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Indoor locating and inventory management based on RFID-Radar detecting data

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Abstract. The new generation RFID-Radar system provides the function of detecting the targets' locations with the measurements of range and angle using a reader and an antenna array to transmit and receive the RF signals. It enhances the application value for RFID when combined with the geospatial information. In this study, an information system embedded with a plan coordinate detection function was developed using the spatial data provided by the RFID-Radar system, to expand the application of indoor locating and meet the inventory management requirements. The in-house developed management system can work for processing the measurements detected by the RFID-Radar system, calculating the target's location, checking the target's status and analyzing the target's movement occurring between the two detecting epochs through a designed GUI (graphical user interface). The system has been tested to show an internal precision of 0.76 m for locating, based on the stability test of the range and angle measurements, and effectively demonstrates the functions for detecting the target's movement and archiving the inventory's management information with a database.

Keywords. Radio frequency identification, indoor locating, inventory management, information system.

1 Introduction

As the wireless communication technology is continuously innovated and successfully applied to geospatial information, location-based services (LBS) are also making significant progress in technical and commercial domains. It is well known that the functions of LBS are highly related to the performance of so-called seamless positioning. Such an ideal is expected to be implemented by introducing new electronic equipment, which is working independently or integrated with the Global Navigation Satellite System (GNSS), to effectively extend the locating areas from outdoors to indoors [3, 5–7].

A new technology based on radio frequency identification (RFID) has been developed in recent years, and could be one of the solutions. RFID can provide spatial information to some LBS applications, such as asset tracking, route guidance, and pedestrian or vehicle navigation [1, 2]. However, most of the RFID-based application systems apply a passive type of RFID for locating, due to the equipment cost and research progress. In this type of locating operation, the system developers need to pre-store the spatial information, e.g., the waypoint IDs, coordinates and spatial relations between each waypoint, for all the RFID tags in use. The system users can simply apply an RFID reader to contact the nearest surrounding tag, acquire its spatial information, and transmit the data to a portable device. An application system is also required to work with the spatial information to carry on its designed functions.

Among various RFID systems, an active type of RFID can also be helpful to develop an indoor locating function, with the advantage of a longer sensing range mainly as the power supplied by the battery attached to the tags [4, 9, 10]. In this type of locating operation, spatial information is also required to be pre-stored to the RFID tags, but the RFID readers can collect various signal intensities from the surrounding tags to estimate the ranges between the readers and the tags and consequently provide a series of highly accurate positions. Its locating algorithm is based on a resection model with a more reliable multi-range data set to effectively carry on a higher density and wider area of trajectory determination. This mode of RFID locating is relatively complicated in terms of range estimation and error control, but it does have more room for further development in some of the technical applications.

One more recently developed RFID system, namely RFID-Radar, was invented by a South Africa-based company using an operating type as a radar [11]. The unique feature of the RFID-Radar system is that it applies low-frequency radio sensors, along with signal antennas and lowcost tags, to perform multitarget scanning within a specified area to collect the target identification and spatial-related information. The system operation is based on a principal similar to that of the radar system for its main role in detecting the angles and ranges between the signal antennas and the target tags. With the known coordinates of the antenna site affiliated to the RFID-Radar scanning, the

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detected data set can then be applied for object identification and location provision in an indoor space.

Due to the accuracy limitations of the RFID-Radar system, the feasibility of using such system for any indoor application needs to be examined. However, it is generally believed 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. It is well known that inventory management has a long history of using bar code systems, which requires more labor and time to realize the current status for each item. This operation mode is not efficient and it is almost impossible to correctly check whether the goods are stored in the room and kept in the right places. A good operation technique for inventory management can be proposed to implement an RFID-Radar system, using a target sensor to provide identification and spatial information, and working with an information system designed to process the detected data and operate the management functions. It is expected that such a system can add spatial information to the logistic applications and make inventory management more effective and informative.

Since the middleware, equipped with the RFID-Radar system, working in-between the RFID reader and the tags are mainly used to control the system operation and show the targets with graphical information on the computer in connection, one other interface program functioning to read the detected spatial measurements and transform the measurements into a digital data set for any further application needs to be developed. Moreover, a GUI-based information system focused on location calculation with the detected range and angle measurements as well as inventory management using identification and spatial data is also designed by this study. A simulation test was carried out in a logistic laboratory to verify the operation functions for the system. The system's operation structure, software features, and function tests for indoor locating and inventory management based on a new type of RFID-Radar system is thoroughly examined and described in this paper.

