The Study on Using Passive RFID Tags for Indoor Positioning

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Abstract: *Radio frequency identification (RFID) is the technology that put an RFID tag on objects or people, so that they can be identified, tracked, and managed automatically. With its wide application in the automobile assembly industry, warehouse management and the supply chain network, RFID has been recognized as the next promising technology in serving the positioning purpose. Existing positioning technologies such as GPS are not available indoors as the terminal cannot get the signal from satellites. To enhance the availability of the positioning systems for indoors, the development of RFID positioning system for locating objects or people have became a hot topic in recent research. Compared with conventional active and high-cost solutions, this paper studied the feasibility of using passive RFID tags for indoor positioning and object location detection to provide real time information for tracking movement. Results of experiment show that readability of the passive RFID positioning system is satisfactory, and it is a more cost effective solution when compared with other positioning technologies.*
Keywords: *Radio frequency identification (RFID), Location aware, Positioning system, Passive tag*

1. Introduction

With the popularity of indoor location sensing systems and numerous research on positioning in wireless networks, the indoor RFID positioning issue has emerged and it is a significant research topic (Ni, L. et al., 2003; Bekkali, H. et al., 2007; Tesoriero, R. et al., 2008). There are many different kinds of positioning technologies such as Global Positioning System (GPS), cellular phone tracking system, Wi-Fi positioning system and RFID Positioning System. All these technologies have different coverage, applications, accessories and limitations (Hazas, M. et al., 2004). The nature of indoor positioning systems is somewhat different from that of outdoor ones. Typically, the coverage of a positioning system is inversely proportional to its detection accuracy.

Among these technologies, the most popular positioning system is GPS at present. It is a satellite based positioning system which is designed for outdoor environment; however, it does not perform well indoors (Na, J., 2006). The GPS signal is easily blocked by most construction materials and hence making it useless for indoor positioning. There is a problem of accuracy and absolute positioning in a specific indoor area. For indoor environments, positioning systems that rely on existing network infrastructures such as Wi-Fi positioning system or Bluetooth are able to provide location accuracies ranging from 1 to 10 m, depending heavily on the usage environment. The Wi-Fi network must exist as a part of the communication infrastructure, otherwise it will require expensive and time-consuming infrastructure deployment. Deriving an accurate propagation model for each Wi-Fi access point in a real-world indoor environment is extremely complex and therefore usually results in a relatively poor positioning accuracy (Widyawan et al., 2007; Yim, J. et al., 2010).

Other than the issue of inaccuracy problem in indoor location detection, cost is another challenge in designing indoor positioning systems. Given the fact that most positioning systems are designed for tracking small quantities of items, there is no cost effective way to track large quantities of items (Jang, W. & Skibniewski, M., 2008). For example, even though Wi-Fi positioning system can be utilized indoors, its development and setup costs are very high when it covers a large area because it requires deployment of expensive Wi-Fi tags for tracking items. Since such tags are relatively expensive, they need to be removed from tracked items objects for reuse on items to be tracked. If the objects to be tracked change frequently, the operation cost of transferring tags for Wi-Fi positioning applications will be very high. All these make the development and setup cost of Wi-Fi positioning system too high to be economically viable. Thus, designing a cost-effective indoor positioning system remains an open challenge at present (Chang, N. et al., 2010).

This paper presents a real time and low cost indoor RFID positioning system. It is an accurate positioning technology which can identify the movement and location of personnel and goods to provide real time information that supports Location-Based Services (LBS). To offer a low cost indoor positioning solution for locating large number of items, passive tags are chosen rather than active ones. To study the effectiveness of using passive RFID as the positioning technology, experiments are conducted in a laboratory under a controlled environment.

2. Literature Review

Positioning is an important function in many areas, such as land surveying, aviation, aeronautic, robotic, or virtual and augmented reality. In the aspect of LBS, positioning systems need to provide considerable coverage and to allow the location of mobile users with small mobile devices or badges (D'Roza, T. & Bilchev, G., 2003). As stated by Yu, K. et al. (2009), LBS is a concept that denotes applications integrating geographic location (i.e., spatial coordinates) with the general notion of services. Examples of such applications include emergency services, car navigation systems, tourist tour planning, or "yellow maps" (combination of yellow pages and maps) information delivery. Traditionally, location information has typically been derived by a device and with the help of a satellite system (i.e. a GPS receiver). However, such satellite system lacks the capability in achieving high coverage and positioning precision in indoor environments. Indeed, indoor positioning systems (generally?) require cost-intensive installations and are (often?) restricted to buildings or even some rooms inside a building. Stimulated by attempts to provide accurate indoor LBSs, interest in the role played by RFID in such applications has started to grow in the late 1990s. A new type of location detection technology and new market interest in data services was heavily researched nowadays (Koyuncu, H. & Yang, S., 2010).

