Indoor Location Awareness and Application Using Multi-types of RFID

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ABSTRACT

A prototype of indoor guidance system, operated by pre-storing the spatial information into the passive tags attached on the decision points along the indoor paths, performs its locating function to find the ways and update the routing suggestions. With the range estimation model, mainly relied on the signal strengths received from the active tags, and a resection program, designed for location computation using ranges, the indoor location awareness is carried out. Moreover, the RFID-Radar system, worked to mainly detect the targets’ range and angle measurements, has been tested for inventory locating and management. The graphical user interface is adopted by all the systems for an easy operation. Three location awareness systems’ architectures, tag contents, calculation algorithms and function tests have been comprehensively discussed by this paper.

Keywords：Radio Frequency Identification (RFID), Indoor Location Awareness, Location-based Services

多型態無線射頻辨識系統之室內位置感知及應用

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摘　要

本研究共計採用有被動式、主動式以及雷達式等三大類之 RFID 裝置，來從事室內定位技術之相關測試。在所開發完成的雛形應用系統中，藉由室內路徑沿線所貼附已儲存空間資訊之被動式 RFID 標籤，將可有效進行室內導引之相關應用。另藉由接收自主動式 RFID 標籤所傳送之訊號強度，配合所研擬之自適性距離估測模型與交會定位程式，亦可提供室內位置之感知功能。另在使用雷達式 RFID 所偵測之距離及角度資料，亦可提供相當便捷之物品定位盤點及管理使用。本研究針對上述以多型態 RFID 為基礎之應用系統，皆已完成圖形化之簡易操作介面，並已對其作業架構、標籤內容、定位演算法以及系統功能等，提供完整之探討。

關鍵詞：無線射頻辨識系統、室內位置感知、適地性服務

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I. INTRODUCTION

Followed with the new technologies developed for wireless communication, it is also the time to apply such devices and related algorithms for indoor locating applications. It is expected to expand the locating space from outdoor, mainly relied on the GPS satellite positioning, to indoor. It is believed that only the space is effectively spread, the seamless positioning can be achieved, and the location-based services (LBS) can be fully implemented [1, 2].

It is noticed that the radio frequency identification (RFID) has played an important role in wireless technology [3-7]. This paper, therefore, aimed at adopting three different kinds of RFID systems, i.e. the passive, the active and the radar types, to identify the indoor objects and locate the positions for a further application.

One of the research tasks is to utilize a passive type of RFID for the development of an indoor guidance system. The RFID tags were adequately distributed along the corridor with the information of coordinate and spatial relation pre-stored insides. The RFID reader can then be used to read and provide the spatial information to the system for guidance. A graphical user interface (GUI) was also designed to perform the functions associated with the guidance system.

One other test was carried out using one set of active RFID to build up a location determination algorithm. The range measurements, based on the received signal strength (RSS) transmitted from the three nearby tags to the reader, were worked with the trilateral resection model to calculate the positions for the mobile users.

This paper also adopted an RFID-Radar system as a sensor to detect the angles and ranges between the reader and the tags. Those spatial data were converted and calculated for the positions, and worked with an inventory management system. The system functions designed by this research have been comprehensively tested.

II. Passive RFID for indoor guidance

2.1 System architecture

This study proposed and tested an indoor guidance system based on the passive type of RFID. This guidance system is constructed as shown in Figure 1. It is noted that the information system is composed of four core functions, i.e. system control, locating, routing and graphic/voice guidance.

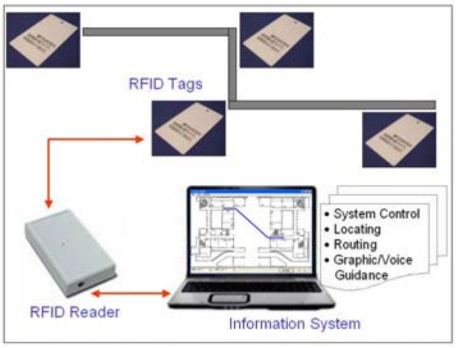

Fig.1. System architecture of using passive RFID for indoor guidance.

The system begins its work by setting up data-storing tags along the indoor paths in advance, and selecting a point of interest. The information system then actives 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.

2.2 Software and hardware

The indoor guidance system was built on a laptop computer with Microsoft Windows XP. 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 for the system, therefore a passive type of RFID, namely the Philips MiFare RC 500 RFID reader as the locating sensor, was used. 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 [8].

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.

2.3 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 realize the application of the "available" path information, a scenario of more than one path between the two nodes is shown in Figure 2 and its routing operation is explained.

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 Figure 2, the system can select one of the "available" paths with the shortest distance from the tag's spatial database.

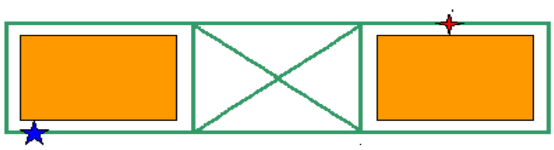

Fig.2. Scenario of "available" paths between two nodes (The symbols of cross, star and circle represent the start, end and way points, respectively).