2 System and operation structure

2.1 System requirements and design

The designed system focuses on inventory management application. Therefore, the operation functions generally used in the stock checking procedure are proposed and developed by this study. It is expected to design and implement a management information system featuring target detecting and locating functions with the help of RFID-Radar for spatial data collection. This system aims to perform automatic identification, spatial measurement, location calculation, and inventory management for indoor stocks attached with tags. The requirements and characteristics of the system worked out are summarized as follows:

(1) Apply RFID-Radar scanning data: To realize RFID-Radar system's specifications and operation procedures; to output, transform and store the system's scanning data in a specific format; and to operate the management system in an off-line mode to fully test its detecting and locating functions.

(2) Establish targets' spatial coordinates: To setup a self-defined local coordinate system for data in use; to obtain and display the targets' 2D coordinates on the system screen; and to compare different epochs' spatial data for location interpretation.

(3) Provide location and management: To acquire the targets' latest status and locations through the detected data; to create a database for inventory checking and tracking; and to expand the performance of using RFID technique for location management.

(4) Demonstrate graphic viewing functions: To integrate graph and text information for a management system; to display the targets' location and its moving situation; and to assist the check personnel to find out and manage the inventory more effectively.

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 based on the RFID-Radar system is illustrated in Figure 1. The system architecture, consisting of the RFID-Radar, application software and database, is depicted in Figure 2.

2.2 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 [11].

The RFID-Radar system operates with three types of transponders, i.e., the claymore, the stick type and the credit card type of tags, for different detecting ranges. The transponders utilize a simple integrated circuit design, so

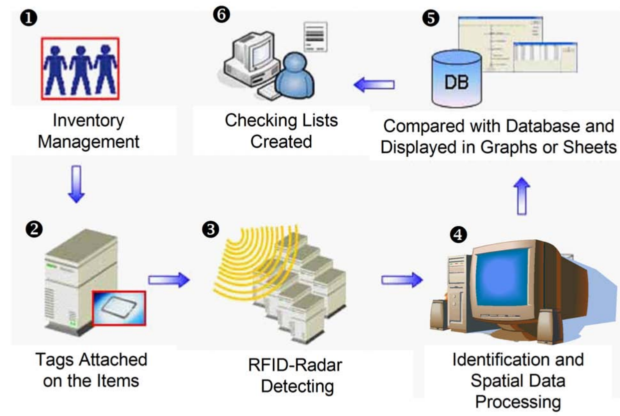


Figure 1. Inventory management operation using the RFID-Radar system.

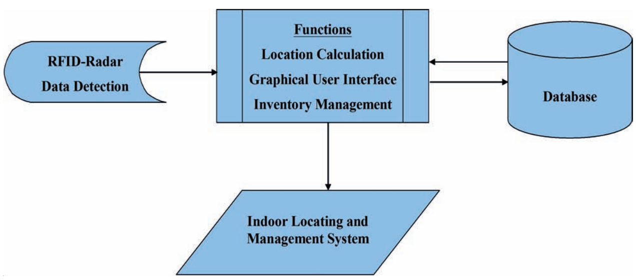
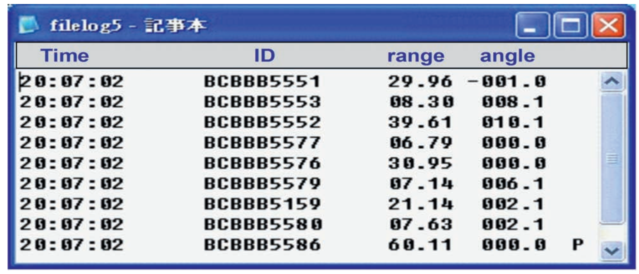


Figure 2. System architecture for locating and management.

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 [8].

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 works for RF signal transmission, whereas the two in a pair 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.


filelog5 - 記事本

Time	ID	range	angle	
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

Figure 3. Text contents of the detecting data.

2.3 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 to carry on the data format conversion. The output of the log file, shown in Figure 3, 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 3 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 3 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.

