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Accurate positioning using long range active RFID technology to assist visually impaired people

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ABSTRACT

The aim of this paper is to describe a new positioning technique to assist the blind and people with low vision to indicate their location and reach their destinations in both indoor and outdoor environments. The proposed technique is based on a combination of power attenuation and a received signal strength indicator (RSSI) using active radio-frequency identification (RFID) technology. The system uses a mobile reader with a power attenuation feature. RSSI is used as a quantized distance estimator for a short range and in combination with one of eight receiver attenuation level settings for a wider range of up to 70 m. A Global Positioning System (GPS) works efficiently in a similar environment but is only accurate to around 10–20 m and does not work efficiently in indoor environments. This research produced a system that identifies various locations such as offices, laboratories, theaters to assist users in reaching their destination of interest. It was then implemented in an indoor environment as an empirical case study to identify laboratories based on a combined technique with a successful identification rate of around 98%. The reader has eight attenuation settings, and the geographic range of each level using various tags was calculated. Then, to evaluate reliability, 6 experiments with 108 samples were conducted using three tags with distances from 1 m to 25 m, using power settings 1–6. A successful detection rate of 93.5% was achieved, as well as a false positive rate of 1%. Following this, the system was implemented in a park to evaluate its ability to indicate the position of the reader among a grid of tags in an open area. A satisfactory result was achieved.

1. Introduction

For blind people and those with low vision, determining their current location is a significant challenge. Over the years, various researchers have discussed navigation issues using RFID technology in order to assist visually impaired people. This work can be classified into three categories. The first group of researchers used passive RFID technology for positioning in indoor environments. An advantage of passive RFID technology is that it does not require a power supply because it depends on the power of the probe signal itself. Furthermore, passive RFID is relatively inexpensive. The second group of researchers used active RFID technology in both indoor and outdoor environments, but almost all of their proposed systems did not use active RFID technology by itself, rather they combined it with other technologies such as GPS. The third group of researchers used active RFID exclusively, based on distributing transmitters (readers) in the ceiling for triangulation purpose then uses the Received Signal Strength Indicator (RSSI) technique to estimate the position of the tag that is carried by a user. However all these methods have some disadvantages:

- The disadvantage of passive RFID approach is that it requires a very short distance to communicate between the reader and the tag.
- The disadvantage of the second approach is that when GPS is unavailable, such as in between skyscrapers or inside buildings, their system is disabled or may provide inaccurate positioning information.
- The disadvantage of the third approach is more costly strategy because it is based on distributing readers rather than distributing tags.

In this research which is a development of our previous research (Alghamdi and van Schyndel, 2012), we extend the indoor-only method described there to include an outdoor environment. The improved system is able to inform users of their current position – whether indoors or outdoors - and provide them with useful information to guide them to their destination using active RFID technology.

The novelty of the system is the use of RFID for positioning the blind using antenna gain controls to selectively receive RFID tag responses at different signal strengths. So instead of measuring the signal strength of the RFID signal directly, the signal strength is implied using a set of impedance settings covering a number of

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ranges. The process is automatic and quantizes the RFID distances. This approach will more easily tolerate small environmental differences.

The direct measurement of signal strength is still used, but only for closer proximity measurement where the uncertainty is reduced. This new technique automatically combines these two methods at various ranges to produce a range estimate for each RFID tag. We have achieved a successful detection rate of 93.5%, as well as a false positive rate of 1%, and it could estimate the position of the reader in outdoor settings with less than 2 m uncertainty in all cases. The proposed system works efficiently in circumstances when GPS fails to work (especially indoors) and provides useful information to blind people with higher accuracy than GPS.

In deployment, the system will appear as shown in Fig. 1, where a user, when entering a building, would receive a floorplan and a list of tags via Wifi, indicating tag positions and labels. The system would then use these to allow positioning indoors. For instance, when users would like to check whether a floor level has an elevator or not, the system will inform them from the downloaded file and estimate the distance to the elevator, indicating the user's position from the destination of interest. In contrast, a passive RFID system cannot provide this kind of service. Also, in the outdoor environment, the system is able to indicate the position of the user on a pedestrian path and inform them of surrounding objects of interest. We do not intend to replace the cane, only to provide an independent positioning system at meter resolutions.

The rest of the paper is structured as follows: related work is outlined in Section 2; the system description is given in Section 3; the results and the case studies are described in Section 4; followed by the conclusion in Section 5.

2. Background and related work

Over the years, many localization technologies have been developed such as those by Najera et al. (2011), Papapostolou and Chaouchi (2011) and Ni et al. (2004). Some of these works can be extended into positioning which uses RFID technology (Tesoriero et al., 2008), and which has been designed to assist people with visual impairments. We found that these works can be classified into three groups.

The first is the group of researchers who used passive RFID technology. The works by Seto and Magatani (2009) and Fukasawa and Magatani (2012) were based on using color sensors and a passive RFID system which required a distance of less than 50 cm to communicate between the tag and the cane. Ganz et al. (2010, 2011) used a passive RFID system which required a distance of 2–3 cm or less than 10 cm such as in Liu et al. (2007) to transfer data from the tag to the reader. Also Di Giampaolo (2010) produced an indoor navigation system based on passive RFID technology which indicated the location of users based on a grid of passive tags located on the ceiling at known positions.

da Silva Cascalheira et al. (2012) succeeded in indicating the middle of a door by computing the power of the receiving signal, then comparing the signal to choose the greatest one which represents the middle of the door. To achieve this goal, it was necessary to deploy an antenna on the doors and a pair of antennas with the receiver to undertake a comparison. It also needed an RF-DC converter radio frequency to direct a current and microcontroller unit (MCU) to compare the signal strength of each antenna, which was useful in assisting blind people to go inside or outside rooms through its doors but it did not guide them to those doors.

Faria et al. (2010) and Shiizu et al. (2007) combined electronic white canes with RFID technology to improve guidance systems for people with visually impairments. The best feature of using passive RFID is that it does not require an external power source because it depends on a magnetic field through absorbing the energy radiated by the reader to transfer data from the tag to the reader. However, to engage in this kind of communication, it requires a short detection range which is a disadvantage because

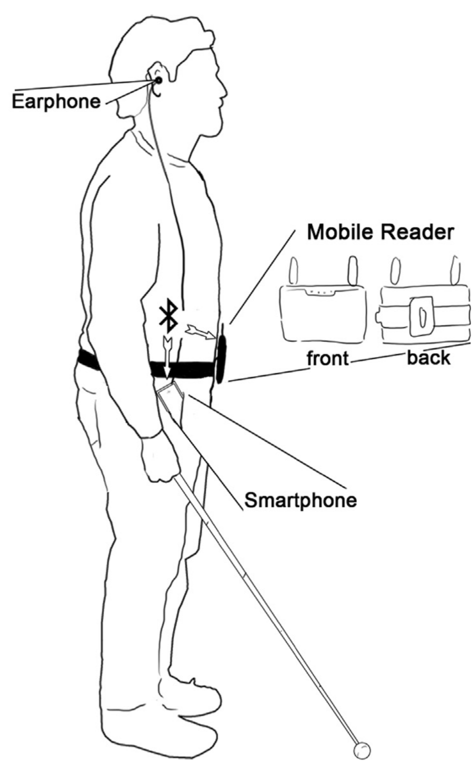

Fig. 1. The system components (test set showing mobile reader and a tag above the door), and the concept design.

the system will perform best when the user is inside its range (which is very narrow in almost all passive systems), therefore it requires another technology or method to guide blind people to the points of that system. Kiers et al. (2011) and Szeto and Sharma (2007) both stated that they will develop a wider range with new passive tags which may contribute to solving part of this limitation.

The second group of researchers, such as Schmitz et al. (2011), Yelamarthi et al. (2010) and Kaiser and Lawo (2012), produced useful systems for blind people but they are dependent on navigation systems that integrate GPS with RFID, therefore their systems will fail to navigate the user when GPS signals are absent.

