An RFID Case Study for Air Cargo Supply Chain Management

Chi-Kong Chan, Harry K. H. Chow, Alex K. S. Ng, Henry C. B. Chan, and Vincent T. Y. Ng

***Abstract* — Air freight is an important part of the global supply chain. In particular, various high-value electronic products need to be transported efficiently by air freight. Currently, many air freight forwarders still rely on manual operations to process air cargo. These manual operations may affect target service levels due to handling delays and human errors, and result in high operational costs. In this paper, we present a novel Radio Frequency Identification (RFID) system and a case study for air freight forwarding operations. The proposed system includes a hybrid RFID system architecture (a combination of data-on-tag and data-on-network approaches) and an integrated RFID air cargo check-in and check-out gateway system with cargo movement detection capability. The system can help air freight forwarders to (i) enhance freight operational efficiency, (ii) efficiently encode data into memory-limited RFID tags, and (iii) facilitate logistics management using a cost-effective RFID-based system.**

***Index Terms* — Air freight forwarding, logistics management, RFID technologies, Supply chain management**

I. INTRODUCTION

In recent years, there has been considerable interest in employing radio frequency identification (RFID) technology to support supply chain management for various industries [1][2]. In this paper, we study its application in an important industry, air freight forwarding [3]. We present an overview of an RFID system that we developed with industrial collaboration. The system provides a cost-effective solution to some pragmatic requirements and technical challenges. The results of the pilot run tests have demonstrated the effectiveness of our system.

A typical operational flow of an air freight supply chain is summarized as follows. First, an air freight customer (i.e., the shipper) sends the items of air cargo to an air freight forwarder. To maximize the utilization of space, the forwarder then aggregates cargo items received from different customers based on their destinations, and transports the items to the required airport cargo terminals for export through airlines. Note that forwarders serve as an agent between customers and airlines. Subsequently, the airlines transport the cargo items to the required destinations. At the airport cargo terminals of these destinations they are collected by overseas forwarders. Finally, the cargo items are delivered to the recipients.

Traditionally, the processing and tracking of air cargo items over a supply chain involves many manual operations. For instance, after a pallet of a shipper's cargo items is received at a forwarder's warehouse, it is often processed manually (e.g., checked and recorded) and the information on the cargo is entered into a computer system by a human operator. In recent years, various automated solutions have been proposed. For example, in the IATA's Cargo 2000 initiative, RFID was proposed as a potential solution to support cargo tracking [4].

However, the development of an RFID-based tracking system for freight forwarding poses many technical challenges. In this paper, we present a solution to these challenges through an RFID case study for air cargo supply chain management. Our system is based on RFID embedded *waybill* labels that provide on-tag data storage for cargo information. Our first challenge is to deal with the issues of high storage density and busy traffic commonly found in forwarder warehouses. To meet this challenge, an advanced module to detect the direction of the movement of cargo was developed. This module not only accurately determines the direction of the cargo items moving through an RFID gateway, but also helps to reduce the size of the interrogation zone. Second, in order to support the reliable and efficient updating of the contents of a tag in a noisy environment, a logical-block-based rewriting scheme was developed. Finally, in order to support the offline reading of memory-limited UHF RFID tags, a hybrid data-encoding scheme was developed. A prototype has been tested in an operational environment and the results are promising.

The remaining sections of this paper are structured as follows. In Section II, we give the background to our study and discuss related works. In Section III, we provide an overview of our system. We also discuss two technical issues on tag movement detection and tag rewriting. In Section IV, we present the results of the pilot run tests. In Section V, we give the conclusions.

