A RFID Logistics Resource Management System for the Warehouses

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Abstract—In the supply chain, a warehouse is an essential component for linking the chain partners. It is necessary to allocate warehouse resources efficiently and effectively to enhance the productivity and reduce the operation costs of the warehouse. Therefore, warehouse management systems (WMSs) have been developed for handling warehouse resources and monitoring warehouse operations. In this paper, a RFID technology is adopted to facilitate the collection and sharing of data in a warehouse. Tests are performed for evaluating the reading performance of both the active and passive RFID apparatus. With the help of the testing results, the efficient radio frequency cover ranges of the readers are examined and the most suitable locations for the installation of the RFID devices are determined. Besides, a RFID case-based logistics resource management system (R-LRMS) is proposed to improve the efficiency and effectiveness of order-picking operations in a warehouse by means of formulating a reliable RFID technology implementation plan. This will enable warehouse resources to be located on a real-time basis and instant material handling solutions will be suggested for handling the customer orders automatically. The feature of real-time and automatic data retrieval in the proposed system is support by the RFID technology, which also facilitates constructing an effective triangular localization scheme to determine the exact locations of warehouse resources.

This management system has three objectives achieved: (i) a simplification of RFID adoption procedure, (ii) an improvement in the visibility of warehouse operations and (iii) an enhancement of the productivity of the warehouse. The successful case example proved the feasibility of R-LRMS in real working practice.

Keywords: Logistics ; Radio frequency identification (RFID) ; Warehouse management systems (WMSs)

I. INTRODUCTION

Due to the effects of globalization, current supply chain networks are increasingly complex. Logisticians have to deal with numerous channel partners who may be located a great distance apart and who request a greater than ever diversity of products, and who need to deal with more statutory requirements and documentation than ever before [1]. Therefore, the fulfillment of customers’ demands with good quality products, on time product delivery and superior logistics services becomes difficult to achieve. In general, enterprises have adopted different approaches for managing the supply chain activities which include material sourcing, production scheduling, warehousing and product distribution. Logistics resource management (LRM) is one of the approaches for managing the activities of the whole supply chain efficiently. It facilitates the allocation of logistics resources to appropriate logistics functions and controls the movement of raw materials, work-in-progress and finished goods, from suppliers to customers in an efficient manner. In doing this, supply chain partners are kept satisfied.

In this paper, a set of RFID reading performance tests is performed. The tags are placed in different positions and attached to different materials for evaluating the reading performance of the active and the passive RFID devices. Based on the test results, the efficient radio frequency cover ranges of the readers are examined and the most suitable locations for the installation of the RFID devices are determined. Besides, a RFID case-based logistics resource management system (R-LRMS) is proposed to improve the efficiency and effectiveness of order-picking operations in a warehouse by means of formulating a reliable RFID technology implementation plan. This will enable warehouse resources to be located on a real-time basis and instant material handling solutions will be suggested for handling the customer orders automatically. The feature of real-time and automatic data retrieval in the proposed system is support by the RFID technology, which also facilitates constructing an effective triangular localization scheme to determine the exact locations of warehouse resources.

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II. CURRENT REAL-TIME DATA MANAGEMENT TECHNIQUES FOR OBJECT LOCATION TRACKING

There is several real-time data management techniques adopted for facilitating information sharing in the existing market. Some of the techniques are also capable of providing object location information. In the outdoor environment, the most well known technology adopted in location tracking is the global position system (GPS). It is a space-based radio-navigation system that uses 24 satellites orbiting around the Earth and receivers to locate objects, in terms of height, longitude and latitude coordinates, on Earth [2]. The main application of GPS is to determine the location of vehicles and the actual traffic condition. Although it locates an object accurately in the outdoor environment, it is unable to locate objects inside the buildings. Hence, Cell of origin (COO) or Cell-ID is proposed to locate objects between indoor and outdoor environment. COO is a network-based location system which uses the latitude and longitude coordinates of the base station and transmitters serving the mobile device as the location of the user [3]. Nevertheless, it is inaccurate in locating a moving object as “blind points” always occur due to defective coverage of the network, especially in the indoor environment. Hence, various technologies have been
developed to locate objects in the buildings. Infrared, ultrasonic and radio frequency identification (RFID) technologies are the most common approaches for locating those objects [4]. Among those three approaches, RFID technology is an emerging technology that has been widely adopted in different environments, such as manufacturing, warehousing, retailing, etc., for object identification. RFID uses a small tag containing an integrated circuit chip and an antenna, which has the ability to respond to radio waves transmitted from the RFID reader. It is able to send, process, and store information [5]. This technology has been widely adopted in different business operations to identify, locate and track people, animals or assets [6-9]. Although it is much more expensive than bar-code technology, enterprises are willing to adopt such techniques so as to improve the accuracy of data capture [10]. By using the RFID technology, the feature of automated data capture is established. However, the mechanism that coordinates the resource management process of analyzing information, decision support, and knowledge sharing is still neglected. This highlights the need to adopt artificial intelligence (AI) techniques integrated with RFID technology to support the management of warehouse processes. In this research, the case based reasoning (CBR) technique is adopted as this is one of the well-known AI techniques for the development of decision support systems.