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.

2.4 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 self-defined plan coordinate (x, y) for a local frame are measured and stored in the tags for each decision point. This coordinate data set allows the system to easily show location on the map, calculate the distance and identify the spatial relationship between any two points. 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 designed to be embedded into the tags (see Figure 3).

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 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. The direction index is also required to be designated for voice guidance.

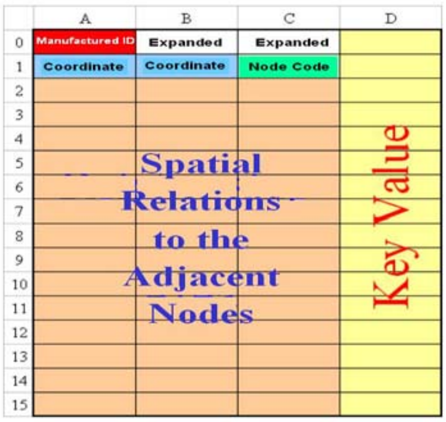

Fig.3. Data contents designed and stored in a multi-block tag.

2.5 System demonstration

The guidance system developed in this study was tested on the ground floor of an educational building. 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 Figure 4).

Press function key on the bottom right most to initiate RFID reader to locate the position of the user.

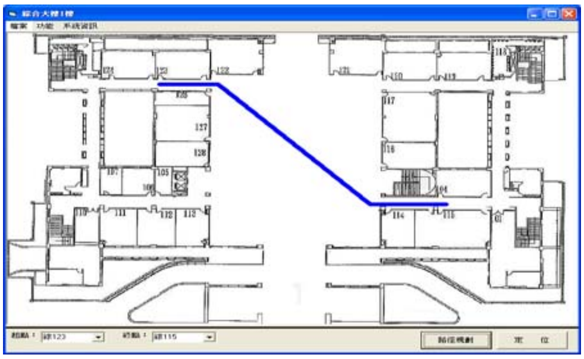

Fig.4. Routing for the shortest path.

(5) 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 Figure 5 and Figure 6).

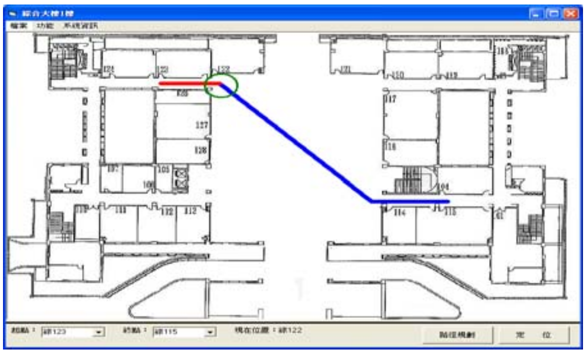

Fig.5. Guidance at the start.

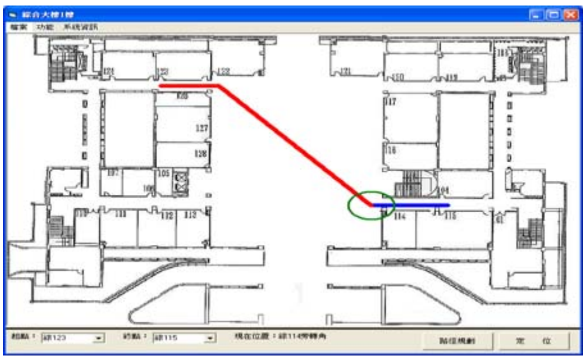

Fig.6. Waypoint guidance.

(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 Figure 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 Figure 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 Figure 9, when it is detected by the system that any waypoint is found to be different from the one suggested.

(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 Figure 10).

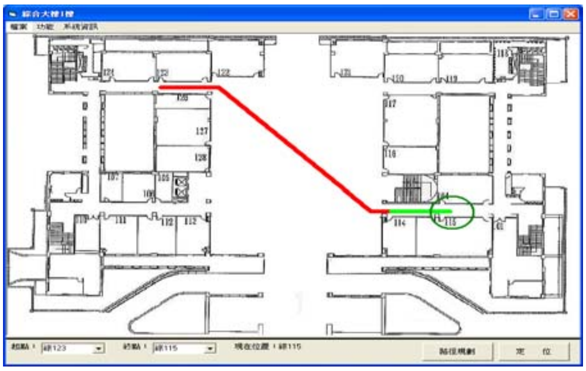

Fig.7. Guidance at the end.