II. BACKGROUND

A. Overview of air freight forwarding operations

In air freight forwarding operations, two documents are used

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for identification and hence air cargo tracking purposes: the master air waybill (MAWB) and the house air waybill (HAWB). HAWBs are documents issued to shippers by forwarders for identification purposes. MAWBs are documents issued to forwarders by airlines. A MAWB may be linked to multiple HAWBs for cargo items packed for the same flight. Typically, these HAWB and MAWB documents are shipped together with the cargo items, but are opened only when required, such as for clearing customs. To link air cargo items to their corresponding HAWB and MAWB documents, special labels called HAWB labels and MAWB labels are placed on the surface of each air cargo item or pallet (Fig. 1). Traditionally, these labels are bar-code-based with essential information from the MAWB and HAWB documents printed on the labels (e.g., destination, place of origin, weight, dimensions, number of pieces, *etc.*). During the check-in process for an air cargo item, a HAWB label is placed on the item before it is stored in the warehouse. After the flight planning process, another MAWB label is placed on the cargo before they are checked out and transported to the airport cargo terminal for delivery to the overseas destination. Across the air cargo supply chain, air cargo items are identified and tracked based on HAWB and MAWB labels. As will be discussed later, our project makes use of RFID-based HAWB labels for cargo identification and tracking.

Fig. 1. Air freight cargo and air waybill label

B. Related works

In recent years, there have been various proposals on applying RFID technology to facilitate cargo processing and warehouse management. For instance, in EURIDICE [5], an intelligent cargo framework was proposed based on RFID, mobile computing, and software agent technologies to facilitate decision making across a supply chain. Similarly, the iSURF project [6] proposed a framework based on the Universal Business Language (UBL) to allow various parties in a supply chain to share data/information and RFID technology for tracking cargo items. These projects share the common vision of setting up an effective Internet-of-Things architecture for cargo processing purposes. While they provide intelligent frameworks to facilitate the sharing of information and, hence, decision making for related parties in a supply chain, the aim of our project is to complement these projects by focusing on front-end processing and pragmatic technical issues for RFID-based air cargo processing.

Our project involves the design of an RFID gateway with movement detection functions for handling the special requirements of an air cargo forwarding warehouse. In the literature, there have been works related to the design of an RFID gateway for warehouse logistics applications. For instance, in [7], Lu *et al*. proposed a passive RFID system to process cargo using RFID gateways set up in a warehouse environment. However, they did not provide the functionality of cargo movement detection, which is essential to our application. An RFID gateway-based solution with movement direction detection was proposed by Son *et al*. [8]. It requires the use of multiple RFID readers controlled by a middleware. A management algorithm is then employed to manage the multiple readers and to determine the direction of movement. Compared to their solution, our integrated RFID gateway requires only one set of readers (with multiple antennas) and the direction of movement is determined at the antenna level instead of at the reader level. Hence, it provides a more cost-effective solution as fewer readers need to be employed. Furthermore, our integrated RFID gateway can also provide a writing function for updating RFID tags.

Other researchers have also investigated non-gateway-based approaches for location management in general and the detection of cargo movements in particular. For instance, Jeon *et al*. proposed an innovative method in [9] in which RFID readers are mounted on forklift trucks. In this way, the movement of the cargo can be detected and tracked. However, environmental factors such as ceiling heights and other obstacles can affect the effectiveness of this method. Furthermore, putting fixed-location RFID tags on a warehouse ceiling is generally not a flexible approach. Hence, a gateway approach is generally preferred.

III. RFID Cargo Management System (RCMS)

A. System Design Principles

Our system is developed based on several design principles, which are discussed throughout this paper. First, it is based on an integrated RFID gateway, a single gateway with movement direction detection and tag writing functions to handle both check-in and check-out operations. The objective is to address the special requirements of the air freight industry, particularly for the Hong Kong environment (e.g., because of its high-density storage requirements). This methodology will be discussed in detail in this section. Second, a hybrid RFID data model is adopted for supporting both off-line and online reading of RFID data. Again this is essential for the air freight forwarding industry because network access may not always be available in the air freight environment.

Our system is also developed based on a commonly used development methodology. The design is based on user requirements obtained from the air freight industry. A prototype system has been developed and tested in our laboratory, and two pilot run tests (for the system as well as the operation procedures) have been conducted with real air cargo items in real-life air-cargo routes.