RFID technology is a non-contact and automatic identification technology that uses radio signals to identify, track, sort and detect a variety of objects including people, vehicles, goods and assets without the need for direct contact (as required in magnetic stripe technology) or line of sight contact (as required in bar code technology). RFID technology can track the movements of objects through a network of radio enabled scanning devices over a distance of several meters (Kwok, S. et al., 2007; Kwok, S. et al., 2008). With such benefits, numerous researchers attempted to use RFID technology in positioning. Fu, A. & Retscher, G., (2009) introduced three common methods (namely cell-based positioning, trilateration, and location fingerprinting) in locating RFID tagged objects. For example, Zhou, Y. et al. (2007) designed a new artificial landmark-based location detection system for mobile robots navigating in indoor environments based on the principle of triangulation. Such location detection system functions like an indoor GPS. Using the trilateration as the positioning technique, Daito, M. & Tanida, N., (2008) applied the location detection system in identifying the position of a victim for disaster rescue. Regarding the highest positioning accuracy, Mori, T. et al. (2008) utilized location fingerprinting method to determine the location of a targeted object in an unknown place. However, all the above studies involve the use of active RFID tags for positioning purposes, whereas this paper attempts to employ a passive solution (which is cheaper and more cost-effective), to serve the purpose.

3. Research Methodology

The research methodology of this study has three phases: evaluating the performance of passive tags, design of the data collection model, and development of the location estimation model for the RFID positioning system by means of passive tags.

3.1 Study on Tag Performance

Different RFID tags operate at a variety of frequencies. In the selection of tags, the general performance and characteristics associated with the permitted frequencies of operation must be considered first. Factors such as attenuation, cross paths of signals and interference from other RFID tags, RFID readers and RF devices, may affect the communication between the tags and RFID readers. Different types of physical objects with RFID tags attached might also affect the performance of tags. Therefore, a preliminary study has to be done on RFID tag and reader to find out the maximum distance at which a tag can be read. In order to determine the performance profile of a passive RFID tag, the Received Signal Strength Indication (RSSI) and the corresponding distance have to be measured. As stated by Zhao, J. et al. (2006), RSSI refers to the power of a received radio signal. It is expected that the RSSI of a passive tag is inversely proportional to its distance from the reader. Thus, the distance of an object from a reader, and in turn the object's position can be determined accordingly.

3.2 Design of RFID Data Collection Model

The RFID signals (i.e. RSSI) of an object attached with a passive tag is automatically detected and recorded in the database for location detection. The selected area for carrying out the experiments would be divided equally into cells formed by a grid. Four RFID readers will be installed at each corner of the selected area. Each RFID reader has an interrogation range which is defined as the maximum distance at which the reader can recognize a tag. In the example shown in Fig. 1, one reader can only cover around one-fourth of the selected area. Thus, in this case four RFID readers are required in total. In addition, the number of readers required will increase for larger areas. When an object with an RFID passive tag is placed inside one of the cells, the RFID readers will first detect the tag. A passive tag derives its power from the signals it receives from the reader and produces a signal back to

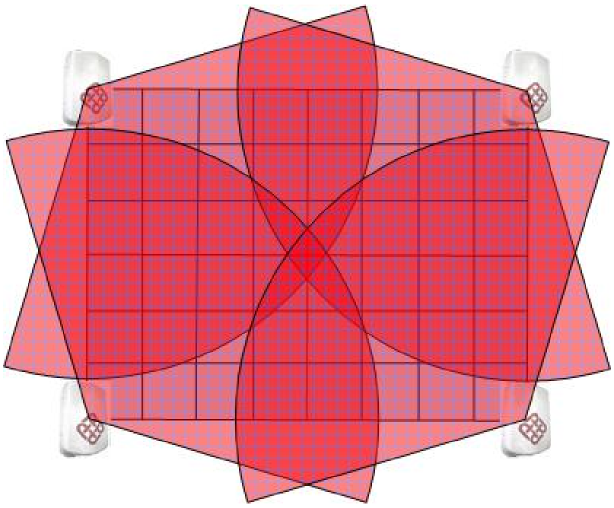

Fig. 1. Four readers are required for total coverage of the given area

the reader. The strengths of the RSSI received by the RFID readers are collected. Each of the four RFID readers will record the specific RSSI of the tag within corresponding cell and such data are stored in a database. As the RFID positioning system is expected to be two-dimensional, data of RSSI picked up by the various RFID readers will be taken at a specific height. For example, if the selected area is divided into 36 cells, the RSSI of that many position points will have to be recorded. This data collection procedure will be repeated six times to find the average RSSI value of each position point to each of the four readers.