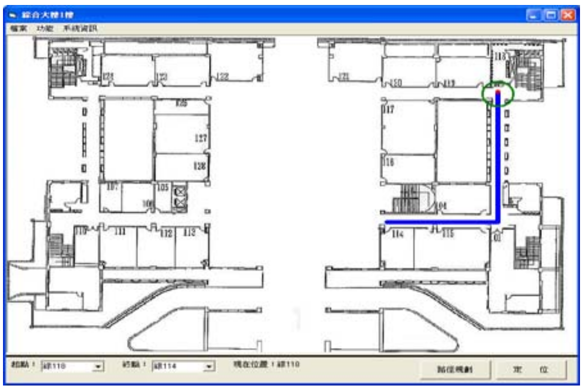

Fig.8. Location awareness at the start of the suggested path

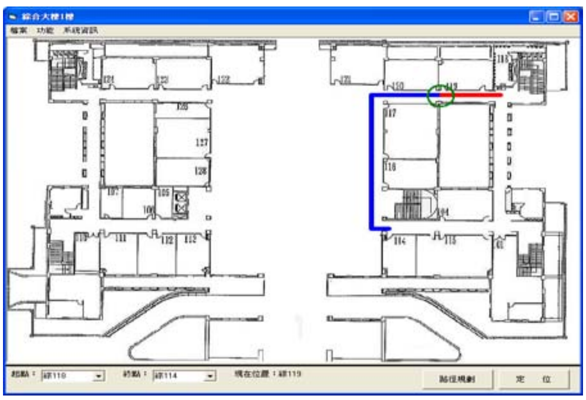

Fig.9. Waypoint guidance after routing modification.

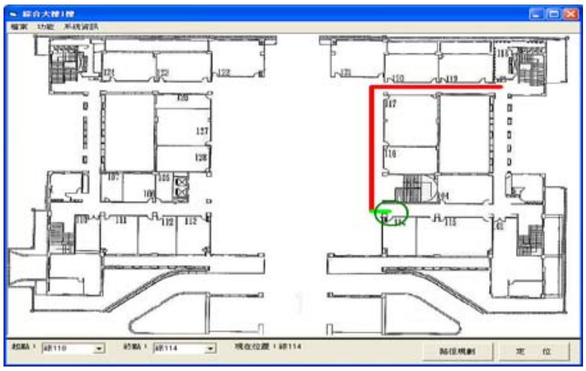

Fig.10. Guidance at the end after routing modification.

III. Active RFID for location awareness

3.1 Operational principle

It is well-known that an active RFID device can be adopted to increase the contact range between the reader and the tag in order to expand the system's feasibility. Unlike the location directly retrieved from the tag contents, as the passive RFID does, this study also applied an active RFID for indoor location awareness by sensing the ranges between the reader and the nearby tags as the measurements for location computation. Using active RFID for locating, it is also necessary to set up a unique ID to each tag for correctly identification by the RFID reader. The reader is also required to be worked with any software for signal strength detection. Based on the received signal strength (RSS) loss along the path from at least three tags, the ranges between the reader the tags are estimated, and the spatial coordinate of the reader can then be calculated using an resection model (see Figure 11).

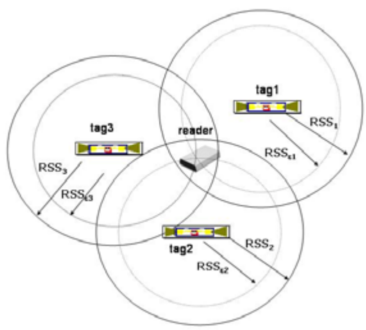

Fig.11. Location awareness using active RFID detected RSS from three tags.

The basic observations used by active RFID locating are the ranges converted from the RSSs [9]. The path loss model applied to the range estimation is as follows

$$PL(d) = PL(d_0) + 10\,n\,\log\left(\frac{d}{d_0}\right) + X_{\sigma} \qquad (1)$$

where, PL(d) is the signal path loss in dB, d is the distance between the reader and the tag, d_0 is a reference distance (says 1 m), $PL(d_0)$ is the signal path loss detected at the reference point, n is the loss index, and X_{σ} is the random errors related to the propagation environment. Through the data collection of d, d_0, $PL(d_0)$ and PL(d), the unknown of n can then be pre-obtained in this specific space. The function can, therefore, applied to estimate the d by using received PL(d) during the locating operation.

After receiving the signal strengths and estimating the ranges from the three tags, the linearized residual equations are expressed with a matrix form as follows

$$\begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} = \begin{bmatrix} \frac{x^0 - x_1}{d_1^0} & \frac{y^0 - y_1}{d_1^0} \\ \frac{x^0 - x_2}{d_2^0} & \frac{y^0 - y_2}{d_2^0} \\ \frac{x^0 - x_3}{d_3^0} & \frac{y^0 - y_3}{d_3^0} \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} - \begin{bmatrix} d_1 - d_1^0 \\ d_2 - d_2^0 \\ d_2 - d_2^0 \end{bmatrix} \qquad (2)$$

and, the solution of plan coordinate (x, y) is iteratively obtained using the approximate values and the unknown vector as follows

$$x = x^0 + \Delta x \quad ; \quad y = y^0 + \Delta y \qquad (3)$$

3.2 Locating analysis

The test field is located in the lobby of an education building with a size of around 6 m x 7 m. A total of 9 RFID tags attached on the celling and 6 test sites set up on the floor, all pre-measured the coordinates, were used for locating tests (see Figure 12). One RFID reader was adopted to measure the signal strengths transmitted from the tags at six test sites for 2 minutes each with a 5 second interval. The variation of the received signal strengths is demonstrated in Figure 13 as a sample.