B. System Design

In this section, we present our RFID-based cargo management system (RCMS). The system's architecture is illustrated in Fig. 2. Typically, an RCMS system is composed of several key components:

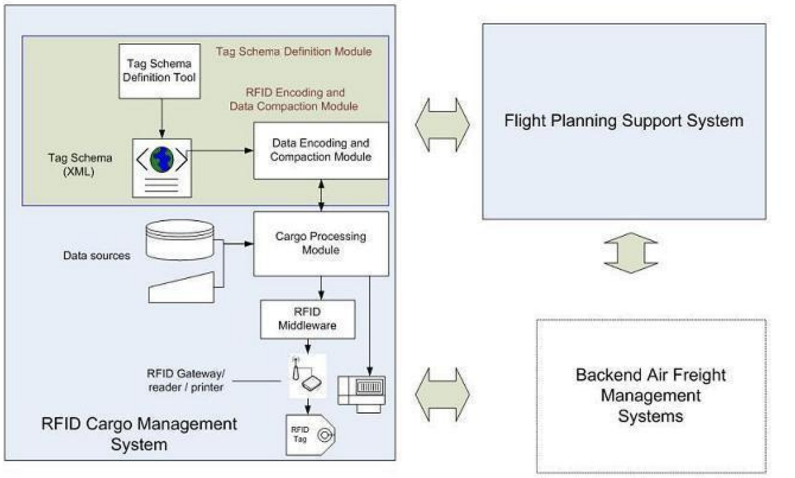

Fig. 2. System architecture

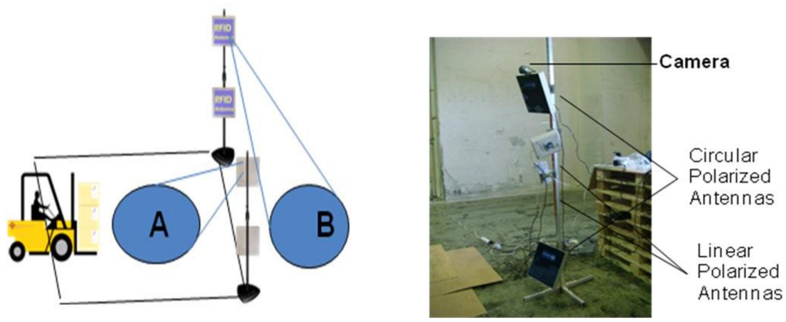

Fig. 3. RFID gateway setting (left) with two types of antennas and a camera (right)

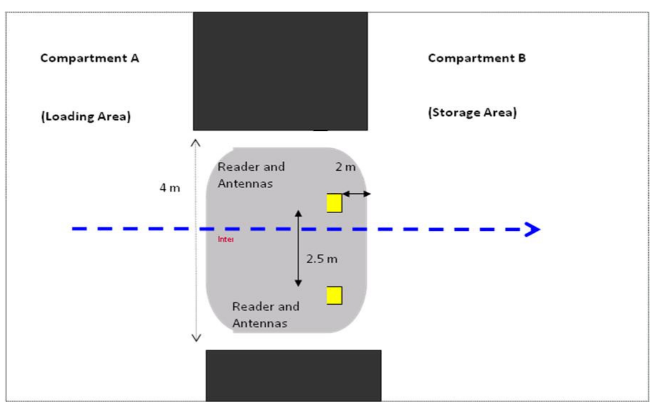

Fig. 4. RFID gateway and interrogation zone

- *RFID Gateway System.* RFID gateways (Fig. 3) are set up at various checkpoints along the cargo supply chain. Each gateway supports RFID decoding (reading), encoding (updating), and cargo movement direction detection.

- *Handheld RFID System*. These are mobile units for processing cargo items in offsite locations with or without networking support. Cargo-related data can be stored temporarily on the devices until it can later be synchronized with a local RCMS server.

- *Local RCMS Servers.* Local RCMS servers are responsible for processing cargo data received from the gateway or handheld system at each local site. For efficiency, updated data are first stored in a local database.

- *Central database.* Data stored at each local RMCS server are synchronized with a central database at regular intervals via a VPN network to facilitate data sharing across multiple sites.