III. DESIGN METHODOLOGY OF R-LRMS

The aim of the proposed R-LRMS is to formulate and suggest the appropriate material handling solutions in a warehouse environment. In doing this, two construction phases for R-LRMS are required. They are:

Phase 1: Defining the operating specification of R-LRMS
Phase 2: Constructing the architecture framework of R-LRMS

A. Phase 1: Defining the Operating Specification of R-LRMS

This phase is to define the operating specification of the proposed system. Five stages are involved in defining it. They are: (i) warehouse layout study, (ii) evaluation of RFID equipment, (iii) RFID reading performance tests, (iv) result analysis, and (v) system design, testing and evaluation.

Stage 1: Warehouse layout study

It is essential to perform a warehouse study before the implementation of the proposed system. This is because the layouts of warehouse vary among different companies. The physical and environmental factors, such as the size of the warehouse, the number of aisles, the number of racks, the types of racks, the types of material handling equipment, the types of products stored, etc., affect the readable range and accuracy of tags[11]. By studying the actual environment, the specification of the warehouse is determined for RFID equipment selection.

Stage 2: Evaluation of RFID equipment

As mentioned before, there are two common types of RFID equipment available on the existing market, namely active RFID technology and passive RFID technology. The items of equipment of these technologies vary in size, cost, reading performance, and in application domains. The most commonly used RFID equipment used in warehouses is the Active (Alien 2850 MHz Series) and the Passive (Alien 9800 series) RFID apparatus. Experiments have taken place for evaluating the reading performance of these types of equipment in order to select the most appropriate one for the actual warehouse environment.

Stage 3: RFID reading performance tests

Four tests, namely (i) orientation test, (ii) height test, (iii) range test, and (iv) Material Test, are proposed in order to evaluate the performance of the RFID device in an actual warehouse environment.

Before performing the tests, it is required to install the RFID readers and tags appropriately so as to obtain reliable experimental results. A pair of antennas is placed at a fixed location and the centre of the antennas is placed 1 m from the ground. Also, tags are stuck onto objects which are placed in various locations, facing different directions and stuck onto various materials. After doing this, the read rates of the tags (total reads per minute) are taken by performing various tests.

(i) Orientation test

The test is to determine the horizontal effective RF cover range of the reader. The tags are stuck onto the front, top and side surfaces of the object and corresponding read rates of the tags are measured by moving the object different distances horizontally. The configuration of the orientation test is shown in Fig. 1.

(ii) Height test

In this test, the effective vertical RF cover range of the reader is determined. The tags are stuck onto the front surface of the object which is placed at 1 m from the reader. After that, the object is moved different distances vertically and the corresponding read rates of the tags are measured. The configuration of the height test is shown in Fig. 2.
(iii) Range test
The test is to determine the maximum RF cover range of the reader in a horizontal direction. As illustrated in Fig. 3, the object is placed 1 m from the reader and the tags are stuck onto the front surface of the object. Read rates of the tags are measured when the object is moved different distances horizontally.

![Figure 3. The configuration of range test (top view)](image)

(iv) Material test
In the material tests, the reading performance of RFID device is measured when the tags are placed on the front and back surfaces of various types of products in the actual environment. Similar to the orientation test, the tags are stuck onto the nearest and farthest surfaces of the object. After that, the object is moved different distances horizontally and the corresponding read rates of the tags are measured. The configuration of the material test is shown in Fig. 4.

![Figure 4. Configuration of material test](image)

The methodology of solution consists of two steps; the first solves the Routing and Loading tasks with the heuristics algorithms ACS and a local search improvement algorithm. The ACS algorithm uses local search improvement algorithm to distribute the products in the vehicle during the construction of the routes. The second step solves the scheduling task.

Stage 4: Result analysis

<table>
<thead>
<tr>
<th>Tests</th>
<th>Expected results</th>
<th>Final result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation test</td>
<td>Horizontal effective RF cover range of a reader</td>
<td>The most effective radio frequency (RF) cover range of the reader</td>
</tr>
<tr>
<td>Height test</td>
<td>Vertical effective RF cover range of a reader</td>
<td></td>
</tr>
<tr>
<td>Range test</td>
<td>Maximum RF cover range of a reader in a horizontal level</td>
<td></td>
</tr>
<tr>
<td>Material test</td>
<td>RF performance effects in handling different materials</td>
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The results of the tests show the most effective radio frequency (RF) cover range of the reader, as shown in Table 1. Based on the results, the RFID devices are installed in the racks, forklifts and SKUs for real-time data collection.