Kaiser and Lawo (2012) suggest an indoor and outdoor navigation system whose indoor navigation system is based on an integrated system of simultaneous localization and mapping (SLAM) approach which has been designed for mobile robots and an inertial measurement unit (IMU) which usually contains accelerometers, gyroscope and magnetometers. On the other hand, their outdoor system is based on a combination of GPS and Pedestrian Dead Reckoning (PDR). The author argued that “data processing will be accomplished by wearable computing devices” and that the system will be “totally independent of any network or networked computer”. It will be interesting to see the development of this system, however it will still have limitations when GPS is not available.

The third group of researchers used active RFID such as Oktem et al. (2008) based on the more costly strategy of distributing transmitters (readers) in the ceiling for triangulation purposes, then uses the Received Signal Strength Indicator (RSSI) technique to estimate the position of the tag which is carried out by a user. Chumkamon et al. (2008) tried to use the UHF RFID system within a proximity range up to 10–15 m using GPRS networks for a navigation device for blind people but they found that there were delay problems in their system. Mooi et al. (2010) produced an efficient RFID tag placement framework for an indoor navigation system for blind people, but it did not solve any of the problems of dependency, short range or cost and it merely produced a guideline for tag placement in indoor environments.

3. Overview of the system

The system consists of a smartphone with custom software installed, a mobile RFID reader, and an earpiece to the smartphone. The RFID reader is connected to the smartphone by Bluetooth, and communicates via Wifi (or Bluetooth) to obtain maps of tag locations. The user communicates by voice to using standard smartphone interfaces, and is informed via audio of tag locations or directions. See Fig. 1 for a concept diagram of the system when deployed.

We are using “*RFCode* M175 Rugged Tags”, operating at a frequency of 433 MHz, as shown in Fig. 2(B). These active RFID tags, have a wide transmission range of more than 70 m. Each tag should be located at a known location, such as an office door, entrance of a department or on a known position on the sides of paths. Also the tags should be installed high up minimizing the likelihood of humans intercepting the signal as confirmed by Najera et al. (2011), “Regarding water attenuation, a tag accidentally covered by nurse's hand, even with a high performance tag (such as the *Alien* ALN-9554M) and reader, would reduce reading distance from 58 m to less than 1 m with unreliable reading accuracy.” The user hangs the mobile reader in his or her belt, as shown in Fig. 1. The reader used in the proposed system is the *RFCode* M220 Mobile Reader weighing 162 g with the belt clip, as shown in Fig. 2(A).

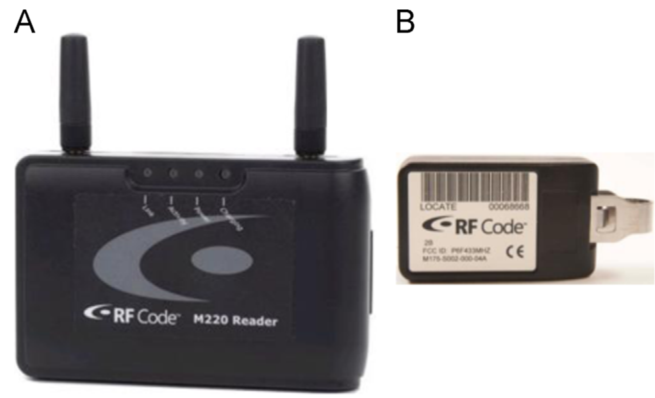

Fig. 2. A: *RFCode* M220 mobile reader. B: M175 active rugged tag.

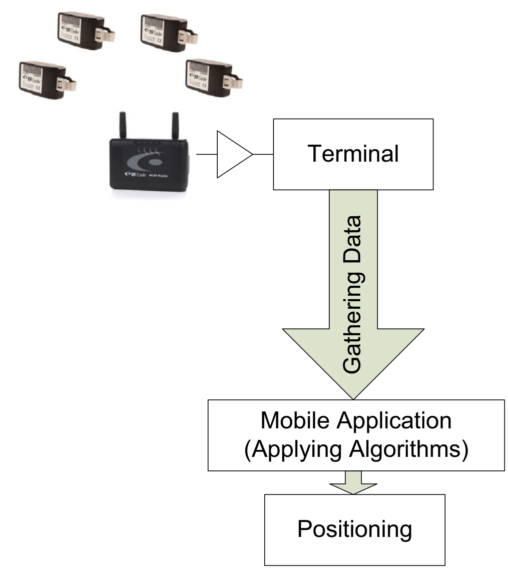

Fig. 3. Layer model of communication between system components.

The system offers a customized terminal-based interface to communicate to and from the tag reader via two kinds of communication interfaces: Bluetooth Serial 1.1 and wired USB 2.0, so users can install the mobile version API on their smart phones. The reader has eight factory programmed attenuation ranges with 5 dB separation. The system will determine the user's position based on the attenuation level itself or based on a combination of attenuation levels and RSSIs as shown in Figs. 7 and 8, where AtnL represents attenuation level or range level.

3.1. Components of the system

As shown in Fig. 1, the device is easy to carry. The system contains hardware and software. The hardware consists of the reader, multiple tags and a smart phone, tablet or laptop which contains an API of the system. The software consists of the reader program and the API which contains the closest tag algorithm and the user position algorithm, the API interface as shown in Fig. 4. Figure 3 summarizes the layer model of communication between system components, and is potentially extensible to other technologies in the future (i.e. the mobile application program may receive input from other sources, using APIs such as *OpenNI*).

The system is nearly omnidirectional and has a wide range of around 70 m with high sensitivity. The system has been designed for both indoor and outdoor environments, so it can be used to assist blind users to reach their destination, such as a particular apartment, lift, specific classroom, particular shop. Tags should be fixed at known locations and a mobile reader will indicate the user's current location.

The mobile software has been designed to be easy to use by the blind, for example: the user can give a voice command by saying “My Position”, or saying “My Global”, or by pressing the buttons (for low-vision people) as shown in Fig. 4.

Additionally, the user indicates either an indoor or outdoor platform, after which the system will change the attenuation level accordingly, and the reader scans for tags using all ranges. An indoor platform and tag which are detected in a narrow range would have a higher priority over other tags on a wider range. Hence, based on this concept, the range itself could be sufficient to indicate the closest tag, unless more than one tag is detected within the same range. When there are two or more tags discovered in the same range, the system uses a combination of range and signal strength. This algorithm is summarized in Fig. 7. Also, an outdoor platform tag which is detected in a close range has a higher priority over other tags in a wider range. Therefore, the closer tags should be assigned higher weights, based on Eq. (1), as shown in Fig. 8. Figure 5 describes the system steps from start to end.

