Designing and Implementing a RFID-based Indoor Guidance System

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Abstract

Most people are not familiar with the indoor environment because most interior spaces are similar, and as such do not arouse the interest of most visitors. Although the GPS combined with the GIS has been broadly applied to many navigation applications, it might be still insufficient in an indoor environment where GPS signals are often severely obstructed. To meet the indoor requirements, the technique of RFID (Radio Frequency IDentification) was utilized to play an important locating role in the implementation of an indoor guidance system. The RFID tags, containing 1 KB capacity divided by 64 blocks, were adopted to accommodate the spatial-related information for working with the shortest routing for the system. By selecting the start and end points in the operation, the guidance system can suggest a direct, shortest distance, path. The locations of the passing points were identified and obtained by retrieving the spatial-related data from the tags next to the moving RFID reader. The guidance messages, including suggested path, modified path and moving directions, can be immediately presented to the users and arrive at their destination via the system's graphic and voice interfaces. This guidance system has been comprehensively tested for its operation functions and was evaluated by a group of users, indicating that the average time for way finding in an indoor guidance trial can be efficiently reduced by 50%. This prototype for an indoor guidance system is expected to be capable of working on a portable device, such as a PDA or mobile phone, thereby extending its practical application.

Keywords: Guidance System, RFID, Indoor Locating, Shortest Routing Operation.

1 Introduction

More and more location-related information is applied with today's computer and communication technologies in order to provide so-called location-based services (LBS) to make our lives safer and more convenient (Williams and Christensen, 2005). Previous LBS activities have been primarily used in many commercial applications, such as personal navigation devices, safety and security services, vehicle tracking and fleet management. Generally speaking, LBS can be appropriately grouped by their application domain, e.g. entertainment applications, e-commerce applications, emergency applications, or mobility applications (Abwerzger et al., 2007).

The tour guide service is identified as one of the important applications of LBS. In this operating scenario, tourists or visitors arriving at an unfamiliar place can utilize a portable platform with mobile positioning capability to download necessary system and information files. Then, they can input their points of interest and obtain the required routing information on how to travel/move to those points. It is obvious that a mobile positioning technique that can instantly provide the locations of the visitor to the information system is a core component of such service (Küpper, 2005).

Among the location performance parameters, i.e. availability, accuracy, reliability, integrity and continuity, the ubiquitous availability both outdoors and indoors is a key factor to create a large number of applications for LBS (Lachapelle, 2004). Nowadays, GPS is the most promising and most popular technology in three-dimensional positioning. However, the reception of GPS signals inside most buildings is not reliable for positioning. Some auxiliary techniques, such as GPS pseudolite and Assisted-GPS, have been developed to more effectively obtain a position in a harsh environment (Barnes, et al., 2003; Bryant, 2005; Chang et al., 2005), but the cost of establishing those infrastructures for practical operation is still high.

In recent years, the indoor guidance system has shown its importance in many places, e.g. museums, hospitals, airport terminals and exhibition halls among others (Chou et al., 2004; Föckler et al., 2005; Lay, 2005). In such a

large indoor environment, people may not be easy to find their way to the points of interest as they generally are confused by the very similar space designs in those places. To meet both technical and cost requirements, this study proposed and tested an indoor guidance system based on the RFID. The RFID is mainly operated for indoor locating, applying the steps of (1) storing accurate location information and other necessary data into the tags; (2) installing RFID tags on paths in a building; and (3) connecting an RFID reader to the guidance system for data retrieval. The guidance system can, therefore, receive the location information from the RFID reader, provide the shortest routing operation, and work with the graphic and vocal interfaces to guide the users to their designated points.

2 Indoor Locating Techniques

A guidance system can be defined as a tool for providing the location and routing information, such as direction and distance between one's present location and one's desired destination, using vocal or graphic functions. While executing a guidance mission, a full system service includes the determination of the standing point, finding the route and direction to the destination, record of the completed trajectory, and the expectations of time and distance for the rest of the journey.