After collecting data six times, the average value of a specific position point's RSSI to each of the four readers is calculated. The average RSSI is used to form a Look-Up Table (LUT) that relates the average RSSI of a specific position point to each RFID reader. An example of a LUT is shown in Fig. 2.

3.3 *Location Estimation Model*

Upon completion of data collection and construction of the LUT, the system can be used to determine the position of the object affixed with a passive tag. When an object is placed inside one of the cells in the RFID covered zone, the signal strength of the object with passive tag will be detected. The four RFID readers will detect their corresponding RSSI of the tagged object. As shown in Fig. 3, when an object is placed in one of the cells, the object will be detected and the four specific RSSI corresponding to the readers will be recorded in the database. Euclidean distance is employed to compare its average RSSI obtained from the four readers and the values in the LUT. The Euclidean distance is computed as follows:

Grid	Reader 1	Reader 2	Reader 3	Reader 4
Grid 1	12250	37015	43110	55040
Grid 2	17460	35208	46832	53982
Grid 3	..	..	..	..
Grid 4	..	..	..	..
..	..	..	..	..
..	..	..	..	..
Grid 48	53958	36392	44918	13487

Fig. 2. Example of a Look-Up Table (LUT)

$$\text{Euclidean Distance } (x_i, x_j) = \sqrt{\left(\sum_{d=1}^{k} |x_{id} - x_{jd}|^2\right)} \quad (1)$$

where x_i is the average RSSI of cell i read from LUT, and x_j is the average RSSI of the detected object at an unknown cell the position of which is to be determined; d is an index that indicates the identity of a reader

The smallest value of the Euclidean distance will be used as the criteria for determining the current position of the object. The smallest value of the Euclidean distance is calculated for a cell, the higher possibility that the position of the detected object is located at that cell. For example, when an object is placed inside the Cell 18, the RSSI of the tag to the four RFID readers will be recorded. The result will then be compared with the values of all cells in the LUT by the Euclidean distance. The one that is closer to the tagged object will have a smaller Euclidean distance. The cell that contains the detected position of the object is shown in red color (Fig. 4).

4. Experimental Setup

In order to study the performance and readability of using passive RFID tags for positioning purposes, an experiment was conducted at a laboratory of the Hong Kong Polytechnic University. The experimental area is a square sized 3m × 3m. It was divided into a grid of nine cells. As shown in Fig. 5, each cell of the three by three grid RFID Positioning System is 1m × 1m.

Several hardware devices such as four readers and four antennas were linked to form a network for the positioning system,. They are connected with the