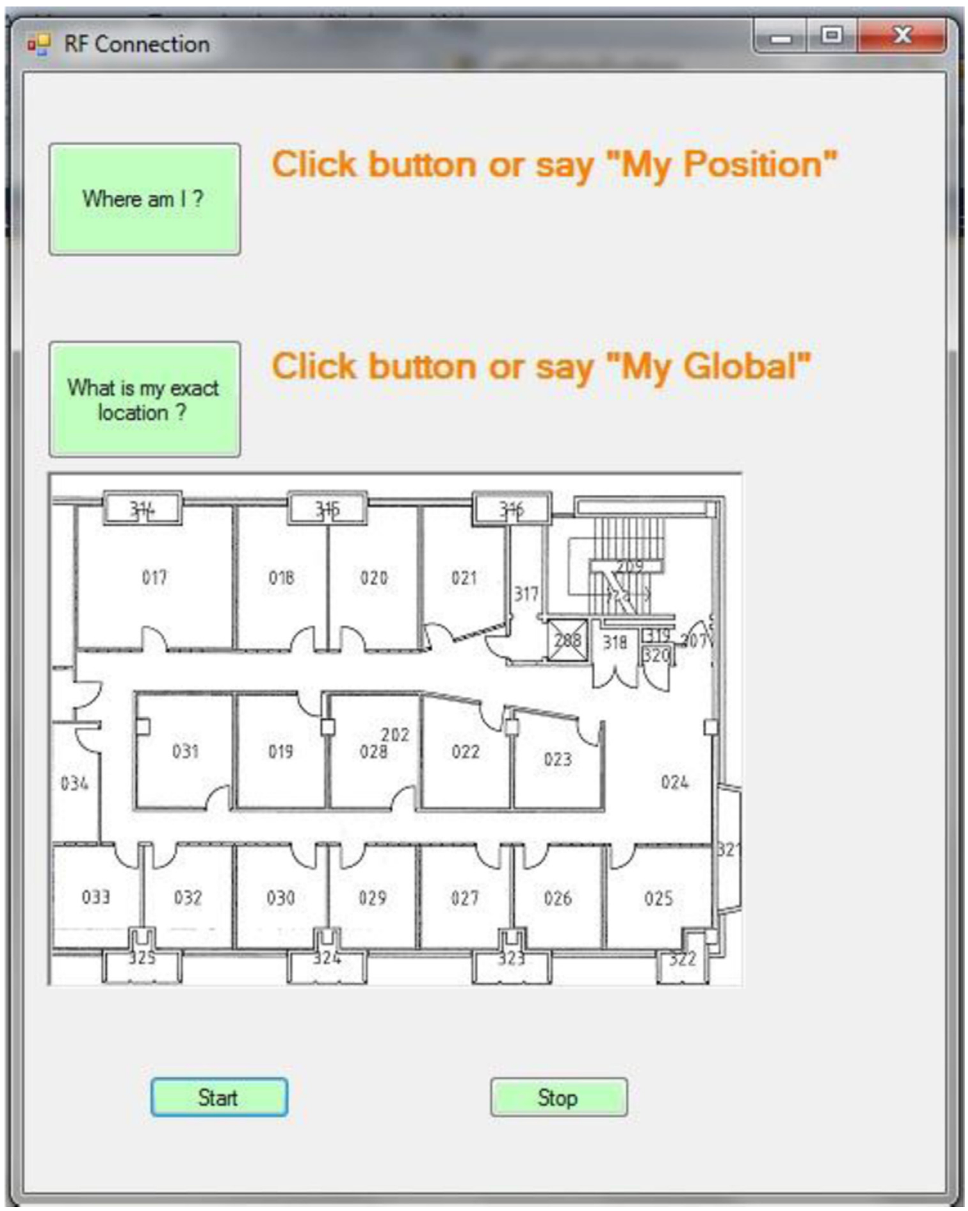

Fig. 4. The interface of positioning system (PC-laptop development version).

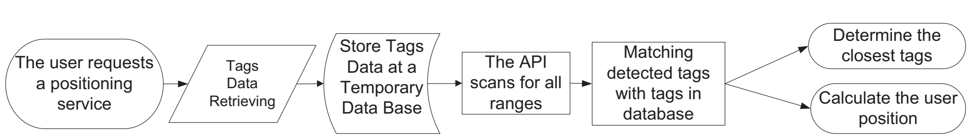

Fig. 5. Summary of the system steps from the start when the user selects the closest tag or calculates the user's position.

3.2. Overview of indoor positioning system

Before the users enter a building, they should choose an indoor platform so that the system will use an available connection offered by the particular building, such as WiFi, to retrieve the tag information for that building. This information retrieves for the whole building as an XMLdatabase. An excerpt of this file is shown in Fig. 6. Such a connection is only needed to download the map files. We do not use WiFi for positioning in this paper, only RFID technology.

After downloading the map file from any network connection (usually Wifi or broadband), the RFID reader starts to scan to locate the tags surrounding the user and provides information on them. The wide range feature is very useful in these circumstances. For instance, when the blind user needs to go to a toilet, the system will determine if there is a toilet in the surrounding area or not by comparing the detected tags with the tags in the data base which have been downloaded from the building on entry. If there is a toilet, the system will estimate the distance to the toilet as well as distinguish the door of the mens toilet from the door of ladies toilet. Therefore, the system plays two roles: firstly, it explores points of interest; and secondly, it detects the destination accurately through using the algorithm, as shown in Fig. 7. Assume that each door has been identified by one tag which has a unique identification number, and in front of the user there are two doors, A and B, the user's destination being door A, not door B. The reader will scan using an attenuation level from one to eight. The tag which is closer to the user will have a higher received signal strength and can be detected on higher attenuation level, and we can use different attenuation settings to separate signals with lower strength from this one.

Thus the attenuation setting alone may be sufficient to isolate the desired tag as a closest tag to a user. This will occur if both A and B are not detected on the same attenuation level. But if A and B are very close to each other, they are more likely to be detected on the same attenuation level, in which case, the system will use RSSI as another pointer to determine which is closer to the user. Note that we do not use the absolute RSSI for distance measurements. We use only the relative RSSI between different tags. We thus avoid some common errors which might affect the absolute measure. When even RSSI cannot be used to separate the signals, the system will combine the user's path to the doors with the user's current orientation (via compass) and describe the correct direction to the user. As described in the results section, we achieve satisfactory results using a combination of these two techniques.

```xml
<?xml version="1.0" encoding="UTF-8" ?>
<RFTrack version="1.0">
<assets>
<asset name="post graduate" desc="exit on north">
<tag id="00068652" taggroupid="LOCATE" />
<location x="20.30" y="5"/>
</asset>
<asset name="Staff Room" desc="my office on south">
<tag id="00068653" taggroupid="LOCATE" />
<location x="9" y="8" floor="1"/>
</asset>
<asset name="Scada Lab" desc="Fenglin's Office on south">
<tag id="00068654" taggroupid="LOCATE" />
<location x="15.80" y="12.80" />
</asset>
<asset name="Scada Lab" desc="Ron's Office on south">
<tag id="00068655" taggroupid="LOCATE" />
<location x="10.90" y="12.80" />
.....
```

Fig. 6. An excerpt part of XML file which shows typical tags data.

3.3. Overview of outdoor positioning system

Outside of buildings the system works as a supplement to GPS because it provides more accurate positioning information to the user. The system has been designed to indicate the position of the user at trajectories of 4 m widths. Based on the algorithm shown in Fig. 8, the system scans using decrement attenuation levels until it detects at least three different tags. It starts with the highest level of attenuation (1) to detect the closest tags first to give them a higher priority (more weight) over distant tags based on the following equation:

$$W_i = \overline{RSSI} \times ((\max AtnL)+1)-(AtnL_{current}) \qquad (1)$$

where $\overline{RSSI}$ represents the average of the Received Signal Strength Indicator, max($AtnL$) represents the maximum level of attenuation which equals eight in this system and $AtnL_{current}$ represents the current attenuation level.

Using this equation, the closest tags would be assigned a higher weight and vice versa, for instance when $AtnL_{current}$ equals to 1, as the start of the algorithm, the RSSI in this case will be multiplied by 8 because the maximum level of the attenuation of this system is eight, plus 1 equals 9, minus 1 equals 8. The opposite will happen if $AtnL_{current}$ equals 7, in which case RSSI will be multiplied by 2 because 8 plus 1 equals 9, minus 7 equals 2, consequently, the weight of the tags which are detected on that level will be lower. Table 1 summarizes how this equation works.

4. Experiments and results

The main purpose of the experimental work of this paper is to confirm our approach to the use of quantized distance measurement using active RFID tags and a map of their locations. As mentioned for the second group of references in Section 2, there seems to be a consensus that distance measurement using RFID alone with one reader is not sufficient, as they all use additional methods. We will show that we have achieved reasonable results using our method alone.