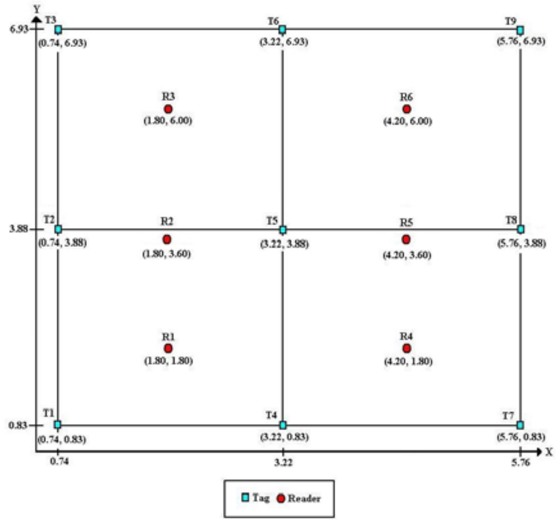

Fig.12. Test field design for active RFID.

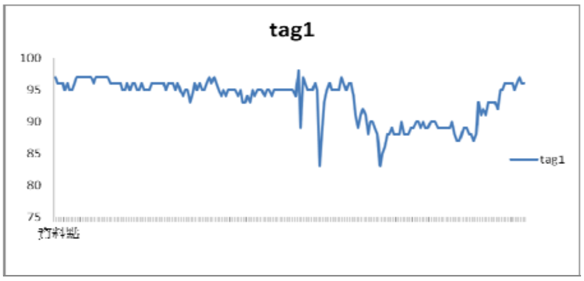

Fig.13. Sample of signal strength received.

To assess the accuracy of the range estimates, the ranges estimated using the path loss model were compared with those provided by a best-fitting curve model as Figure 14. The accuracies of the ranges, estimated using two different models with the same path loss of RSS, are expressed with the root mean square errors (RMSE) and listed in Table 1. The locating accuracies based on the two sets of range estimates are compared in Table 2, where the 2D represents the plan distance vector.

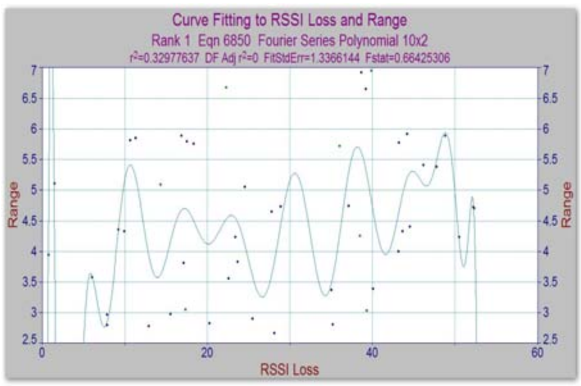

Fig.14. Best-fitting curve model for range estimation.

Table 1. Accuracy of range estimates

Accuracy	Range Estimation Model	
	Path Loss	Curve Fitting
RMSE (m)	2.4	1.0

Table 2. Accuracy of locating test

Coordinate Component	Range Model	
	Path Loss	Curve Fitting
N (m)	1.0	1.0
E (m)	1.1	1.2
2D (m)	1.5	1.6

It can be seen from Table 2 that two sets of range estimates perform a consistent accuracy in the locating test, where a small level of 0.1 m difference is found. However, more efforts need to be made in order to improve the locating accuracy for active RFID as an error ratio (error circle over room size) is shown by 17%, which is regarded to be in a higher level.

IV. RFID-Radar for inventory management

4.1 System requirements and design

It is generally believed that the RFID-Radar system has a certain level of potential to serve as one of the indoor locating tools for logistic applications, such as inventory management. When the inventory checking procedure is executed with an RFID technique, it is required to collect the targets' identification and spatial data by the operating RFID-Radar and tags. As the RFID-Radar is connected to a computer working with an in-house developed management information system and database, those detecting data are stored and utilized at the back-end application system. After a new set of detecting data is processed and compared with the historical data sets, the application system can display and analyze the inventory with graph and text information for the selected management function as well as the locations of the targets detected. The inventory management operation procedure based on the RFID-Radar system is illustrated in Figure 15The system architecture, consisting of the RFID-Radar, application software and database, is depicted in Figure 16.