An RFID-embedded HAWB label is attached to each item following the arrival of the item. Each label contains an RFID tag with 240 bits of memory, which stores the HAWB information required for identifying and processing cargo. A number of RFID gateways (with fixed RFID readers and antennas) are set up at required locations inside the warehouse (e.g., near the entrances of storage compartments). During the cargo stock-in process, the cargo items are carried by forklift trucks into the warehouse storage area. When the tagged cargo items pass through an RFID gateway, RF signals are received by the reader and a series of tag-reading events are sent to the system's Cargo Progressing Module. The contents of the tag are then decoded and processed by the system's RFID Data Encoding and Compaction Module. After all items from the same shipment are received and stocked-in, the cargo processing module sends a notification to the flight-planning support system to generate a flight plan. The outputs of the flight planning process include a master air waybill (MAWB) number and related cargo routing information. When the cargoes are ready to depart, they exit from the warehouse via the RFID gateway once again. This time, the tags are updated with MAWB data and the checked out items are sent to airport terminals for loading onto the corresponding planes. The local databases are updated automatically throughout the process and are synchronized with the central database at regular intervals (every 10 minutes in our current setting). Apart from the gateway, a handheld RFID reader-based version is also provided to facilitate locations where gateways cannot be set up.

It will be the airlines' responsibility to transport the cargoes to their destinations, where they will be collected and verified by overseas freight forwarder agents. Cargo data as stored on the tags are decoded and displayed on the spot for verification. The data are then uploaded to the server when the operator returns to his office, and will be regularly synchronized with the central database.

C. Cargo processing at an RFID Gateway

Each RFID gateway in RCMS consists of UHF RFID fixed readers and up to eight UHF RFID antennas, as depicted in Figs. 3 and 4. Two antenna poles, separated by a distance of 2.5 meters, are erected at the two sides of a cargo-tracking area (e.g., at the entrance/exit of a storage area). On each pole, there are two linearly polarized RFID antennas as well as two circularly polarized antennas. Optionally, a web-camera facing the forklift truck path near the gateway is also mounted on one of the poles. The circularly polarized antennas are responsible for the general reading of tags during stock-in and stock-out, and for updating (rewriting) the contents of the tag during stock-out. The linearly polarized antennas and the web-camera are used for determining the direction of the movement of cargo. Additionally, an area of 2 meters surrounding an RFID gateway is reserved as an *interrogation zone* (Fig. 4). No items of cargo, except those for stock-in and stock-out purposes, should enter that area.

D. Gateway design and cargo movement detection

In a typical RFID gateway situated in a freight forwarder warehouse, RF signals are received from cargo items passing through the gateway (during stock-in and stock-out operations), as well as from various background noises (e.g., signals received from other forklift trucks getting close to but not entering the gateway, or from various reflected signals). This means that a mechanism is needed to distinguish between the following cases:

a) Valid cargo traffic entering a storage area via the gateway (i.e., cargo for stock-in)
b) Valid cargo traffic leaving a storage area via the gateway (i.e., cargo for stock-out)
c) Any other signals received by the antennas (e.g., cargo items placed in a nearby storage area, whose signals are picked up by the antennas, or a forklift truck passing by the gateway without entering).

Traditionally, infra-red sensors can be employed to handle this issue. Whenever a forklift truck passes through a gateway, the system is activated by infra-red sensors to read the tags, and the direction of movement of the items can be detected using multiple sensors. However, in a forwarder's warehouse, this approach may be ineffective due to the high storage density and busy traffic conditions there. For example, infra-red sensors may be incorrectly triggered by other objects that are passing by (e.g., a warehouse staff member) while the system picks up signals from nearby tagged items that are stored too close to the gateways.

In our system, we developed an *Advanced Tag Detection* mechanism based on RFID, as described below. In each gateway, four linear polarized antennas are designated as movement detection antennas. These four antennas are divided into two pairs, with the first pair facing inward (toward the storage area; i.e., facing zone B in Fig. 3), and the other pair facing outward (toward the loading and packing area; i.e., facing zone A in Fig. 3). The idea is that the inward pairs and outward pairs serve as motion detection antennas. By observing the order and sequence of the tag detection events at each antenna, we can determine the direction of the movement of the cargoes in the following manner. Let a and b be the forward-facing and backward-facing pairs of antennas. Let A^c and B^c represent the tag reading events detected by the antenna pairs a and b, respectively, for a given cargo item c that approaches the gateway. A sequence of such tag reading events for the item c over a given period of time can be represented by $S_c = \{e_1^c, e_2^c, \ldots, e_n^c\}$, where each $e_i^c \in \{A^c, B^c\}$. Each event sequence S_c is then processed by matching it with some predefined *action rules* of the form:

```
Rule: subsequence => action
```