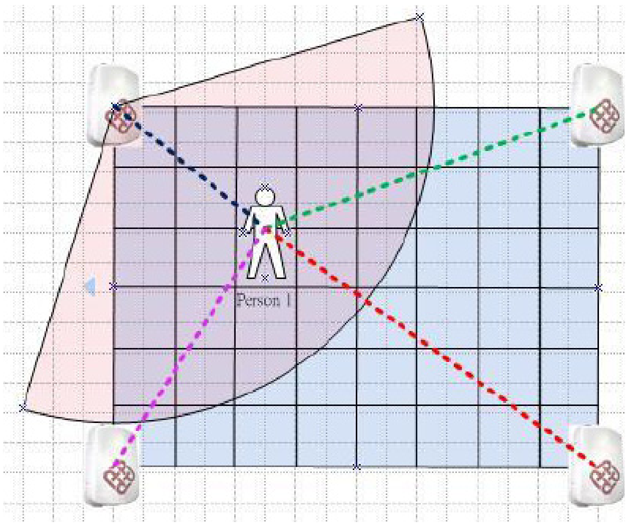

Fig. 3. Example of an object in an RFID covered zone

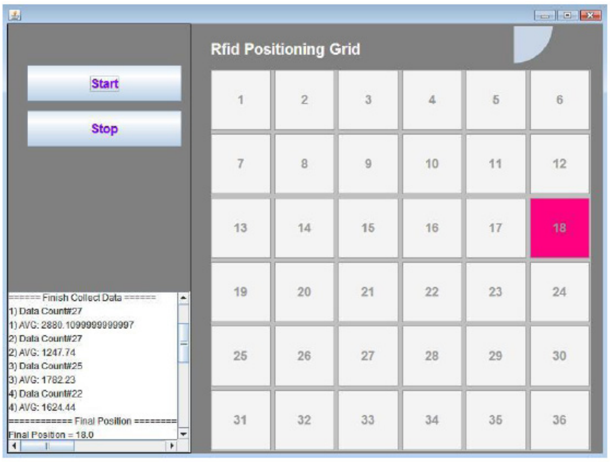

Fig. 4. Screen capture of an RFID Positioning System

middleware for data processing. Alien ALR-9900 Enterprise Reader is chosen as the reader of this experiment. The four readers required by this system were installed at the top of each corner of the selected area.

4.1 Study on Tag Performance in the Selected Area

A study was conducted to determine the maximum read range of the reader for detection of a passive tag. In the preliminary study, a passive tag was placed at a distance of 0.5m in front of an RFID reader. Then, the distance was changed at increments of 0.2m until 9m was reached. The result, as illustrated in Fig. 6, shows that the response rate of the reader is nearly 100% between 0m to 3m. From 3m onwards, the response rate drops sharply from 100% to 20% when 6m is reached. . Finally, it continuously decreased to 0% after 8m. Thus, the expected read range of the reader is 8m.

4.2 Preliminary Study

Configuration of the hardware items will affect the rate of reading the signal strength and accuracy. If these items are not installed properly, the experiment as well as the positioning result may not be accurate. Therefore, in order to improve readability, the height of the object with passive tag, and the orientation of the reader facing the selected area are taken into consideration before the design of data collection model.

- Height of the object being tracked

The object with passive RFID tags is placed at heights of 0.75m, 1m and 1.25m respectively above ground. At heights of 0.75m and 1.25m, some cells will become blind

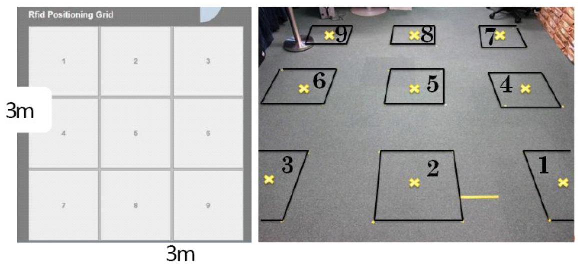

Fig. 5. Layout of the 3 by 3 Grid RFID Positioning System

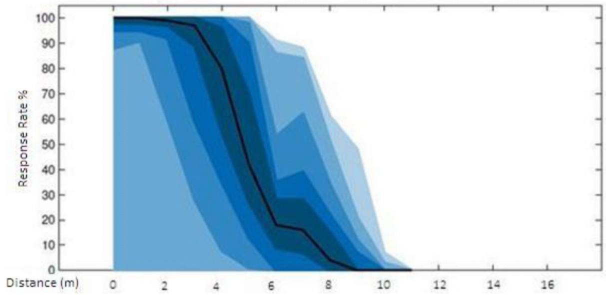

Fig. 6. Tag readability performance on the selected area

spots and cannot be detected by the readers. Only at the heights of 1m, the object can be reliably detected by the RFID readers. Therefore, the height of 1m was chosen.

- Orientation of the reader

In order to cover the whole area of the selected zone for positioning, the readers must be oriented to the centre of the area.

4.3 RFID Data Collection Model

Data collection for the positioning system will be discussed in this section. The aim of collecting RSSI of a tagged object to the various readers is to calculate the average RSSI for each cell and hence to form the LUT. The steps of building the data collection model are described below.

STEP 1: Place the object with passive tags at Cell 1 at 1m height.

STEP 2: Record the corresponding RSSI of the tags to each of the four readers for 15 seconds. The data will be automatically stored in the database. Two conditions may occur when the data are collected:

Sub-step 2-1: If the system can get 20 readings of RSSI of the object within 15 seconds, it will stop and show the result.