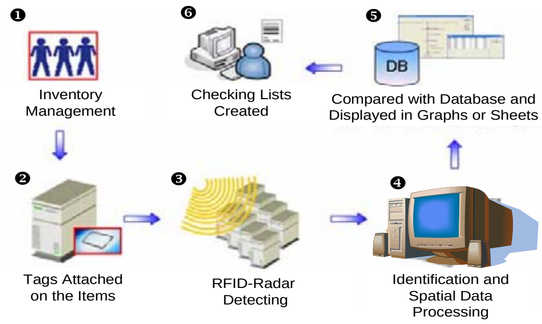

Fig.15. Inventory management procedure with the RFID-Radar system

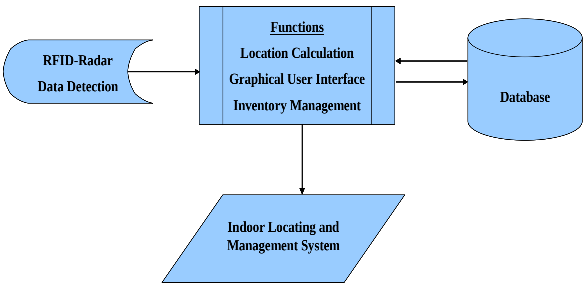

Fig.16. System architecture for RFID-Radar locating and management.

4.2 Equipment and Specification

The RFID-Radar system consisting of four components, namely the reader, antenna array, tags and middleware, was used by the study as the data detecting tool. The main specifications of the RFID-Radar system include an operating frequency of 860~960 MHz, operating bandwidth of 10 KHz, RS232 interface port, 2-dimension scanning, operating range of up to 40 m, reading up to 100 tags in a zone, range measuring precision of 0.5 m, angular measuring precision of 1°, and reporting the position at 1 sec intervals [10].

RFID-Radar system operates with three types of transponders for different detecting ranges. The transponders utilize a simple integrated circuit design so a lower cost tag is made. According to an internal test report conducted by the manufacturer, the metallic reflection effect can be minimized and the system identification capability can then be improved when the tags are attached on the cardboard boxes and placed parallel to the axis of the antenna array [11].

The main component of the RFID-Radar system is the reader, which is working to control the RF signal connectivity between the antenna and the computer. An external antenna array is associated with the reader to transmit and receive the RF signal to and from the targets and provide the spatial sensing data to the system. The antenna array is composed of three patches, which are assembled with specific lengths and expected to effectively detect and correctly estimate the range and angular measurements between the antenna and the transponders in a sector reading area for up to 60°-64° and 40 m. The single patch placed on the left works for RF signal transmission, whereas the two in a pair situated on the right are used for RF signal reception.

The middleware acts as the interface between the reader and the application software. When the user switches on the computer connected to the reader and executes the application software, the API (Application Programming Interface) provided by the middleware can be utilized to activate the reader, scan the transponders, and interpret the responding data. The middleware can also display the tags' locations along with the IDs on the computer screen. For those range and angular measurements detected by the reader, a log file with the defined name of 'filelog.txt' can be created for any further application, such as the inventory management information system developed by this study.

4.3 Detecting data conversion

Since the detecting data, in particular the spatial measurements, obtained by the RFID-Radar play an important role in the management system to be developed, it is necessary to design a computer program to automatically convert this original log file into a self-defined format for better communication between the two system platforms. This research has modified the source code of the API with its same programming language of Power Basic, as shown in Figure 17, to carry on the data format conversion. The output of the log file, shown in Figure 18, enables the identification and spatial information for the tags, and works as the data source for the in-house developed inventory management information system.

Figure 18 shows that the text contents consist of both the identification and spatial data for the tags in the scanning area. The information shown in Figure 18 also reveals that nine tags were scanned at the same time, in which the time of scanning, ID of the tag, measurement of range in meters, and the measurement of the angle in degrees are all listed in a row. A character of 'P' possibly appearing in the final column stands for signal loss of lock, where the detected data is not processed by the management system to this target at this scanning epoch.

```
IF %logdata=1 THEN
    OPEN "filelog.txt" FOR OUTPUT AS #3
    CLOSE #3
    OPEN "filelog.txt" FOR APPEND AS #3


IF %logdata = 1 THEN
        PRINT #3,TIME$,datid$,datrange$,datstatus$
        END IF
            FOR n=1 TO 20
            IF datid$=tagid$(n) THEN

              tagvalue$(n)=datrange$
              IF datstatus$="P" THEN
                tagstatus%(n)=1
                tagmess$(n)=datrange$ & " " & datstatus$
              ELSE
                tagmess$(n)=datrange$ & "  "
                tagstatus%(n)=0
                taglife%(n)=lifepred%
              END IF
```

Fig.17. Programming syntax for log file conversion.

```
filelog5 - 記事本
檔案(F) 編輯(E) 格式(O) 檢視(V) 說明(H)
20:07:02      BCBBB5551    29.96  -001.0
20:07:02      BCBBB5553    08.30   008.1
20:07:02      BCBBB5552    39.61   010.1
20:07:02      BCBBB5577    06.79   000.0
20:07:02      BCBBB5576    30.95   000.0
20:07:02      BCBBB5579    07.14   006.1
20:07:02      BCBBB5159    21.14   002.1
20:07:02      BCBBB5580    07.63   002.1
20:07:02      BCBBB5586    60.11   000.0  P
```

Fig.18. Text contents of the RFID-Radar detecting data.