It is necessary that a guidance message is correctly provided at some "decision" points for all the waypoints. For an indoor guidance, a sensor attached to the person or moving object to locate the standing points by receiving the relevant spatial information from the responder at the decision point is an effective way of carrying out this mission. Previous development for indoor locating includes the use of GPS, bluetooth, infrared and WiFi etc. (Sun et al., 2005; Wang et al., 2005; Peng et al., 2006; Retscher, 2007). However, the RFID technique operates with many advantages, such as inexpensive, lightweight, tag re-writable, wireless sensing without line-of-sight, with a wide range of operation, a high communication speed, friendly to RF propagation, large data capacity, easy programming, and less dependence on RF links to the external data sources, and therefore has been gaining many interests in locating application (Finkenzeller, 2003; Chon et al., 2004; Chou et al., 2004; Miller, 2006). The performances of some existing indoor locating techniques are compared and summarised in Table 1.

It is evident from Table 1 that the performance of the RFID system has shown its potential for indoor locating application. Briefly, the RFID system consists of three components, tags, reader and software including driver, middleware and application. The tags, also known as the transponders, can store the ID and additional information for any proposed application. The RFID reader is capable of writing/retrieving information into/from the tags. Through the communication between the antennas in both reader and tag, the application software is functioning to show the embedded information to the system users. The RFID system can be categorised by either an active or a passive system, depending if the tags are equipped with an internal battery or not. The RFID can also be grouped by frequency range, such as low (100-500 kHz), high (10-15 MHz), ultra high (850-950 MHz) and microwave (2.4-5.8 GHz) frequency.

3 System Development

The system's architecture and the tag's data contents were both designed for the purpose of developing an indoor guidance system based on RFID for locating. The hardware, software, interface and routing operation were selected and programmed for implementation in this guidance system.

3.1 System Architecture

The RFID-based indoor guidance system is constructed as shown in Fig. 1. The core operating functions rely on the information system developed in this study. This information system is composed of four basic functions, i.e. system control, locating, routing and graphic/voice guidance.

After setting up data-storing tags along the indoor paths in advance, the system begins its work by selecting a point of interest. The information system then activates the RFID reader to retrieve the spatial information from the nearest tags based on the control function, and locates the position of the user on a map using the system's locating function. Based on the shortest path for any decision point as suggested by the system's routing function, the guidance system operates its graphic and voice functions to guide the user to the destination.
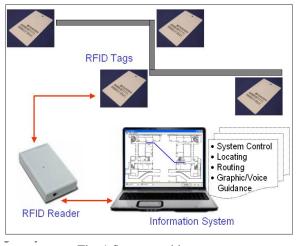
Table 1 Comparison of indoor locating techniques

Performance	GPS	Bluetooth	Infrared	RFID
Accuracy	Low	Medium	High	High
Signal Error Ratio	High	Low	Low	Low
Power Consuming	High	High	Low	Low
Penetration	Bad	Good	Bad	Good

Fig. 1 System architecture

3.2 Software and Hardware

The indoor guidance system was built on a laptop computer equipped with Microsoft Windows XP, Intel Pentium(R) 4 mobile CPU (1.6 GHz) and 256 MB RAM. The system was programmed using Microsoft Visual Basic 6.0, which corresponds with the zlg500B.dll function library for developing the control command for the RFID reader. In addition, the voice interface was based on Microsoft Speech SDK 5.1.

A relatively low cost device was considered at this stage in the development, therefore a passive type of RFID was used. The system utilized a Philips MiFare RC 500 RFID reader as the locating sensor. This type of RFID is based on the RS-232 communication protocol, 13.56 MHz frequency, ISO14443A standard and a maximum 10 cm communication range. It should be noted that an active RFID device can be alternatively adopted to increase the contact range between the reader and the tags in order to expand the feasibility of this guidance system.

The tag used in combination with the RFID reader is a MiFare S50, which has a 1 KB memory. This type of tag consists of 16 sector sets and 4 block sets. A total of 64 data blocks (16 x 4) can be defined to contain all the location and spatial information required for indoor guidance.

3.3 Routing Operation

Since the indoor environment is usually quite regular, the decision points defined as the interest points and turning points on the routes can be given a node code together with its location coordinate and the spatial relationship to the adjacent nodes. The RFID tags, embedded with the location-based information and attached at all the decision points, are used to provide the necessary information for the routing operation to carry out the indoor guiding.

