds of type 2 Signal Level Matrixes are set up corresponding to the type 2 areas within 1 meter around Tag22: A22U, A22D, A22L, A22R, A22UL, A22UR, A22DL and A22DR as examples shown in Figure 5. The main characteristic is that it senses Tag22's signal level S22 = L1, and some other signal's level equals to L2, so as to distinguish the direction of signal levels.

TABLE I
SIGNAL LEVEL TABLE

Signal level	Reader & Tag’ s Dictance
L0	<0.5m
L1	0.5m~1m
L2	1m~2m
L3	2m~3m
L4	3m~4m
L5	>4m

S11=L3	S12=L3	S13=L3
S21=L3	S22=L0	S23=L3
S31=L3	S32=L3	S33=L3

Fig. 4 Example of Type 1 Signal Level Matrix (SLM of A22)

S11=L3	S12=L2	S13=L3
S21=L3	S22=L1	S23=L3
S31=L3	S32=L3	S33=L3

(a) A22U’s SLM

S11=L3	S12=L2	S13=L3
S21=L2	S22=L1	S23=L3
S31=L3	S32=L3	S33=L3

(b) A22UL’s SLM

Fig. 5 Examples of Type 2 Signal Level Matrix

In the third situation, if the distance between Reader and all Tags is over 1 meter, namely, it is just located among 4 Tags (e.g. 4 blocks in Figure 6: A22DRX, A23DLX, A32URX and A33ULX), the corresponding Signal Level Matrix can be constructed based on the signal strength of peripheral 16 Tags, as examples shown in Figure 6. The main characteristic is that the four adjacent signal levels are L2; and the level of another two signals equals to L3, the level of the signal on the cross equals to L5. In addition, if the user is just located in the small block between A22DR and A22DRX, the final location will be determined by T33's signal strength S33 which may be Level 2 or Level 3.

S11=L5	S12=L4	S13=L4	S14=L5
S21=L4	S22=L2	S23=L2	S24=L4
S31=L3	S32=L2	S33=L2	S34=L4
S41=L4	S42=L3	S43=L4	S44=L4

(a) A32URX’s SLM

S11=L5	S12=L4	S13=L4	S14=L4
S21=L4	S22=L2	S23=L2	S24=L4
S31=L4	S32=L2	S33=L2	S34=L3
S41=L4	S42=L4	S43=L3	S44=L4

(b) A33ULX’s SLM

Fig. 6 Examples of Type 3 Signal Level Matrix

C. Fault-Tolerance Mechanism

Since the signal strength of Tag often fluctuates within a range, the signal strength of adjacent position may fluctuate between adjacent signal levels, and then cause errors in location. The proposed fault-tolerance mechanism can solve this problem. For example, taking the first situation in Figure 7 as an example, a normal Signal Level Matrix should be as that shown in Figure 4, but the fluctuation of signal strength may result in non-standard Signal Level Matrix as example shown in Figure 7 (a). In this case, as proved by experimental experience, since the Reader is very close to Tag22, the signal strength of L0 is very stable, so it still can be located at A22 successfully.

Taking A22U of the second situation as an example, a normal Signal Level Matrix should be as that shown in Figure 5 (a), but the fluctuation of signal strength may result in non-standard Signal Level Matrix as shown in Figure 7 (b). If this circumstance happens, although mismatching the standard SLM, the position still can be determined according to the directionality of signal strength in SLM, and located in the area of A22U correctly. Similarly, if a non-standard SLM as shown in Figure 7(c) occurs, it can also be located in the area of A22UL. In addition, if a non-standard SLM as examples shown in Figure 7 (d) and (e) occurs, it can also be located in the area of A32URX and A33ULX correctly according to the orientation of L5 signal.

An active RFID CF card Reader with frequency of 2.45GHz and 16 active RFID Tags were used in the experiment for testing. When proper signal strength thresholds for specific

Tags were analyzed, the sensing areas of all RFID Tags would form the sensing overlap areas, as shown in Figure 3.

Figure 8 is the analysis chart of the measured signal strength of Tag22 at different distances in the experiment. As seen, although the signals of the Tag fluctuated, the signal strength was inversely proportional to the distance between Reader and Tag approximately. Figure 9 shows the mean value of signal strength of multiple Tags at different distances. The signal level of this Tag at each distance can be set according to this mean value (as shown in Table 2), and the Signal Level Matrix can be set up based on the signal levels of these Tags.