4.4 System development

The in-house designed management system was developed using the Microsoft Visual Basic (VB) programming language, which is easy to link to Windows-related application programs. Moreover, the VB can utilize many function libraries and offers a graphical user interface and cross platform programming to effectively reduce the system development efforts.

The RFID-Radar-based information system is expected to perform location and management functions for the objects in the scanning area. It is a necessary step to load the spatial information, i.e., the time, tag ID, range, and angle, from the log file created by the RFID-Radar scanning project into the information system and work with the associated database. The system can then execute a plan coordinate (x, y) calculation using the measurements of range (SH) and angle (θH) with Equation (1). This 2D local coordinates system is self-defined by an origin of (0, 0) referred to the location of the antenna array (see Figure 19). Limited to a scanning range of around 40 m and an angle of around ±30° along the signal axis with the RFID-Radar, the information system is designed to work for the objects located in the scanning area, thus providing only positive coordinates in the y component.

$$x = S_H \sin\theta_H$$
$$y = S_H \cos\theta_H \qquad (4)$$

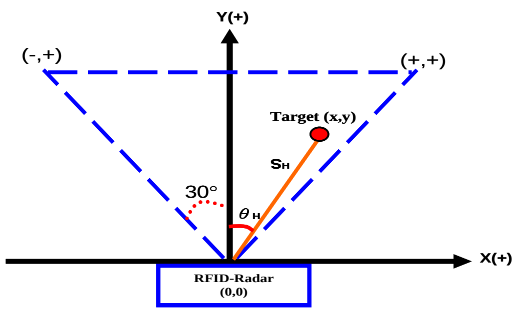

Fig.19. Self-defined 2D local coordinate system for RFID-Radar operation.

The GUI designed by this study consists of three parts, namely the system function area, the graphical information area, and the target information area (see Figure 20). The core system operating for inventory management is selected from the system function area, in which the functions are acting for inventory checking, location comparison, and data enquiry. In addition, the graphical information area occupies most of the system page to mainly display the spatial distribution and location interpretation of the targets detected by the RFID-Radar. One set of auxiliary information showing the IDs and (x, y) coordinates to the targets is offered on the lower right corner of the system page.

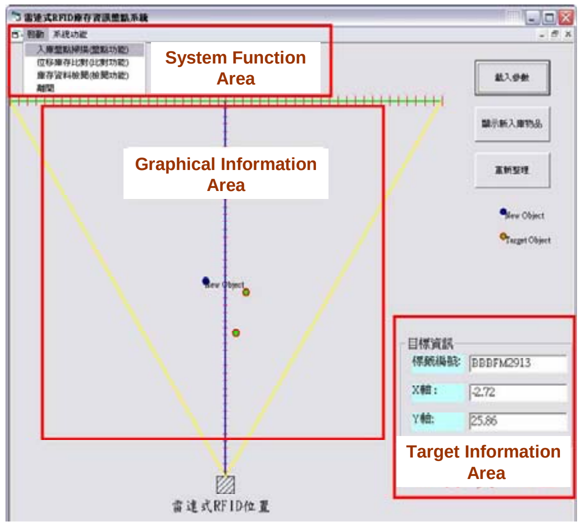

Fig.20. Graphical User Interface (GUI) of the information system.

To emphasize the system's spatial feature, the so-called location comparison function is specifically designed and offered by the system. When operating this function, the log files scanned by the RFID-Radar at two different checking epochs and managed by the database are loaded for comparison. The object's checking result can be easily provided if any object's ID is identified to be new or gone at this checking epoch, compared to one of the historical log files scanned before. A special case occurs to the same object ID existing in the two log data sets, leading to a location interpretation to its spatial movement. If the coordinate difference between the two epochs is larger than the threshold defined, this object will be identified to be moved from its original position, whereas the object will be checked to be not changed. The results of the spatial interpretation will be noticeably displayed in the graphical information area with different colored dots, such as green, blue and red, to represent the scanned object as existing, new and moved, respectively.

4.5 System tests

(1) Locating test

To determine a threshold value required by the information system to identify the object movement in the scanning area, a testing procedure following the RFID-Radar's calibration process was implemented. This test was carried out using an RFID-Radar to transmit the scanning signal with a one second interval and settling a single tag at a standard distance of 9 m to reply to the signal. Three sets of measuring data, each scanned for 180 epochs, were collected for analysis. These data sets were then extracted for two kinds of spatial measurement, i.e., the range and the angle. One set of sample data is plotted in Figure 21 and Figure 22 for the variations in range and angle, respectively. The precisions acted as the reference value to the movement threshold, and based on the standard deviations over the stable period of measurements, are listed in Table 3.

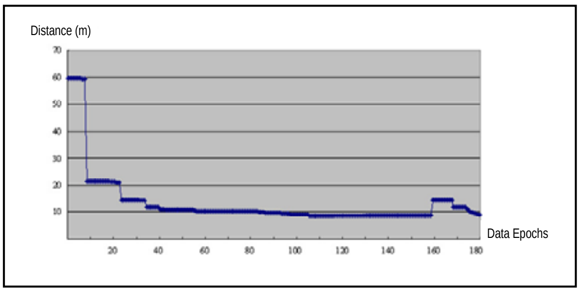

Fig.21. Range measurements in 180 epochs (standard value: 9 m).