In this study, the routes connecting any two adjacent nodes are generally identified as an "available" path. However, the routes were also possibly defined as an "unavailable" path if the two nodes are not able to pass or are not next to each other. For the routes marked "available", the spatial-related information for the two adjacent nodes are managed by a database and written into the tags affixed at the decision points. On the other hand, the information for the "unavailable" path is not stored by the tags and is certainly not provided for routing. To further realise the application of the "available" path information, a scenario of more than one path between the two nodes is shown in Fig. 2 and its routing operation is explained.
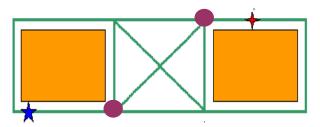

Fig. 2 Scenario of "available" paths between two nodes (The symbols of cross, star and circle represent the start, end and way points, respectively)

When the start and end points are set up, any possible routes pre-defined as the "available" paths are selected for the routing operation. For the scenario shown in Fig. 2, the system can select one of the "available" paths with the shortest distance from the tag's spatial database. The routing operation can automatically provide all the waypoints along the suggested route, even though the user may not follow the suggestion and take an alternative route to reach the end point. This routing operation is easy to program and requires the least amount of processing time. The practical operation adopted by the system for routing is listed as follows:

1. System and Device Initiation
2. Select Case Function
3. Case Locating:
4.   RF Sensing; Read Block C1
5. Case Way Finding:
6.   RF Sensing; Read Block Coordinate & Node
7.   Until Node = Destination or Stop Character
8. End Select
9. If Stop Character <> True Then
10.   Guide Location or Path via Speech & GUI
11. Else: Show Message
12. End If

It is evident from the above-mentioned operation that RFID function programs must be loaded to initiate and command the RFID device. When carrying out a locating function, the RFID reader retrieves tag information to obtain the location. Once the routing command is made, the system reads more spatial information from the tag to determine the shortest path for the user to arrive at the desired point of interest. At the same time, the graphic and vocal interfaces are activated to give more advice to the system users if needed.

3.4 Tag Contents

Considering the memory constraints of a tag, it would be almost impossible to store all the required spatial information in a tag. However, some useful information, such as the coordinates and codes of the decision points, can be embedded into the tags for application. The plan coordinate components (x, y) for a local frame are measured and stored in the tags for each decision point. This data set of coordinates allows to easily show locations on the map, calculate the distance and identify the spatial relationship between any two points. On the other hand, the code information given to each point is a simple type of data occupying less memory in a tag, but it must be maintained by a database for establishing its location and spatial relationship with other tags. Since the tags applied are multi-blocks for data storage, the spatial information including the coordinate, node code and spatial relationship between the two adjacent nodes were decided to be embedded into the tags (see Fig. 3).

Fig. 3 Data contents stored in a multi-block tag

The data storage of a multi-block tag is defined by a read-only A0 block for the manufactured ID, the entire D blocks of key values for access control, and the B0 as well as the C0 blocks for function expansion. The coordinate components of (x, y) and the node code are stored at A1, B1 and C1 block, respectively, for a location designated as a decision point for guidance. The rest of the blocks, from A2, B2, C2 to A15, B15, C15, are used to describe the spatial relationship between that point and other adjacent nodes (see Table 2 for an example).

Table 2: Numerical example for a spatial relationship

Character	1	2	3	4	5	6	7	8
Value	4	0	0	0	0	1	1	2
Value	5	0	0	0	0	1	1	5

The tags used by the guidance system contain 64 (16 x 4) blocks for the entire data storage, in which a total of 52 (14 x 3) blocks are available to store the spatial relationship with this tag's location. For each block, the data capacity is 8 bits. As seen in the first row of Table 2, the 1st character 4 represents an adjacent node located at this tag's right-hand direction with node code 112 is stored in the 6th to 8th characters. Another node with code 115, also located at the right-hand side and next to code 112, has a value of 5 at the 1st character of row 2. This relation means that code 112 and code 115 are sequential on the same route and in the same direction as this tag. It should also be noted that the 2nd through the 5th characters are reserved with 0000 for any further definitions, such as the values for expressing the different floors or buildings. The direction index shown in the first value of a row, as shown in Table 3, can be designated for voice guidance.