This means that if any subsequence in S_c matches with the antecedent of a rule, the appropriate status update action is performed. As an example, suppose that we have the following sequence of events detected for a cargo item c:

$$S_c = \{A^c, A^c, B^c, A^c, A^c, B^c, B^c, B^c, B^c, B^c\}$$

and the two action rules:

`Rule1:` $\{A^c, A^c, B^c, B^c\}$ => `Stock-in` for c
`Rule2:` $\{B^c, B^c, A^c, A^c\}$ => `Stock-out` for c

In this case, a subsequence of events (A^c, A^c, B^c, B^c) matches with the antecedent of rule 1. The item is therefore updated as stocked-in and its new location is correspondingly recorded.

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In practice, in order to deal with irregularities and signal noises, a sliding window and majority rule-based filtering mechanism is adopted before the sequences are matched against the rules.

In addition, we developed an optional webcam-based method to complement the aforementioned RFID-based method for determining the direction of the movement of cargo (see Fig. 3). Basically, when a forklift truck passes through a gateway, video footage of its passage is captured by a webcam and analyzed by a frame-based image processing technique, so that the direction of the movement of the cargo can be determined.

E. Cargo stock-out and on-tag data updating

After the flight planning process is completed, flight-related information (e.g., the MAWB number) becomes available. In our system, these data are written (appended) onto the original RFID tags during the stock-out process when a cargo item passes through an RFID gateway.

However, the rewriting of RFID tags is not a straightforward matter due to various kinds of interference caused by background noises and other environmental factors. To tackle this issue, we developed a block-wise writing procedure. Basically, data are written in logical blocks. During the writing process, an index is used to keep track of the position of the last logical block that is successfully written, so that after a failure, only the remaining logical blocks need to be rewritten.

F. RFID On-tag Data Encoding

Our system utilizes a hybrid RFID data storage model with two modes of operation, namely the online mode and offline mode. The basic idea is that in addition to storing data on network databases, where data are retrieved online when a tag is read, essential data are also stored on the tags to enable offline reading. Thus, in most locations, where network access is available, an online approach is used that is similar to the EPCglobal-based approach [10][11], except that a shorter identifier rather than a longer EPC code is stored. Note that the identifier can be mapped to an EPC code in a network database to ensure backward compatibility with the EPC-based approach. The remaining space in the tags is used to store essential cargo data based on an encoding scheme specified on an XML-based tag schema file. To provide the flexibility for different applications, each type of tag in our system is associated with a tag-schema, which defines all of the fields to be stored on the tag. A copy of the tag schema file is stored in the server connected to each RFID reader. The encoded data is then further compacted into a single numeric value using a data compaction algorithm according to the tag schema definition.

IV. PILOT RUN TEST

In May 2010 and February 2011, we completed a series of pilot runs of the system in collaboration with our industrial collaborators (see Table 1).

The two tests were conducted on cargo routes from Hong Kong to selected regional destinations (Taipei, Taiwan and Incheon, South Korea), with support from a leading global freight forwarding company. An RFID gateway system was set up in an airport warehouse located in the Airport Freight Forwarding Centre (AFFC) of Hong Kong, and handheld RFID systems were used at the destinations. Three checkpoints were in place. Namely, during cargo check-in at the AFFC, during cargo check-out at the AFFC, and also after the arrival of the cargo at their destinations. Note that the first two checkpoints were processed at the same gateway, as the entering and exiting cargo items can be differentiated by the movement detection function. These tests had the following objectives. First, we wanted to verify that the system is capable of functioning as expected in a real operational environment. At any point, background signal noises should be filtered and must not interfere with the system. Second, we wanted to identify any unforeseen technical and operational issues that may arise in a real-life operation.