Sub-step 2-2: If the system cannot get 20 readings of RSSI of the object within 15 seconds, it will continue to take data for another 15 seconds until 20 readings have been collected. The maximum time allowed for taking the data for Cell 1 is 1 minute. If the system cannot collect enough data, then this cell will not be available for position detection.

STEP 3: Repeat STEP 2 for six times to obtain an average value that will be used as the fixed RSSI value of Cell 1 in the LUT.

STEP 4: Repeat all the steps above for the remaining 8 cells. Finally, six readings of RSSI for each of Cells 1 to 9 will be stored in the database.

4.4 LUT Formation

After collecting the six sets of data, the system will calculate the average RSSI for each cell. After the average RSSI values of each cell picked up by the four readers have been determined, they will be used to form the LUT. Fig. 7 shows the average RSSI of each cell to the four readers for the 9-Cell Positioning System.

	Reader 99	Reader 100	Reader 101	Reader 98
Grid 1	1957.23	3162.41	2242.75	701.67
Grid 2	2280.79	979.66	1248.12	1067.18
Grid 3	2239.92	1055.99	1117.32	1076.02
Grid 4	1359.02	2675.14	4418.33	1682.80
Grid 5	620.07	1487.20	1346.76	1313.04
Grid 6	2071.36	1301.99	1320.56	1283.70
Grid 7	2159.65	1401.46	3269.13	1440.50
Grid 8	1559.74	1668.47	1945.65	2241.71
Grid 9	2945.15	1303.77	1496.75	1426.48

Fig. 7. LUT of the 9-Cell Positioning System

4.5 Location Estimation

When an object is placed inside one of the cells within the selected experimental area, the 9-Cell RFID Positioning System will notify the RFID readers and then record the RSSI of the object picked up by the four readers. From the LUT, each cell has a fixed set of four average values of RSSI. The system will then calculate the Euclidean distance of that object to the readers. The cell that has the smallest Euclidean distance would mean that it is nearest to the current position of the detected object. The result is shown in Fig. 8.

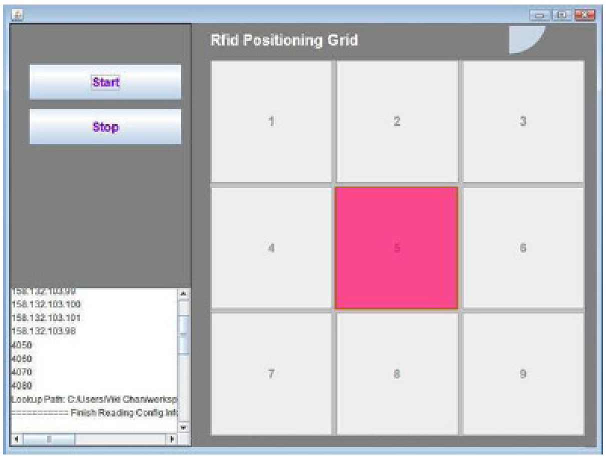

Fig. 8. Result displayed by the RFID Positioning System

		No. of trial										
		1	2	3	4	5	6	7	8	9	10	Accuracy
Grid	1	○	○	○	○	○	○	○	○	○	○	100%
	Position determined	/	/	/	/	/	/	/	/	/	/	
	2	○	○	●	○	●	●	○	○	○	○	70%
	Position determined	/	/	3	/	3	3	/	/	/	/	
	3	○	○	○	●	○	●	○	○	○	●	70%
	Position determined	/	/	/	2	/	2	/	/	/	2	
	4	○	○	○	○	○	○	○	○	○	○	100%
	Position determined	/	/	/	/	/	/	/	/	/	/	
	5	○	○	○	○	○	○	○	○	○	○	100%
	Position determined	/	/	/	/	/	/	/	/	/	/	
	6	○	○	○	○	○	○	○	○	○	○	100%
	Position determined	/	/	/	/	/	/	/	/	/	/	
	7	○	○	○	○	○	○	○	○	○	○	100%
	Position determined	/	/	/	/	/	/	/	/	/	/	
	8	○	○	○	○	○	○	○	○	○	○	100%
	Position determined	/	/	/	/	/	/	/	/	/	/	
	9	○	○	○	○	○	○	○	○	○	○	100%
	Position determined	/	/	/	/	/	/	/	/	/	/	

Fig. 9. Results of the trials for the 9-Cell RFID Positioning System

(○ represents "Correct Position" and ● represents "Incorrect Position"; if the system cannot determine the object's position, ● will be listed at the space under that trial)

5. Performance Evaluation

Fig. 9 shows the testing result of the trials. It shows that the RFID positioning system can correctly determine 7 positions out of 9 in 10 trials. For Position 2, the system determines it as Position 3 in 3 out of 10 trials. For Position 3, the system determines it as Position 2 in 3 out 10 trials. Amongst the 90 trials for all the cells in the positioning system, 6 trials are incorrect. Therefore, the overall accuracy for the RFID Positioning System is (90−6)/90×100% = 93%, which is a satisfactory result in using passive RFID for positioning purposes.