In this section, we will first describe some potential problems with orientation and sensitivity effects of tags and reader, and whether these problems are significant, and then describe our results for indoor positioning, using both algorithms, followed by outdoor positioning. We then study the detection reliability using the quantized approach. Finally, we study the use RSSI as a distance measure.

4.1. Orientation and sensitivity variations

While the technology used in this system is ideally omnidirectional and with all tags identical, in practice, we cannot make these assumptions. The next three subsections discuss this in more detail.

4.1.1. Reader orientation effect

The equipment used has an omnidirectional range, but the results show that signals are not equal in all directions. To test this, we used signal strength as an indicator on three levels 40 dB, 50 dB and 55 dB and the distances were registered for each level on different angles. As shown in Fig. 9, the reader is stronger at 180° compared to when it is facing the tag. However, these are within the quantization boundaries imposed by the attenuation levels, and so the reader orientation differences are not sufficiently significant compared to other environmental effects. Consider that this is an interactive system, and that the user will respond

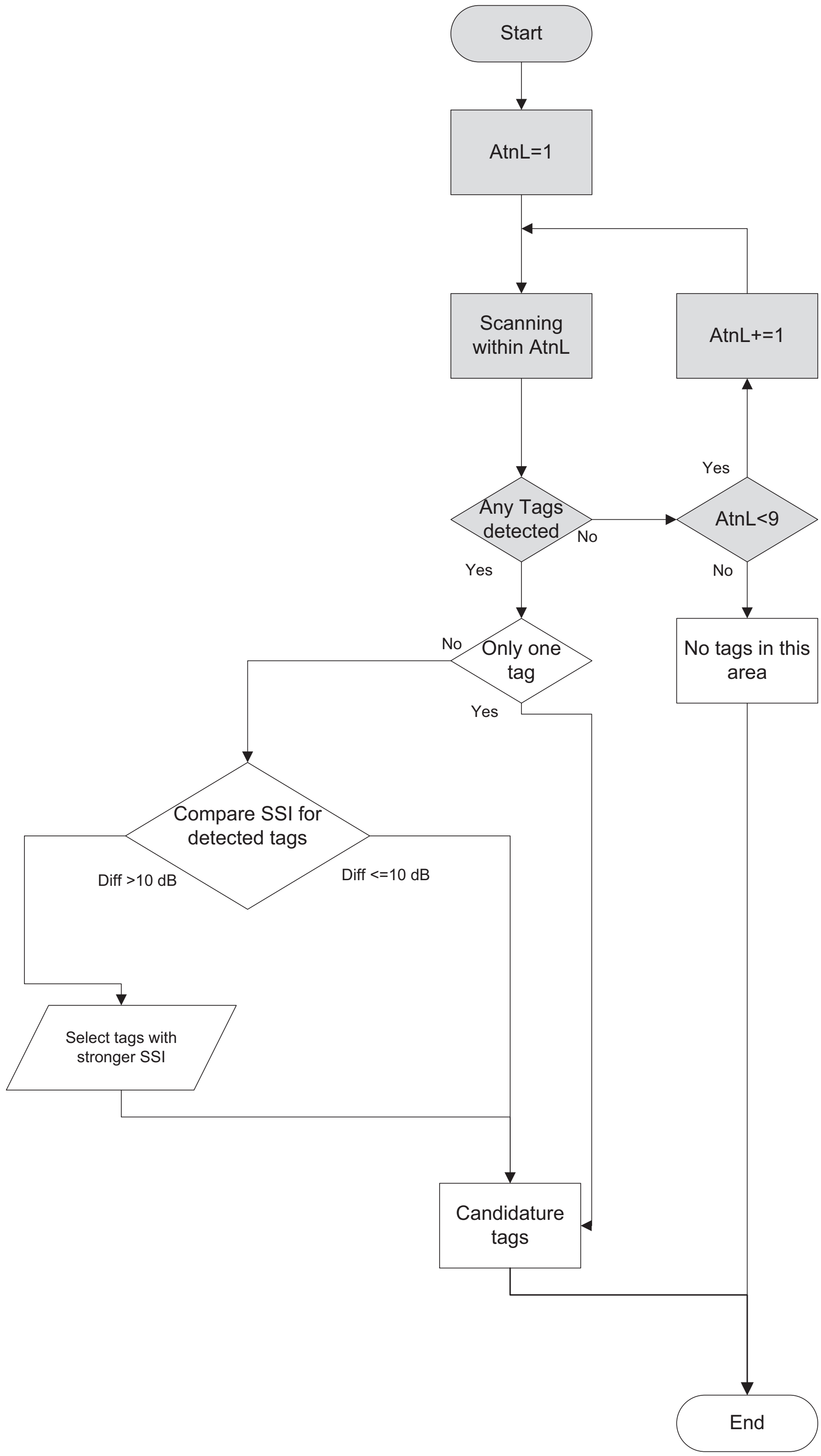

Fig. 7. Flowchart of algorithm to indicate the closest tags.

dynamically to the information received. We have found that any uncertainty such as the “body” effect mentioned in Najera et al. (2011), will tend to reduce as the user approaches the desired tags and its received signal strength increases. We reasonably assume that the user is always traveling forward. In deployment, the reverse (body) direction will typically be shielded.

4.1.2. Tag orientation effect

We found that the orientation of the tag does not play a significant role, as shown in Fig. 10. To test this, we repeated the experiment for the same tag under the same circumstances but different orientation, and obtained consistent results, as shown in the same figure.

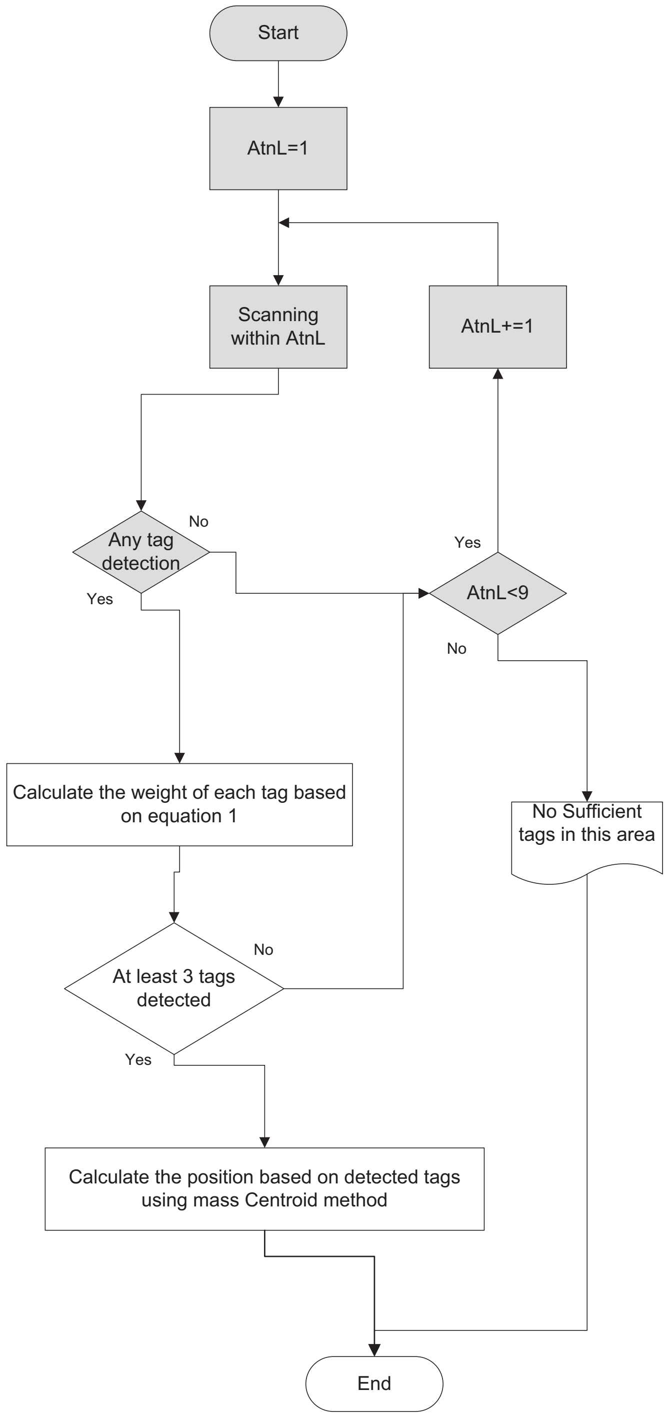

Fig. 8. Flowchart of algorithm to indicate the location of the reader.