Stage 5: System design, testing and evaluation
After defining all the operating specification, the architecture of R-LRMS is designed. It is then tested under a simulated warehouse environment to ensure that all the equipment work within the defined specification.

B. Phase 2: Constructing the Architecture Framework of R-LRMS
After finishing Phase 1, the data capture capability of the RFID part is verified. This shows the architecture framework of R-LRMS, which is a three-tier system. The first tier is the data collection tier, through which the raw warehouse operation information is collected. In the middle tier, the retrieved information is stored in the centralized database systematically. The final tier encompasses the relevant operation components for formulation of the pick-up routes.

Tier 1: data collection
In this tier, RFID devices are adopted for data collection in a warehouse environment. Two types of data, namely static and dynamic warehouse resources data are captured by the RFID readers to visualize the actual status of warehouse operations. The static warehouse resources data involves the locations and quantities of SKUs stored the types of SKUs, the available space for incoming products, etc. The dynamic warehouse resources data involves the locations of forklifts/warehouse staff members, the inventory levels in each rack, the status of order-picking operations, etc. With the help of wireless network, i.e. 802.11 g WIFI network, the warehouse resources data that was collected is transferred and stored in the centralized data. The general picture of data collection tier of R-LRMS is illustrated.

Tier 2: data storage
This tier adopts the database management system (DBMS) and structured query language (SQL) statement to provide the function of data retrieval and storage for users. It helps minimize the time used and human mistakes in preparing the program statement for obtaining the required datasets are avoided. In order to increase the speed of data retrieval in the database, Query optimization technique is applied into R-LRMS.

IV. EXPERIMENTAL RESULTS
After the pilot run in the case study, the benefits of the proposed R-LRMS are examined and described in this session. These insights are the references for the enterprises who are interested in adopting the RFID solution in their own situations.

(i) Simplify the RFID adoption procedure
Through the proposed reading performance tests, the reading performances of active and passive RFID devices are determined in different scenarios, such as in different locations, with different materials being handled. According to the results shown in B, the distance at which an active tag is able to receive a signal is about 10 m but a passive tag can not receive a signal beyond a distance of approximately 2 m.
The reading performance of an active RFID device is better than that of a passive RFID device. Besides this, the results reveal that all of the tags have the best performance when placed at the same level as the antennas. Based on the results, the procedures for the RFID equipment selection are simplified, and the locations suitable for the installation of RFID devices in the GSL warehouse are easily determined.

(ii) Improve the accuracy of retrieved information

Once the RFID equipment is installed effectively, the accuracy of retrieved warehouse information is significantly improved. The inventory level recorded by R-LRMS is exactly the same as the actual level. It is better than using manual documents to record this information. In addition, R-LRMS provides the exact location of material handling equipment. The visibility of warehouse is significantly increased.

(iii) Enhance the productivity of the warehouse

As the RFID technology and query optimization technique are adopted in the R-LRMS, the performance of retrieving and storing information are significantly enhanced.

The times for retrieving and storing specific warehouse information are reduced from 1 min and 10 s to 5 s and 2 s, respectively. Moreover, the job assignment process is changed from being manual-based to being automatic. The speed of assigning pick-up jobs and formulating material handling solutions for fulfilling customers' demands is significantly enhanced. Previously, the average time for formulating one material handling solution is about two minutes. However, it is greatly reduced to fifteen seconds when R-LRMS is implemented. This helps enhance the productivity of the warehouse.

V. CONCLUSIONS

In this paper, a radio frequency identification case-based logistics resource management system (R-LRMS) is proposed for formulating and suggesting the appropriate material handling solutions in a warehouse environment. In doing this, two construction phases for R-LRMS are required. With the help of Phase 1, the effective radio frequency (RF) cover ranges of the RFID technology are revealed and operation specifications of R-LRMS are determined. These results are the references to help enterprises to select the most appropriate RFID equipment and to install the equipment in the most suitable locations for data collection in the environment where it is being used. In Phase 2, three technologies are adopted in R-LRMS. An effective triangular localization scheme is developed for locating the moving objects in warehouse environment. However, it is only applied by the passive RFID technology. Therefore, it is essential to modify the effective triangular localization scheme for applying it in active RFID equipment as well.

Nowadays, people are more conscious of all their different partners in the entire supply chain performance. The generic R-LRMS described in this paper is able to manage the logistics resources for improving the operation performance in such a supply chain. In future, studies on different parties, such as production, distribution, etc., should be considered to determine the requirements for modifying the current architectural framework of the R-LRMS to fit the whole supply chain network.

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