In general, the results were satisfactory. In particular, regarding the first objective, the findings are summarized as follows:

A. In general, the tag encoding and decoding performance during the tests at each checkpoint was satisfactory. The tests verified the feasibility of applying the encoding/decoding scheme in a real-life operational environment.

B. Testing results for the advanced tag detection mechanism were satisfactory. Both the RFID-based and camera-based cargo direction detection mechanisms functioned correctly. An on-site analysis indicated that background signal noises generated from nearby items were indeed a major issue. However, the results indicated that these noises could be filtered correctly by the Advanced Tag Detection mechanism.

C. Tag rewriting during cargo stock-out was satisfactory. The tests verified the feasibility of applying the tag rewriting scheme in a real-life operational environment.

Regarding the second objective, it was found during an early phase of the test that the accuracy of tag reading and writing can be affected by several environmental factors. These problems were handled by special operational procedures, as follows:

i) *Speed of forklift trucks.* As expected, the speed of the forklift trucks passing an RFID gateway can have a significant impact on the tag reading and writing performance of the system. It was found that by setting a speed limit of about 1 m/s at the gateways, a satisfactory performance could be obtained. This proposed speed is still within the recommended speed range according to the safety guidelines of our collaborators.

ii) *Placement of RFID tags and impact of nearby metallic objects.* The performance of UHF RFID tags can be affected

Table 1: Pilot run tests

Test	Date	Route	Cargo type	RFID system
1	May 2010	Hong Kong to Taipei	Palletized cargo	Gateway, handheld
2	February 2011	Hong Kong to Incheon	Palletized cargo	Gateway, handheld

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if the tags are placed too close to a nearby metallic object, partly because of the blocking of RF signals and an effect known as detuning. This can be a potential problem for our application, since the forklift trucks contain a great deal of metal. We handled this by setting up a guideline specifying that a minimum distance of 8 cm be maintained between the tags attached on the cargoes and the metal frame of the forklift trucks. If necessary, padding materials should be used to maintain this distance.

It was found that, by carrying out these operational procedures, we were able to achieve a satisfactory performance. These measures will require cooperation at the operational level, which is feasible but will require that extra guidelines be followed during the palletization and transportation of cargo. However, this is necessary if a full-scale implementation is to be carried out in the future.

In the air freight forwarding industry, a key performance indicator is the total processing time per shipment during the checking in or checking out of cargo. Compared with the current manually-based operation procedure, our system can on average achieve a saving of 15-30 minutes per shipment process in a checkpoint. It is expected that this saving of time can be turned into a directly measurable Return-On-Investment (ROI). In fact a 10-25% ROI has been reported in similar applications, according to research studies conducted by [12][13] [14].

V. Conclusions

Air freight forwarding is an important part of the global supply chain. In this paper, we have presented an RFID system using RFID-embedded waybill labels to facilitate the handling and tracking of air cargo for the air freight forwarding industry. The system is based on an integrative RFID gateway with an advanced tag detection mechanism. By using a combination of linear and circular polarized antennas supplemented by low-cost cameras, we are able to achieve a high degree of accuracy in the reading and writing of tags, while providing cargo direction detection capability. We have also developed a logical-block-based tag writing scheme for updating cargo information onto RFID tags (e.g., for updating RFID data during the check-out process). Finally, we also developed a hybrid data encoding scheme for writing data onto the RFID-based waybill labels for the support of both online and offline cargo processing. By storing a short identifier, additional object-related data can be encoded on the tag using a data compaction algorithm based on an XML-tag-schema file that is accessible to the reader.

The system was tested and demonstrated in pilot run tests for selected air cargoes from Hong Kong to Taiwan and South Korea. Some potential challenges were identified during an early phase of the tests (e.g., the impact of forklift truck speeds and the effect of nearby metallic objects on the RFID tags). These issues can be overcome by making appropriate changes to the operational procedures. Overall, a saving in processing time of 15 to 30 minutes per shipment was achieved in a checkpoint. Overall, the results are promising, and the pilot run should provide a valuable case study for the air freight forwarding industry.

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