Table 1
Description of tag weights based on Eq. (1).

AtnL	(Mean (RSSI))*X
1	$X = 8$
2	$X = 7$
3	$X = 6$
4	$X = 5$
5	$X = 4$
6	$X = 3$
7	$X = 2$
8	$X = 1$
$AtnL_{current}$	$X = ((\max(AtnL) + 1) - AtnL_{current})$

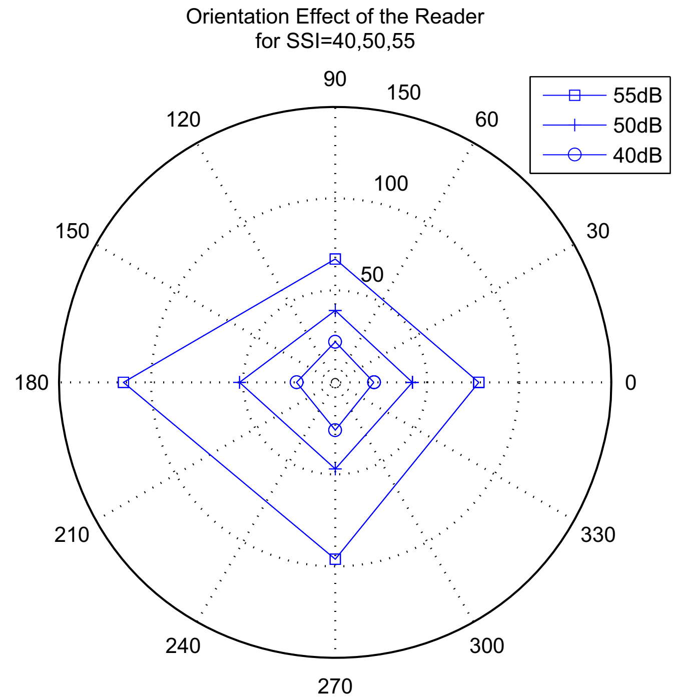

Fig. 9. The directional sensitivity of the reader used was sufficiently omnidirectional, to allow our system to operate as described, as shown for three signal strength levels based on the average of three tags.

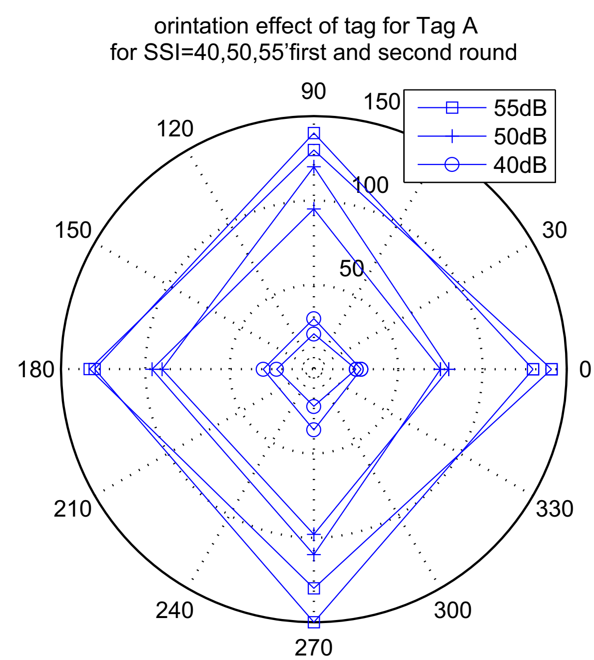

Fig. 10. The directional sensitivity of the tags used was sufficiently omnidirectional, to allow our system to operate as described. The experiment was repeated with different tags (with extremes shown on the figure) and obtained consistent results.

4.1.3. Differences in sensitivity of tags

Active RFID systems can support wide signal ranges. Typically, each tag has its own power source such as a battery which may affect the sensitivity of tags. Upon analysis, we found sensitivity differs from tag to tag but in general, they are convergent. As exemplar, the ranges of three random tags for three attenuation levels were measured and the result showed that tag A and tag B were very similar but tag C was a little stronger, as shown in Fig. 11. Another experiment was conducted on the same tags, with

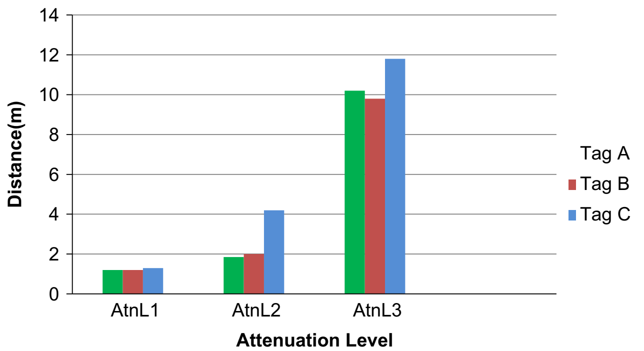

Fig. 11. The distance at which each tag was initially discovered by the reader, for one of three attenuation levels. This is representative of differences in sensitivity for different tags.

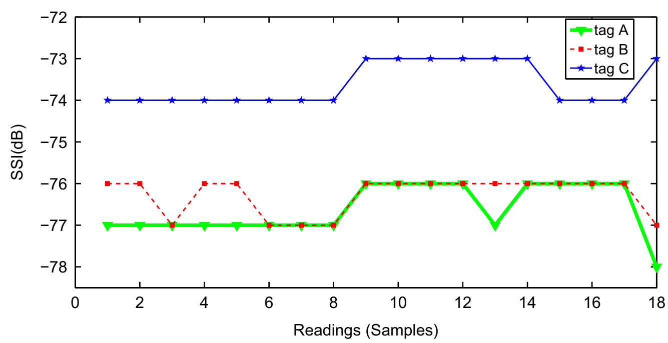

Fig. 12. Sample readings were quite consistent between samples. Differences were due to tag sensitivity variations. Tags that were *too different* (as in tag C here) were not used for the rest of this paper.

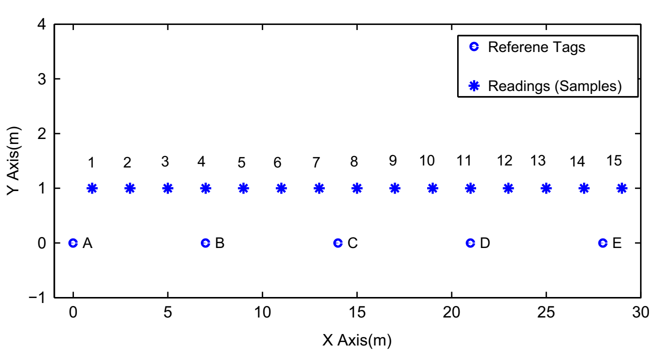

Fig. 13. Calibration set, with equal distances between tags.

a fixed distance between the tags and the reader; RSSI readings were taken three times for all attenuation levels, the results indicating that tag C was always stronger than tag A and tag B, as shown in Fig. 12. In actual deployment, a calibration stage will need to be used to ensure tags sensitivity that is relatively uniform, so that signal strength can be used as a distance estimator.