2.4 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

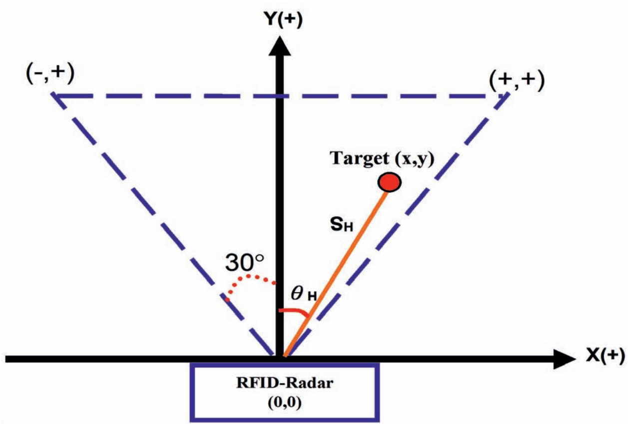


Figure 4. Self-defined 2D local coordinate system for system operation.

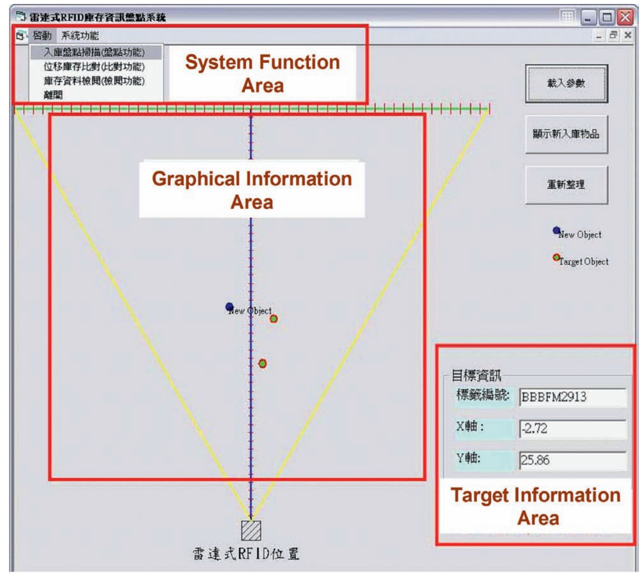


Figure 5. Graphical user interface (GUI) of the system.

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 S_H and angle θ_H with Equation (1) for the target. This 2D local coordinates system is self-defined by an origin of $(0, 0)$ referred to the location of the antenna array. Limited to a scanning range of around 40 m and an angle of around $\pm 30°$ 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 (see Figure 4).

$$\begin{aligned} x &= S_H \sin \theta_H, \\ y &= S_H \cos \theta_H. \end{aligned} \tag{1}$$

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 5). 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.

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.

3 System test and evaluation

3.1 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 6 and Figure 7 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 1.

The sample data shown in Figure 6 and Figure 7 reveal a higher level of data variation at the beginning of 40 epochs

Data Set	Spatial measurement		Coordinate (m)		
	Range (m)	Angle (deg)	x-component	y-component	2D-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
Average	±0.73	±1.43	±0.23	±0.73	±0.76

Table 1. Precision evaluation to spatial measurements.

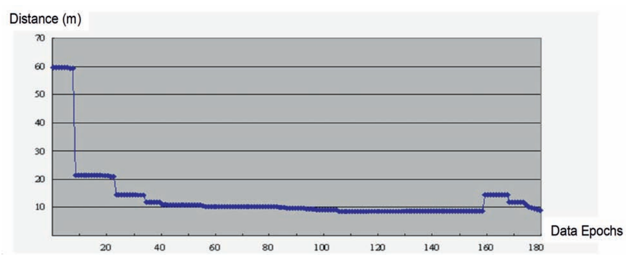


Figure 6. Range measurement in 180 epochs (standard value: 9 m).

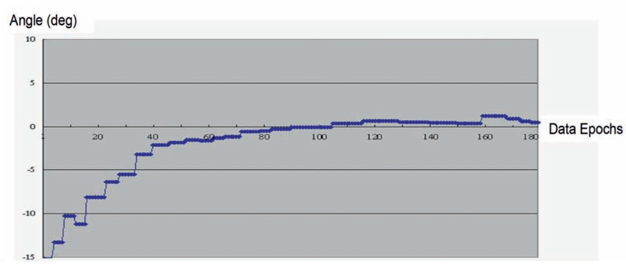


Figure 7. Angular measurements in 180 epochs (standard value: 0°).