6. Discussion

Accuracy of the RFID Positioning System is 93% which is a high accuracy rate. Due to the limited time for taking data and conducting the trials, only 10 trials were made in each cell. If more readings of each cell are taken, the resulting average RSSI will be close to the current RSSI of the detected object as the outliers will be eliminated. Thus, accuracy will improve. In addition, the system in this study wrongly determines the position of the object in two adjacent cells. For example, it locates Cell 2 as Cell 3 in 3 out of 10 trials, and vice versa. It is expected the longer distance between the cells and the corresponding reader, the weaker will be the signal strength. But our result indicated the relationship between the signal strength of the grid recorded by the reader is not in direct proportion to their distance. The main reason of that is due to the high degree of similarity of the average RSSI of Grid 2 and Grid 3. Sine the similarity of the average RSSI of Gird 2 and Gird 3, the Euclidean distance calculated by the system will be similar. As the criteria used to determine the position is the shortest Euclidean distance of a grid when compared to the current position of the detected object, thus, the system determine Grid 2 as Grid 3 for 3 out of the 10 trials. To address this issue, it is suggested that more trials should be conducted to build the LUT and divided the selected area into more number of grids for capturing the RSSI.

The main objective of this study is to design a cost effective as well as low cost solution for indoor positioning. Therefore, the satisfactory results of tag readability show that using passive tags instead of expensive active tags is promising. The current cost of passive RFID tags is around HKD $2 each while that of active RFID tags is about HKD $100 each. Therefore, if passive RFID is selected, the cost of acquiring RFID tags for positioning will be more affordable. Furthermore, Read-Only tags are chosen in which the tag ID is burned into the tag during the manufacturing process, lowering the cost even further. Due to the low cost of passive tags, the positioning system using passive RFID tags can be implemented for large-scale deployments. A passive tag does not require a battery, in which it uses some of the RF energy transmitted by a reader through its antenna to power its circuitry. As energy is collected from the antennas and no power source is required, the operating cost for replacing the battery is eliminated. Also, because the passive tag contains no battery, its lifespan is unlimited. Therefore, passive tags have a lower overall cost due to lower acquisition costs and longer tag life.

7. Conclusion

The feasibility of employing passive RFID tags for positioning detection has been studied. The conclusions are summarized in four parts as follows.

- The trend of the indoor RFID Positioning System

RFID has been widely applied in supply chain for tracking goods, the technology of RFID applications is quite mature, and there is a trend of developing positioning systems to meet the demands of indoor location sensing applications, driving more research topics on RFID positioning issues. Therefore, there is a need to develop a positioning system that employs RFID technology.

- Principle of the indoor RFID Positioning System

This Passive RFID Positioning System is based on RSSI which is a measurement of the power present in a received radio signal to determine the location of an object with passive tags. Through the relationship between the distance and the signal strengths, the position of an object can be determined accurately.

- Cost effectiveness

In order to develop an indoor positioning system at low cost, this paper proposes the use of passive RFID tags. At the same time, the labor cost of removing passive tags on tracked objects for reuse on other objects to be tracked can be saved due to the low per-unit cost of the passive tags. If large quantities of items need to be positioned, then the average cost of using the Positioning System will become lower due to the low price of the variable cost, i.e., passive tags. Thus, this Passive RFID Positioning System can determine the location of an object at low cost.

- Feasibility

The experimental results conclude that the passive positioning solution is feasible based on the measurement of RSSI and Euclidean distance. The low overall cost of implementing the positioning system at small warehouse makes it easy to be accepted by the industry. Also, if standardized code is used in the passive tags, all companies in the supply chain can implement the same positioning system to locate their goods without attaching tags on the items to be tracked more than once. However, several issues, such as ensuring that the system can withstand harsh conditions or continuous change of operating environment, are required to be considered in future study.

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