4.2. Indoor localization technique implementation

All tags have been distributed at known positions, so each tag represents one particular location. The role of the system is to indicate the closest tag to the user. As an initial calibration step, Fig. 13 presents the experimental implementation. Dots A, B, C, D and E represent the location of fixed tags, and the numbers from 1 to 15 represent the real locations of the readers.

When tags are equidistant, the system was 100% successful in indicating the closest tag for each location. For example, tag A is

Table 2
Using power attenuation to indicate the closest tag for the calibration set.

Reading position	Closest tag	Attenuation level
1	A	1
2	A	2
3	B	2
4	B	1
5	B	2
6	C	2
7	C	1
8	C	2
9	C	3
10	D	2
11	D	1
12	D	2
13	E	2
14	E	1
15	E	1

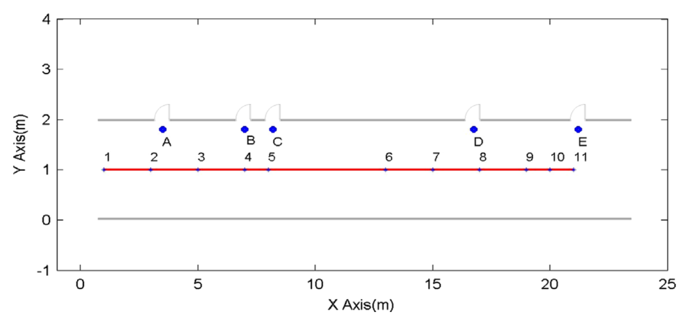

Fig. 14. Case Study 1: Indication of laboratory doors in a straight corridor.

Table 3
The results for Case Study 1: using combination of attenuation level and RSSI to indicate the closest tag to the user.

Reading position	Closest tag	Positioning technique		
		AtnL level	AtnL only	AtnL+RSSI
1	A	3		✓
2	A	1	✓	
3	A, B	2		✓
4	B	1	✓	
5	C	1	✓	
6	D	4	✓	
7	D	2	✓	
8	D	1	✓	
9	E	2		✓
10	E	2	✓	
11	E	1	✓	

the closest tag to location 1 and it was detected in this position on attenuation level 1, as shown in Table 2. Also, the same tag was detected alone on attenuation level 2 at position 2. For all 15 samples, the system indicates the closest tag by giving a tag which is detected on a narrow range with higher priority over the other tags on wider ranges.

The following information should be known at any time: the user's position within the map (from the local tags); the user's direction of travel (from proximity to other tags prior to the target); the compass direction of the user (from the smartphone); and the location of tags from the map. From all of these, it is possible to describe a vector direction given the measured distance, relative to current user orientation. Given that the user's orientation is known, the relative orientation of the tag is also known given its position and the user's calculated position.

The system can thus be used to guide the user to a tagged object, or to establish the user's position and orientation within a field of tags.

4.3. Evaluation of the indoor system (Case Study 1)

To evaluate the efficiency of the system, we conducted a practical experiment, the system role being to describe the current position of the users by indicating the closest door to them. Tags have been placed on laboratory doors which are represented by A, B, C, D and E in Fig. 14. Then, we took readings from various locations 1–11 along the corridor, as shown in the same figure. The system aims to inform the user of a destination of interest in the surrounding area. Furthermore, as shown in this case study, the system identified the lab based on the user's location. Table 3 presents how the system indicated the tag closest to a user. For instance, at position 1, the reader could not discover any tag on attenuation levels 1 and 2, but on attenuation level 3, tag A and tag B were detected, so it was necessary to use a combination technique to indicate which one of them to select. At position 2, the reader was very close to tag A, so A was detected alone on attenuation level 1 so the attenuation level technique was sufficient to indicate the closest tag. As shown in Table 3, there was a partial error at position 3. The system reported that the user was in the middle of A and B; this is true, but it was biased 45 cm to tag A. In contrast, the system had very high accuracy at position 9 because the reader was closer to tag E than tag D by only 5 cm and the system was able to detect this.

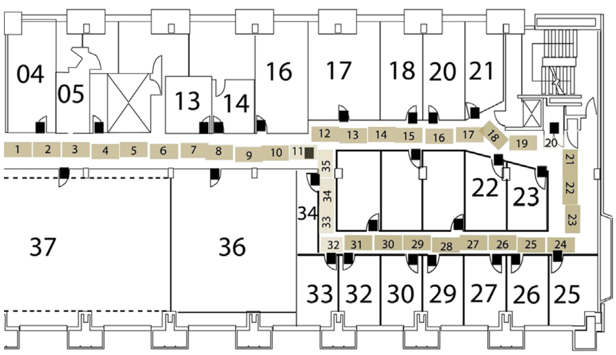

Fig. 15. Case Study 2: Indication of user position among crowded indoor environment.

4.4. Evaluation of the indoor system (Case Study 2)

To evaluate the reliability of the system to work in a real environment; more experiment was conducted in more complex area as shown in Fig. 15 where the black squares represent tags and the numbers in the corridors represent the positions of reading locations, the system has succeed in almost cases to determine the positions of the user by describing the surrounding tags as shown in Table 4. Where the first column contains sample numbers which represent sample positions in Fig. 15. The second column should indicate the tags first identified in the power level where they were first found. Clearly the system at 70 m range all tags are detectable in Fig. 15 however as per the flowchart in Fig. 7

Table 4
The results for Case Study 2: evaluation of detection reliability in a more complex circumstance.

Sample no.	The correct closest tags	The estimated closest tags	True +ve	False -ve	False +ve
1	Office 004	Office 004	1	0	0
2	Office 004 and Lab 37	Office 004 and Lab 037 and Office 407	2	0	1
3	Office 004 and Lab 037 and Office 407	Office 004 and Lab 037 and Office 407	3	0	0
4	Office 407	Office 407 and Lab 037	1	0	1
5	Office 407 and Office 013	Office 407	1	1	0
6	Office 407 and Office 013	Office 407 and Office 013	2	0	0
7	Office 013	Office 013 and Office 014	1	0	1
8	Office 014 and Lab 036	Office 014 and Lab 036 and Office 013	2	0	1
9	Office 014 and Office 016 and Lab 036	Office 014 and Office 016 and Lab 036 and Office 013	3	0	1
10	Office 016 and entrance	Office 016 and entrance	2	0	0
11	Entrance	Entrance	1	0	0
12	Entrance and Office 017	Entrance and Office 017 and office 034	2	0	1
13	Office 017	Office 017	1	0	0
14	Office 017 and Office 018 and Office 019	Office 017 and Office 018 and Office 019	3	0	0
15	Office 018 and Office 019	Office 018 and Office 019 and Office 020	2	0	1
16	Office 020	Office 018 and Office 019 and Office 020	1	0	2
17	Office 020 and Office 021 and Office 022	Office 020 and Office 021	2	1	0
18	Office 021 and Office 022	Office 021 and Office 022	2	0	0
19	Office 022 and Office 023 and Exit 318	Office 022 and Office 023 and Exit 318	3	0	0
20	Exit 318	Exit 318	1	0	0
21	Office 023 and Exit 318	Office 023 and Exit 318	2	0	0
22	Office 023 and Office 025	Office 023	1	1	0
23	Office 023 and Office 025	Office 025	1	1	0
24	Office 025	Office 025	1	0	0
25	Office 025 and Office 026	Office 025 and Office 026 and Office 027	2	0	1
26	Office 027 and Office 026	Office 027 and Office 026	2	0	0
27	Office 027 and Office 028	Office 027 and Office 028 and Office 029	2	0	1
28	Office 028 and Office 029	Office 028 and Office 029 and Office 030	2	0	1
29	Office 029 and Office 030	Office 029 and Office 030	2	0	0
30	Office 030 and Office 031	Office 030 and Office 031 and Office 032	2	0	1
31	Office 031 and Office 032	Office 031 and Office 032 and Office 033	2	0	1
32	Office 033	Office 033	1	0	0
33	Office 033 and Office 034	Office 033 and Office 034 and Office 032	2	0	1
34	Office 034	Office 034	1	0	0
35	Office 034 and Entrance	Office 034 and Entrance and Office 017	2	0	1
		Total number of tags	61	4	16