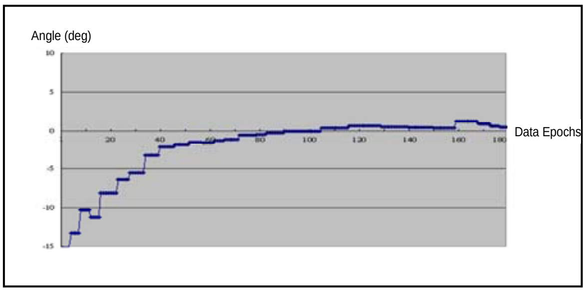

Fig.22. Angular measurements in 180 epochs (standard value: 0°).

Table 3. Precision evaluation to spatial measurements

Data Set	Spatial Measurement		Coordinate Component (m)		
	Range (m)	Angle (deg)	x	y	vector
1	±0.76	±1.48	±0.21	±0.76	±0.79
2	±0.64	±1.36	±0.23	±0.64	±0.68
3	±0.78	±1.46	±0.25	±0.78	±0.82
Avg.	±0.73	±1.43	±0.23	±0.73	±0.76

The sample data shown in Figure 21 and Figure 22 reveal a higher level of data variation at the beginning of 40 epochs and end of 20 epochs, causing the data to be discarded from the precision evaluation. It is also found that the rest of the measurements are relatively stable, but the RF signal is still possibly interfered with the people working in the room. It has been estimated from Table 3 that the RFID-Radar enables the provision of a coordinate precision of 0.23 m and 0.73 m in the x-component and y-component, respectively, with the system's locating function. For practical use by the information system, a threshold value to identify the possible movement of the inventory is then set to be 0.8 m, based on the 2D coordinate precision of 0.76 m estimated in Table 3.

(2) Testing environment

The testing environment conducted by this research was situated in a logistics laboratory, which could be treated as a small warehouse. To test and verify the functions developed for the management system, an RFID tag was attached on the front of the carton to each item in the warehouse. The antenna array was mounted overhead in parallel with the targets to be scanned, to effectively minimize any possibility of signal reflection, and to increase identification capability.

(3) Item checking function

This set of tests focused on the item checking function provided by the in-house developed inventory management system working with RFID-Radar's detecting data. For this test, five targets attached with different tags, coded with final four digits from 4774~4778, were set up on the two sides along the signal transmitting axis. After the data was scanned by the RFID-Radar, the log file was read and loaded by the information system to calculate every target's location. The spatial distribution of the targets detected was then displayed on the system page as Figure 23.

Figure 23 shows that the system expresses five items existing in the store room. By using the computer icon to touch the target symbol, the tag ID and coordinate in the x- and y-component can also appear on the lower right area for each item.

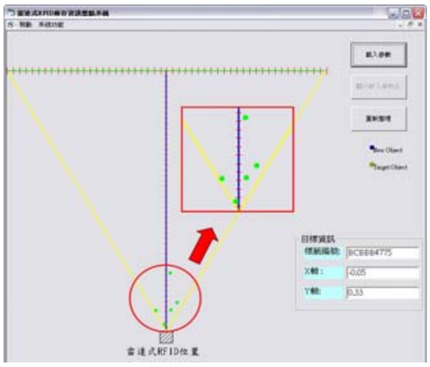

Fig.23. GUI displays the item checking result (with the locations magnified).

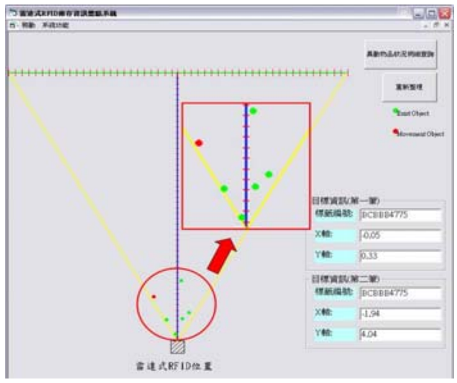

Fig.24. GUI displays the location comparison result (with the locations magnified).

To meet the requirement of inventory management, two data sheets, namely the spatial data sheet and inventory data sheet, are also created and managed by a database, such as the MS-Office Access for single user. The inventory data sheet, acting as an attribute-like data file, simply contains the information on item number, tag ID, item name, and management status. The contents of the spatial data sheet include the data sequence, tag ID, date and time, range, angle, x-coordinate, and y-coordinate.

(4) Location comparison function

This set of tests examined the main function of the management system for detecting the location movement. The items used were the same as those checked in the previous test. However, one of the targets, i.e., the item attached with a tag ID of BCBBB4775, was moved on purpose for a certain distance. For location comparison, the spatial data collected by the previous test was treated as the 'historical' data set. When those five items were scanned once again by the RFID-Radar, new data was created and applied for movement identification. It was expected to display the different locations to the tag assigned effectively, and to provide clearly identified information on its movement.