Table 3: Direction index designed for the spatial relationship

Direction	To Next Node	To Node	Sequential
Keep Going	0		1
Turn Right Front	2		3
Turn Right	4		5
Turn Right Rear	6		7
Make U Turn	8		9
Turn Left Rear	A		B
Turn Left	C		D
Turn Left Front	E		F

4. System Demonstration

The guidance system developed in this study can be applied to control the RFID device, locate a position, suggest the shortest path and provide both graphic and vocal guidance messages. The system was tested on the ground floor of the administration building at Yu-Da University. The system operation is demonstrated and described as follows:

(1)   Select a building and floor from the scroll menu on the top left to display its plan map on the system.
(2)   Select a start point from the scroll menu on the bottom left most for this mission.
(3)   Select an end point also on the bottom left for this mission.
(4)   Press function key on the bottom right to carry on routing operation and provide the shortest path for this mission (see Fig. 4).
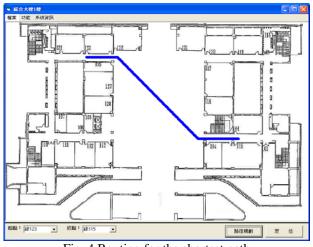

Fig. 5 Guidance at the start

Fig. 4 Routing for the shortest path

Fig. 6 Waypoint guidance

(5)   Press function key on the bottom right most to initiate RFID reader to locate the position of the user.
(6)   For waypoint guidance, the system shows the route traveled and the user's present location at the waypoint with a different colour (see circles in Fig. 5 and Fig. 6).
(7)   On the final section of the route, the waypoint colour is changed again to show that the user, using the RFID-based guidance system, has followed the suggested path and has arrived at his/her destination (see circle in Fig. 7).
(8)   For a user not following the shortest path suggestion, a routing modification function has been developed and is provided by the system. As seen in Fig. 8, the user is located at the starting point on the suggested route. The system's graphic page soon shows a new routing path, see Fig. 9, when it is detected by the system that any waypoint is found to be different from the one suggested.
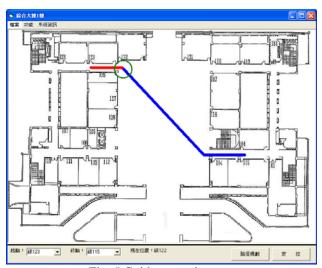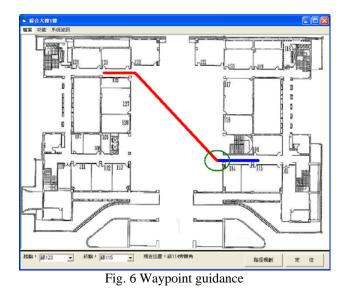

Fig. 7 Guidance at the end
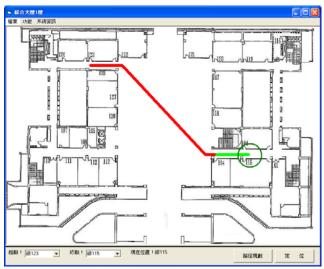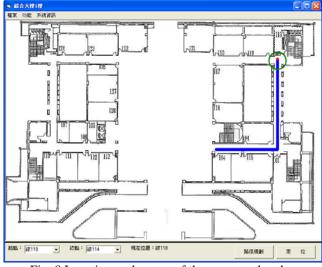
Fig. 8 Locating at the start of the suggested path

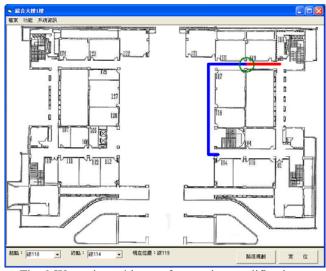Fig. 10 Guidance at the end after routing modification

Fig. 9 Waypoint guidance after routing modification

(9) After routing modification, the user can follow both the graphic and the voice guidance to move along the updated path to reach the destination (see Fig. 10).