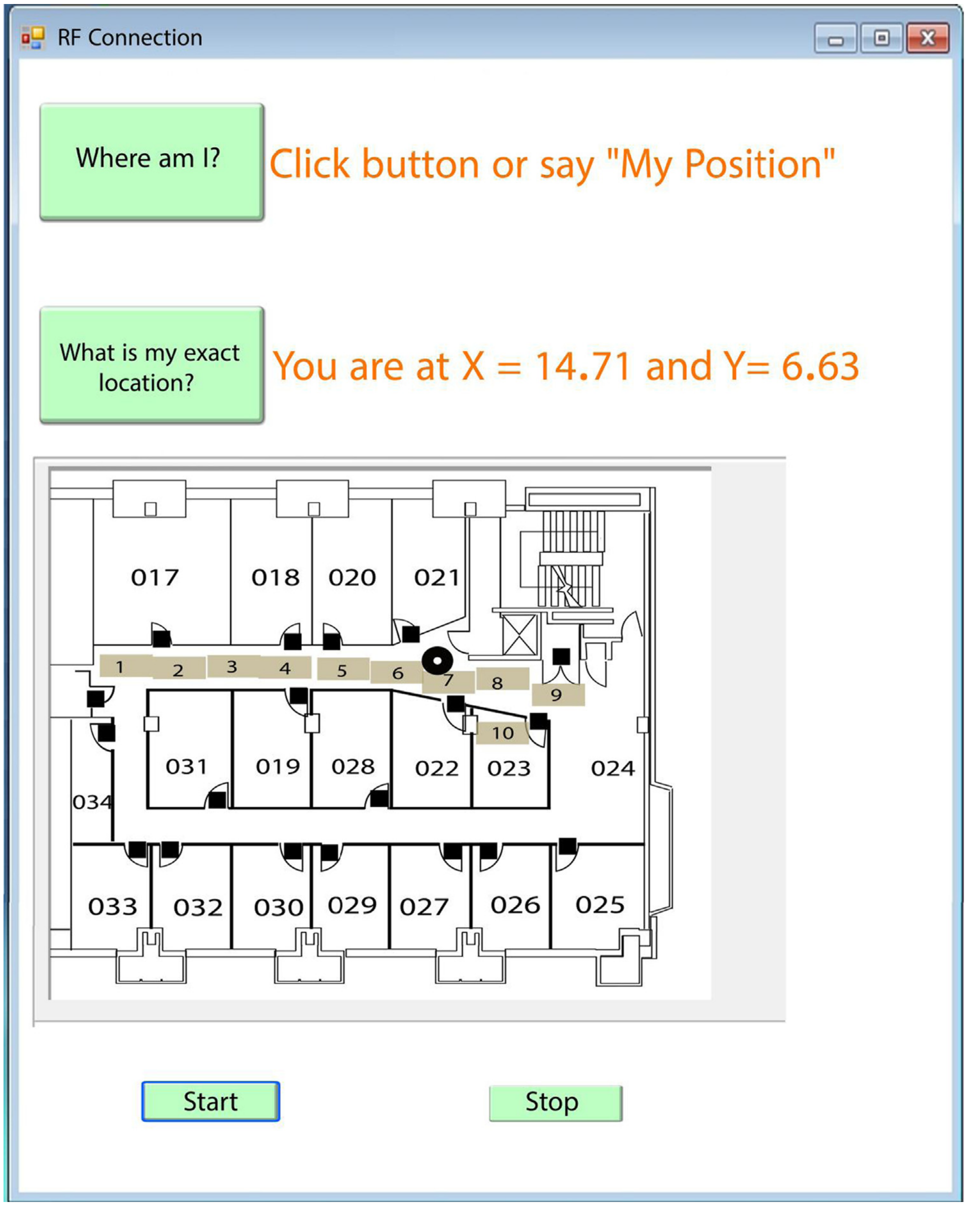

Fig. 16. PC-based development window of second algorithm in indoor environment.

the system scans only until the first level at which tags are found, at that level the tags found are indicated as in column three. The next column shows the "ground truth", the measured results, in the table. The true positive column represents accurate identification of tags as well as accurate distance of the tags from the sample location in terms of attenuation level. For instance, for sample no. 29 the user was close to tag 29 and tag 30 so it should detect both tags and this is what occurred, therefore, true positive equals 2 for that sample. The false negative column represents the number of missing tags that were not identified at the level which other tags were detected. For instance, at sample 22 the system was supposed to detect two tags, but it detected only one of them, so true positive equals 1 and false negative equals 1 as well. The false positive column represents the number of tags that were identified correctly but at the wrong distance. For example, at sample 4, the system should detects only tag office 407, that tag was detected correctly but a further unexpected tag was also detected which was tag for lab 37, so true positive equals 1 and false positive 1 too.

Table 5
Positional accuracy of the second algorithm.

Position	Real *X*	Real *Y*	Est *X*	Est *Y*	Error (m)
1	1.6	6.60	3.66	7.14	2.12
2	4	6.60	4.40	7.07	0.61
3	6.5	6.60	6.20	6.48	0.32
4	9	6.60	9.49	5.98	0.79
5	11	6.60	11.63	6.58	0.63
6	13	6.60	12.32	6.60	0.68
7	15	6.80	14.71	6.63	0.33
8	18	7	16.51	6.28	1.65
9	20	7.20	18.20	7.14	1.80
10	18	9	17.93	7.28	1.72

4.5. Evaluation of the system at indoor environment using second algorithm

The second algorithm has been applied in an indoor environment for evaluation purposes as shown in Fig. 16. The numbers in the corridors represent precalibrated positions that we take during debugging. The measurements are taken at these positions and Table 5 shows the differences between measured and real positions. For example, the circle represents the estimated position of sample number 7. In an indoor environment, the user could depend on the first algorithm instead of the second algorithm because the first algorithm provides useful information synchronously to the user by describing the surrounding tags based on the current position of the user. This may be of more immediate relevance than the user's actual position.

4.6. Outdoor localization technique implementation

As described in the outdoor overview in Section 3, higher attenuation leads to a more narrow range. Therefore, the system does not deal equally with all reference tags, but assigns a weight to each of them, based on a combination of RSSI from that tag and the used attenuation level, as shown in Eq. (1). For instance, the average of RSSI for the tag which is detected on attenuation level 1 will be multiplied by 8 and so on, as described in Table 1.

4.7. Evaluation of the system in outdoor environment

To test the success of the system in an outdoor environment, we placed the tags on the sides of a pedestrian path in Edward Park in a zigzag formation on each side of the path, 4 m apart, as shown in Fig. 17. A–F represent reference tags; the red line represents the real path and the blue dashed line represents the estimated path. The readings were taken at positions from 1 to 7. Table 6 presents the reference tags used for each position and the attenuation level and Table 7 presents the real coordinates and estimated coordinates for the path points. The positions were estimated using the mass centroid method, based on the weights which were given to each tag calculated on the combination of RSSI and attenuation level. As shown in Table 7, the errors occurred around 1 m or less.

Although a larger interval between tags can be used, given the maximum range of 70 m, the uncertainty also increases due to the range setting available. Clearly there are times when such a tradeoff in uncertainty with sparser coverage is justified upon deployment.