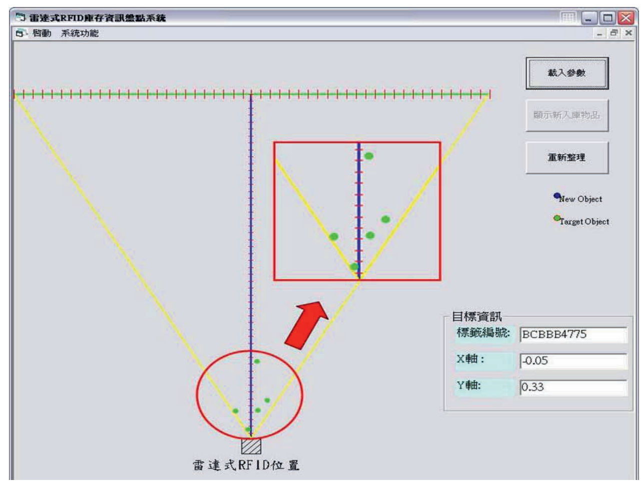


Figure 8. GUI displays the item checking result (with the locations magnified).

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 1 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 1.

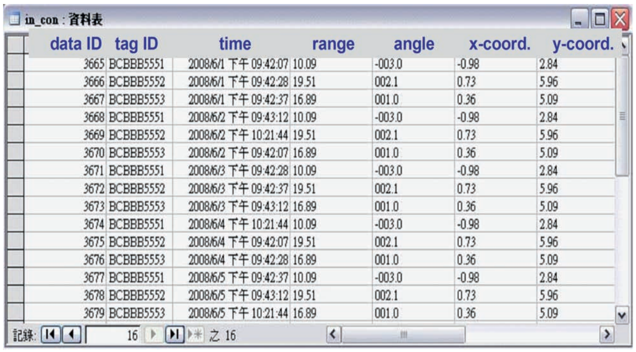
3.2 Testing environment

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.

3.3 System function tests

(1) 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 to 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 8.

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



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data ID	tag ID	time	range	angle	x-coord.	y-coord.
3665	BCBBB5551	2008/6/1 下午 09:42:07	10.09	-003.0	-0.98	2.84
3666	BCBBB5552	2008/6/1 下午 09:42:28	19.51	002.1	0.73	5.96
3667	BCBBB5553	2008/6/1 下午 09:42:37	16.89	001.0	0.36	5.09
3668	BCBBB5551	2008/6/2 下午 09:43:12	10.09	-003.0	-0.98	2.84
3669	BCBBB5552	2008/6/2 下午 10:21:44	19.51	002.1	0.73	5.96
3670	BCBBB5553	2008/6/2 下午 09:42:07	16.89	001.0	0.36	5.09
3671	BCBBB5551	2008/6/3 下午 09:42:28	10.09	-003.0	-0.98	2.84
3672	BCBBB5552	2008/6/3 下午 09:42:37	19.51	002.1	0.73	5.96
3673	BCBBB5553	2008/6/3 下午 09:43:12	16.89	001.0	0.36	5.09
3674	BCBBB5551	2008/6/4 下午 10:21:44	10.09	-003.0	-0.98	2.84
3675	BCBBB5552	2008/6/4 下午 09:42:07	19.51	002.1	0.73	5.96
3676	BCBBB5553	2008/6/4 下午 09:42:28	16.89	001.0	0.36	5.09
3677	BCBBB5551	2008/6/5 下午 09:42:37	10.09	-003.0	-0.98	2.84
3678	BCBBB5552	2008/6/5 下午 09:43:12	19.51	002.1	0.73	5.96
3679	BCBBB5553	2008/6/5 下午 10:21:44	16.89	001.0	0.36	5.09

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Figure 9. Spatial data sheet for management information system.

Tag ID	Range (m)	Angle (deg)	x-coordinate (m)	y-coordinate (m)
BCBBB4774	2.44	16.6	0.70	2.34
BCBBB4775	0.33	−9.4	−0.05	0.33
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

Table 2. Spatial related data used in function tests.

include the data sequence, tag ID, date and time, range, angle, x-coordinate, and y-coordinate (see Figure 9).