S11=L2	S12=L3	S13=L3
S21=L3	S22=L0	S23=L3
S31=L3	S32=L3	S33=L3

(a) In A22 may result's SLM

S11=L2	S12=L2	S13=L2
S21=L3	S22=L1	S23=L3
S31=L3	S32=L3	S33=L3

(b) In A22U may result's SLM

S11=L2	S12=L2	S13=L3
S21=L2	S22=L1	S23=L3
S31=L3	S32=L3	S33=L3

(c) In A22UL may result's SLM

S11=L5	S12=L4	S13=L4	S14=L5
S21=L3	S22=L2	S23=L2	S24=L4
S31=L3	S32=L2	S33=L2	S34=L4
S41=L4	S42=L3	S43=L4	S44=L4

(d) In A32URX may result's SLM

S11=L5	S12=L4	S13=L4	S14=L4
S21=L4	S22=L2	S23=L2	S24=L3
S31=L4	S32=L2	S33=L2	S34=L3
S41=L4	S42=L3	S43=L3	S44=L4

(e) In A33ULX may result's SLM

Fig. 7 Examples of Non-standard Signal Level Matrix

V. Experimental Results

In this experiment, each active RFID Tag was set as sending a signal to RFID Reader every 0.3 second. The system calculated the average value of signal strength of RFID Tag at intervals of 3 seconds, converted the average value of signal into special signal level for specific Tag, and grouped all Tag signal levels collected at the same time into a Signal Level Matrix. The results showed that RSS value sometimes surged (too high or too low RSS value) because of environmental disturbance, thus, the difference between the new average value of signal strength and the previous average value of signal strength was set as 10% at most, so as to remove the disturbance of surging. In addition, the experimental experience also proved that the non-standard Signal Level Matrix derived from fluctuation of signal strength could really complete location through the fault-tolerance mechanism effectively.

Table 3 shows the analysis of positioning accuracy rate of experimental results. Our system coded 12 blocks around Tag22 with A~L (as shown in Figure 10). The experimental results showed that the accuracy rate of positioning error within 0.5 meter is 53%~73%, the average value is 66%; the accuracy rate of positioning error within 1 meter is 80%~100%, the average value is 88%; the accuracy rate of positioning error within 2 meters~4 meters can be 100%.

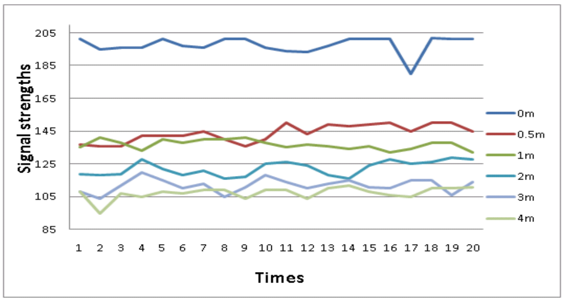

Fig. 8 Signal strength of Tag22 at different distances

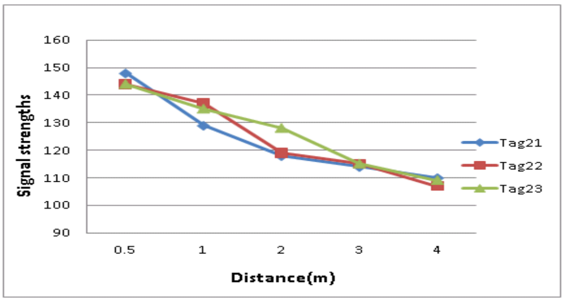

Fig. 9 Average value of filtered received signal strengths

Table II
Analysis of signal levels of Tag22

Signal level	Reader & Tag's distance	RSS
L0	<0.5m	>144
L1	0.5m~1m	137~144
L2	1m~2m	119~137
L3	2m~3m	115~119
L4	3m~4m	107~115
L5	>4m	<107

TABLE III
ANALYSIS OF POSITIONING ACCURACY

Distance \ Block	A	B	C	D	E	F	G	H	I	J	K	L	Average
0.5M	60%	66%	66%	73%	60%	73%	66%	73%	73%	66%	60%	53%	**66%**
1M	86%	86%	80%	100%	93%	86%	80%	80%	93%	86%	93%	93%	**88%**
2M	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	**100%**

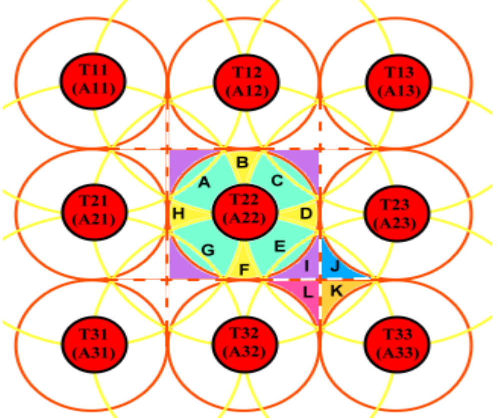

Figure 10: Schematic diagram of sensing areas

VI. CONCLUSIONS

In this paper, we propose the concept of Signal Level Matrix (SLM) to develop an active RFID positioning system to achieve efficient deployment mode, low cost and high accuracy. Based on the characteristic of the signal strength of RFID attenuating as the distance increases, this paper first classified proper signal levels at different distances and carried out indoor localization according to the matrix formed by these signal levels. The experimental results indicate that the proposed method can adjust the suitable signal strength threshold adaptively according to the differences of the localization environment and specific Tags. Combined with fault-tolerant mechanism, the method can improve the positioning accuracy and the stability effectively.

In addition, this system uses uniform and efficient distribution mode, while requiring only one RFID Reader and some Tags to complete positioning, thus reducing the cost of positioning system effectively. Furthermore, as compared with other positioning system, because of the users carry one RFID Reader, which allows the system administrator to know about the user's location, and the user can know his location, too. Thus, this system can indicate the position of the user timely, and can be applied in guides of exhibition halls, museums, airports or campuses.

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