4.8. Analysis of the relationship between attenuation ranges and distance

Figure 18 shows six of the eight geographic ranges of the reader power attenuations. We obtained these boundaries using multiple readings at various distances in an open field, and for different tags. As mentioned in previous sections, power attenuation is the core technique in the proposed system. Therefore, 108 samples were taken at distances of 1 m, and 5, 10, 15, 20, 25 m and in random sequence, in order to evaluate the reliability of power attenuation as a quantized distance measure. The results given in Table 8 show that there were only seven incorrect samples (shown by the “false” columns) of the 108 samples.

The methodology is that a tag is presented at a certain distance, and should be detectable for all levels corresponding to that range and greater. So a tag positioned at 5 m, would be detectable for all ranges beyond range 1, but not range 1 at 2.5 m as per the legend in Fig. 18.

4.9. Analysis of the relationship between RSSI and distance

The main techniques of the provided system are power attenuation and the signal strength indicator. The experiments showed that power attenuation was reliable but a higher degree of accuracy was achieved when power attenuation was combined with RSSI. One very important advantage is that the attenuation level is automatically adjusted in the reader for positioning purposes, rather than using a fixed reader sensitivity.

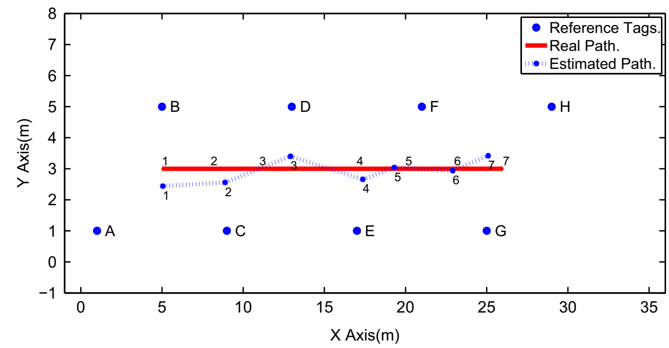

Fig. 17. Indication of user position for outdoor path. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

Table 6
Successful detection of tags A–H for the outdoor experiment.

Pos	A	B	C	D	E	F	G	H	AtnL
1	✓	✓	✓						4
2	✓	✓	✓	✓	✓				4
3		✓	✓	✓	✓	✓			4
4			✓	✓	✓	✓	✓		5
5				✓	✓	✓	✓		5
6					✓	✓	✓	✓	5
7						✓	✓	✓	5

Table 7
Positional accuracy for the outdoor platform.

Pos	Real *X*	Real *Y*	Est *X*	Est *Y*	Error (m)
1	5	3	5.05	2.44	0.50
2	8	3	8.89	2.56	0.99
3	11	3	12.92	3.40	1.96
4	17	3	17.37	2.66	0.50
5	20	3	19.31	3.04	0.69
6	23	3	22.91	2.94	0.10
7	26	3	25.09	3.42	1.00

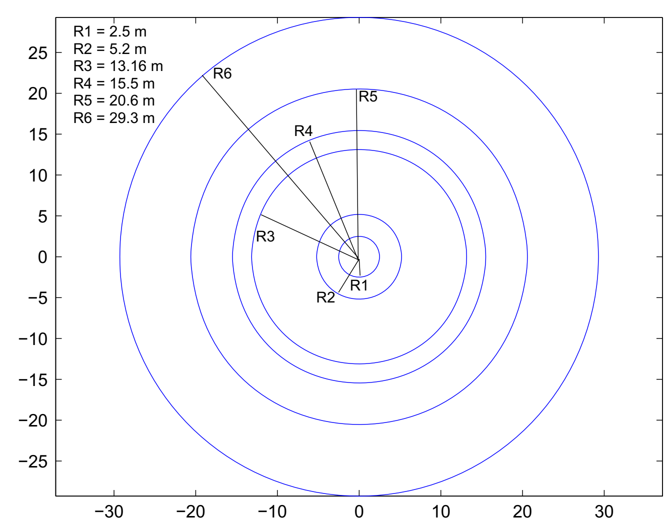

Fig. 18. The geographic range representing the relationship between power attenuation and distance.

Table 8
Evaluation of Detection Reliability.

Distance (m)	True +ve	False -ve	True -ve	False +ve
1	18	0	0	0
5	15	0	3	0
10	8	4	6	0
15	9	0	9	0
20	5	1	12	0
25	2	1	14	1

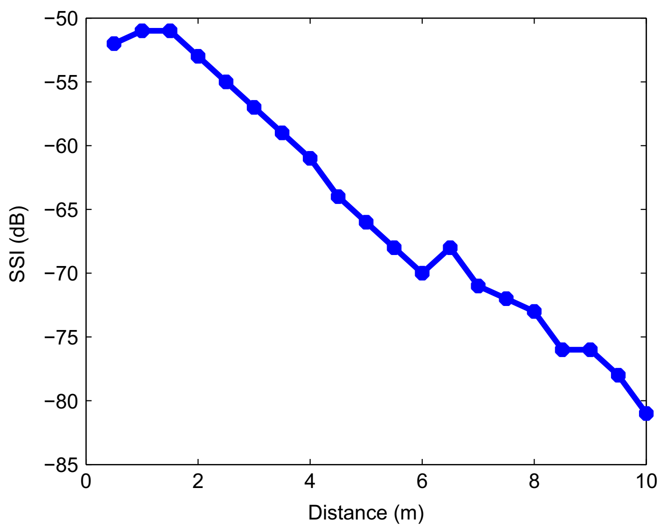

Fig. 19. The near linear relationship between distance and RSSI for short range.

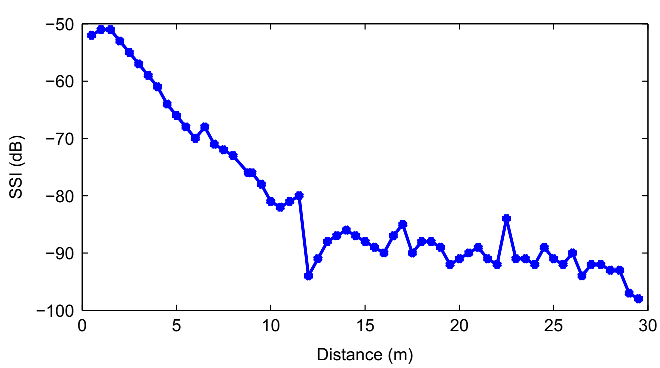

Fig. 20. The linear relationship between distance and RSSI breaks down for wider ranges.

We tested the effect of distance on RSSI and found there is a rough inverse linear relationship between RSSI (measured in dB) and short distance (up to 10 m) as shown in Fig. 19. When the reader detects more than one tag on the same attenuation level, this means all detected tags are in the same range. In similar circumstances, the RSSI technique is useful to indicate a closer tag from a distant one.

On the other hand, we found that RSSI failed to work in many cases by itself for wider ranges (more than 10 m) as shown in Fig. 20 which shows a vaguely negative exponential relationship. In this paper, we do not use RSSI for the wider range. We will explore this further in future. We have used the combination of both RSSI and RAttenuation for short range only as a result.

5. Conclusion

This paper has discussed a new technique to assist the blind or people with low vision to reach their destinations in both indoor and outdoor environments using a wide range active RFID system. The mobile reader has eight power attenuation levels and the geographic range of each level was calculated. A successful detection rate of 93.5% was achieved, as well as a false positive rate of 1%. Furthermore, a combined technique of power attenuation and RSSI was formulated to identity locations to assist visually impaired people to reach their destinations accurately.

To evaluate this technique, two case studies were conducted: the first one inside a building which was designed to assist a user to reach a particular laboratory door in our school, achieving a very high success rate where error rates were less than half meter in all cases; the second was designed to help blind people indicate their position accurately on a pedestrians path, achieving an error rate of around 1 m in almost all cases.

In deployment, the map would be downloaded using Wifi upon entering the building. The details of finding a suitable service discovery methodology are beyond the scope of this particular paper and will be addressed in a future paper.

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