Figure 9 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. The value shown on the system page has been manually checked with the measuring and computing data listed in Table 2 for its validity.

(2) 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 10.

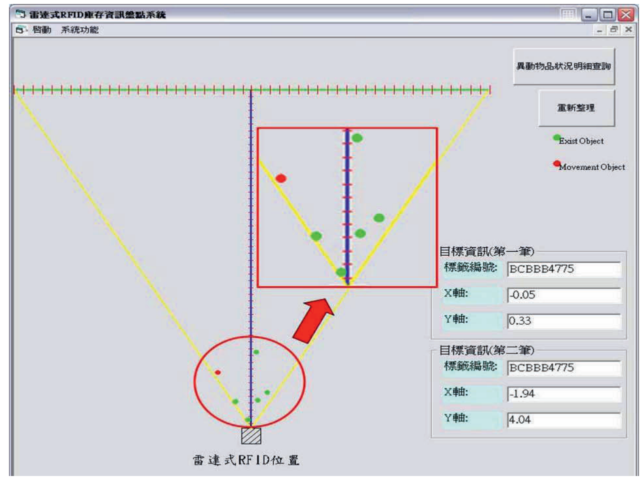

Figure 10. GUI displays the location comparison result (with the locations magnified).

Figure 10 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 10, 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.

(3) 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

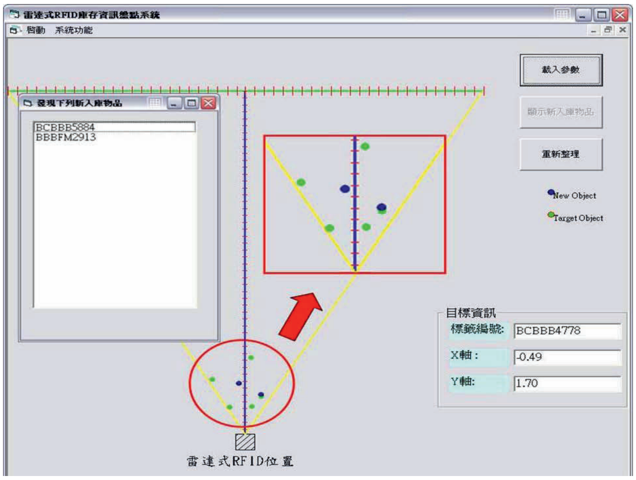

Figure 11. GUI displays the new items added result (with the locations and data registration magnified).

Tag ID	Range (m)	Angle (deg)	x-coordinate (m)	y-coordinate (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

Table 3. Spatial related data associated to the item added test.

errors of manual data registration. The results of this testing are shown in Figure 11 for system exhibition.

Figure 11 shows that 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 11. The locations calculated to the newly added items can be provided in Table 3. It can be found that the coordinate of BCBBB4775 is changed by the location movement test and the coordinates of BCBBB5884 and BBBFM2913 are newly added by this set of tests, both compared to the test results shown in Table 2.

4 Conclusion and suggestions

This research utilizes RFID-Radar equipment to collect identification data as well as the range and angular measurements for an in-house developed information system on inventory management. This system, based on its data detection and indoor locating functions, was designed, implemented and tested by this study. Some concluding remarks and suggestions are summarized as follows:

1. The system using a new generation of the RFID device, namely RFID-Radar, was developed for inventory management, including the functions on data scanning, target identification and item checking, in an indoor environment. The most extraordinary function is the spatial information offered by the system for greater quality and more efficient management operation.

2. This system created a procedure for 2D coordinate capture, associated with the RFID-Radar equipment. The spatial information, based on the self-defined local coordinate system referred to the scanning site of the antenna array, was proven to be effective in location comparison for movement interpretation of items in a store.

3. This system was designed to be a graphical user interface (GUI), along with the traditional text type of data sheet, for a clear exhibition of the items detected and analyzed in the scanning area. It is easier for the users to realize the item's status and location in stock, and to assist the staff in managing the items correctly and efficiently by using this automatic checking procedure.

4. Limited to the equipment and time, 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 system also needs to be tested for real-time data processing if the data detected by the RFID-Radar can be directly transmitted to the information system. This improvement can then be expected to work for a mobile device to boost the applications of location-based services (LBS).

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