During the function test, two different epochs of data sets, scanned at the same place for the same items, were selected to compare their location differences. The information system then connected to the database and carried on the location comparison with the 2D vector difference. The location movement analysis provided by the system function is shown in Figure 24.

Figure 24 shows six targets were detected by the system, but presented with different colored symbol. It is also easy to find out one of the green and red dots has the same tag ID of BCBBB4775, meaning this tag had been moved to a new location. According to the system design, the same tag symbol turning from green to red represents a spatial situation where the item has been moved by more than 0.8 m, which was the threshold value defined by the system.

Moreover, as two epochs of coordinate data are necessarily selected on the same target for its location comparison, it is natural this system displays two groups of spatial data in the so-called target information area. As can be seen from the testing example shown in Figure 24, the tag ID BCBBB4775, detected as a item moved over the threshold value, presents the coordinates changed from the previous (-0.05, 0.33) to the new (-1.94, 4.04), which is 4.16 m away from its original location. In addition, the information system enables the provision of a so-called data enquiry function to review the checking report on the item's ID, coordinate, and status (check in, check out or location moved) by simply linking to the database.

(5) Item added function

Another testing was designed to examine the system function related to new items added into the inventory for management. This testing kept the same layout to the targets used in the previous test, but added two new tags with IDs of BCBBB5884 and BBBFM2913. The purpose of this test is to realize the system functions working for the new items detected and to register the data into the database automatically, to minimize the possible errors of manual data registration. The results of this testing is shown in Figure 25 for system exhibition.

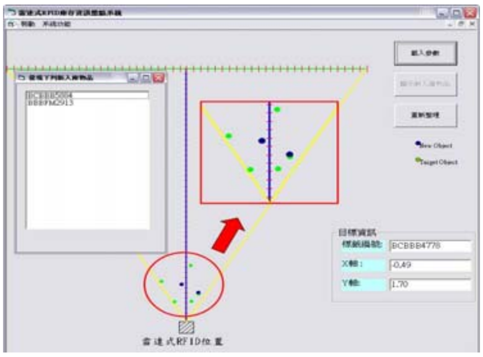

Fig.25. GUI displays the new items added result (with the locations and data registration magnified).

Figure 25 shows the two new items, BCBBB5884 and BBBFM2913, were successfully detected as the new ones and displayed with the blue dots on the system page. The data registration has also been processed, as magnified on the left side of Figure 25. The locations calculated to the newly added items can be provided in Table 4. It can be found the coordinate of BCBBB4775 is changed by the previous location movement test, and the coordinates of BCBBB5884 and BBBFM2913 are newly added by this set of tests.

Table 4. Spatial related data associated to the item added test

Tag ID	Range (m)	Angle (deg)	x (m)	y (m)
BCBBB4774	2.44	16.6	0.70	2.34
BCBBB4775	4.48	-25.7	-1.94	4.04
BCBBB4776	1.81	0.8	0.03	1.81
BCBBB4777	5.34	0.8	0.07	5.34
BCBBB4778	1.77	-16.2	-0.49	1.70
BCBBB5884	2.92	-7.4	-0.38	2.90
BBBFM2913	2.35	17.3	0.70	2.24

V. Concluding remarks

Based on a comprehensive study of using RFID for indoor locating, it has shown that the passive, active and radar type of RFID have a great potential for geospatial information technology, in terms of the indoor location awareness and its applications.

It can be realized from the first part of the study that a low cost indoor guidance system based on passive RFID and information technology has been proposed, developed and tested. Its main contributions include the design of the tag contents and the development of an information system, which is capable of operating the tag-stored spatial data to work with the GUI-displayed system for locating, routing and vocal guidance in an indoor environment. However, this system can be further expanded by coupling a low cost orientation sensor to indicate the direction in a more automatic manner, or designing a suitable tag contents to operate the function in a multi-floor environment.

This study also presented a technique of using active RFID to locate the indoor position, based on the ranges converted from the received signal strengths between the reader and at least three tags. This paper has proposed the algorithms for range estimation and position computation. It has shown the range estimation errors of 1-2 m, leading to an accuracy of around 1.5 m for 2D positioning. There is still a room to improve the accuracy for the range estimation models.

The third part of this study utilized a radar-like RFID equipment to collect identification, range and angular data transmitted between the reader and the tags. The measurements work with an in-house developed information system for inventory management. This GUI-displayed system, based on its data detection, indoor locating and management functions, was designed, implemented and tested. Limited to the equipment, the system is now able to only process the data scanned to a sector area in the front view so only the plan coordinates are provided for the items, leading to an operation difficulty for the items stored on a multi-layer shelf.

Moreover, the active and radar types of RFID indoor locating techniques need to be further tested for real-time data processing if the data detected by the RFID reader can be directly transmitted to any mobile devices to boost the applications of location-based services (LBS).

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