5. Efficiency Tests

To determine the efficiency of using this RFID-based indoor guidance system, an evaluation was carried out by inviting 10 visitors to find their way from the same starting point to the same destination. The time needed by each participant was recorded and used to evaluate the system efficiency.
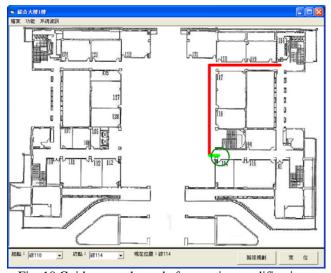
The 10 participants were divided into two equal groups. Five participants used the guidance system to find their way, and the other five did not use any auxiliary device for guidance. A total of 5 sections of trial paths were selected from the indoor environment for the tests. The average times needed in 5 trial paths for the 5 participants in each group, non-system user and system user, are listed in Table 4. The efficiency of the proposed guiding system, based on the ratio of time saved by the system user over the time needed by the non-system user, is also given in Table 4. The comparison of the time difference for each trial path is shown in Fig. 11.

Table 4: Average way finding time for the two test groups

Trial Path	Non-System User (sec)	System User (sec)	Reduction (sec)	Efficiency (%)
1	118	45	73	62%
2	92	41	51	55%
3	112	48	64	57%
4	102	37	65	64%
5	51	45	6	12%
Average	95	43	52	50%

It is evident from Table 4 that the system users required less time in each trial path to find the way to their destination. The average time required for each of the 5 trial paths could be reduced from 95 seconds to 43 seconds when the RFID-based guidance system was applied. The efficiency indicator showed that the time required could be significantly reduced by 50%, with the use of the proposed guidance system. Fig. 11 also shows that the system users consistently took a similar amount of time to find their destination in each trial path, whereas the non-system users tented to show a slightly downward

trend in the time required to arrive at their destination as they worked their way through the 5 trial paths.
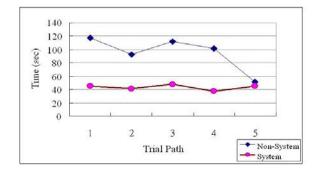

Fig. 11 Comparison of way finding time for the five trial paths

To further investigate the reasons for taking more time in way findings for the non-system users, their feedbacks were collected and summarised as follows:
(1) It was not able to clearly remember what routes I had already passed in this unfamiliar indoor environment;
(2) It was not easy to judge the direction in which I was going in the beginning of the trials, with the result that I repeated several routes;
(3) There usually was no spatial indication provided at the decision points, making it difficult to find the shortest paths to where I needed to go;
(4) It was getting used to this indoor environment towards the end of the trails so that it became easier to my way to the destination;
(5) The destinations could be inferred from the room numbers in a sequence to save time in the way findings.

It should be noted that this guidance system was only implemented in a small and simple space measuring around 100 m x 100 m, with regular room and route patterns. It is expected that the system efficiency can be further improved for more complicated or larger space.

6. Conclusions and Suggestions

This paper proposed, developed and tested a low cost indoor guidance system based on RFID and information technology. The advantages of using RFID for indoor locating, the architecture for the system, the software and hardware used for the development, the routing operation applied for way findings, the spatial information defined for the multi-block tags, the graphic/voice functions used for the system demonstration as well as the system efficiency tests were all carried out and described in this paper.

The indoor guidance system using an RFID reader along with the tags embedded with the spatial information was proven to be feasible in the preliminary phase. However, many issues need to be further investigated, such as (1) adopting a higher frequency or an active type of RFID device to increase the contact range to 1-3 m, based on an anti-collision design for tag data retrieval; (2) coupling a low cost orientation sensor to indicate the direction in a more automatic and continual manner, instead of manually pre-storing that information in the tags; (3) developing a more comprehensive design for tag content and display interfaces to accommodate a multi-floor indoor guidance system c/w a video play function; and (4) expanding this prototype of indoor guidance system to work in a portable device, such as a PDA or mobile phone, for more practical applications.

Acknowledgements

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