RFID-based Automatic Airport Baggage Handling System

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ABSTRACT

RFID (Radio Frequency Identification) technology is being integrated into a large number of public transportation systems, including air travel. Nevertheless, there are still several issues to be resolved in such RFID-based systems such as security, efficiency, and cost. In this work, we have developed an embedded system prototype of an RFID-based automatic airport baggage handling system using Lego Mindstorm, ARM processor, FPGA, and motors. The prototype shows how to solve several problems, currently encountered in the barcode systems at Taiwan's CKS international airport, including manual classification into different cabins and low identification rates.

1: INTRODUCTION

Currently, RFID is being used in only 6% of international airports around the world; however, it is estimated that more than 40% will use RFID by end of 2009 [1]. Each airport has different focus for implementing RFID systems. For example, Hong Kong airport mainly wants better customer satisfaction, while Las Vegas airport is focused on security. Anti-terrorism is also a major focus these days at several US airports. Some other airports would like to save money so that the number of lost baggages can be reduced by using RFID systems. The number of lost baggages is about 204,000 per annum on a basis of 30 million bags being mishandled for 2 billion passengers [1]. In Taiwan's CKS international airport, we would like to mainly make the baggage handling system more efficient and increase customer satisfaction.

The article is organized as follows. Section 2 shows how RFID is better than barcode in several characteristics. Section 3 presents the background required for our prototyping. Section 4 gives the overall architecture of the developed prototype. Section 5 gives details on its implementation. Section 6 gives the final conclusion.

2: MOTIVATION

A barcode consists of lines of various thickness that can represent a baggage identification number. RFID is a chip with radio-based transmission capabilities that can store a tag of data. We compare the characteristics of a barcode with RFID in Table 1 [2].

Except for cost, Table 1 lists all the advantages of RFID compared to the barcode [3]. This is also the motivation for replacing barcode with RFID. Still, RFID is not immaculate; it has the following limitations when applied to a real environment [4].

Table 1. Comparison between Barcode and RFID

Function and characteristic	Barcode	RFID Tag
Structure	paper quality, and easily broken	firmly encapsulated, unbreakable
In dark environments	unreadable	readable
Security	can be duplicated and forged	can be encrypted
Data Storage Space	small	large
Re-write Property	cannot be rewritten	can write data repeatedly
Read Property	read one at a time	100+ parallel reads
Transmission	read by the infrared ray	send data to chip by the radio frequency
Storage Format	bits of barcode	variable with encryption
Operating Environment	easily affected by abominable environment of light	unaffected by abominable environment of light
Corrupt Property	if corrupted, it will be unable to extract any information	defiling surface will not influence reading data
Encoded Range	have already reached limit, will face insufficiency problem two years later	latest code standard, large manufacturers will popularize it soon
Cost	low	high

- **No standardized specification yet**

Except for RFID products, RFID readers, tags, and applications have not followed the ISO communication standard until now. The standardized specification includes RFID operating frequency, generality, active or passive specification of tag, data format (grammar, data structure or encoding style), distinguish and expression method, the communication protocol of reader and tag and such others [5].

- **High cost**

As mentioned in Table 1, the main restriction of an RFID system is its high cost currently. Only when it drops to an acceptable price, all trades and professions will use RFID system actively to replace the existing barcode system. Note that the prime cost of an RFID system lies in the price of tags [6].

- **The problem of interruption**

Using RFID readers to read tags in an airport environment can be interrupted by metallic materials. When a reader is placed on a metallic material or when a passive tag (tag without power) is stuck on or below a metallic material, the metal will absorb radio waves, thus reducing the electromagnetic coupling energy of RF radio wave, shortening the reading distance of readers, and restricting the read direction. In addition, some watery materials will also shorten the reading distance of readers [7]. This is a problem that can be overcome by technology, like placing reader to read tag between the different transportation tracks [8].

- **The problem of human privacy**

Due to the extremely restricted computing and storage capabilities of RFID tags, security cannot be guaranteed and thus human privacy also becomes a major obstacle to the widespread use of RFID [9], especially if tags are implanted into the human body or used in passports [10].

Despite these issues, RFID systems are gaining popularity as evidenced by new UK and US passports having RFID starting August 2006. Based on the above described pros and cons of RFID, we would like to prototype an airport baggage handling system that can alleviate some of the problems currently faced in a barcode baggage handling system operating in the Chiang Kai Shek (CKS) International Airport of Taiwan, including the manual classification of baggage into different classes of seats of the same flight, the manual and tedious retrieval of baggage from the van when passengers fail to board a flight, and the low identification rate of baggage that require manual scanning of barcodes.

3: DESIGN CHOICES

An RFID system consists of tag readers, tags, edge servers, middleware, and application. In a typical RFID system, individual objects are equipped with a small, inexpensive tag. The tag contains a transponder with a digital memory chip that is given a unique electronic product code [11]. The interrogator, an antenna packaged with a transceiver and decoder, emits a signal activating the RFID tag so it can read and write data to it. When an RFID tag passes through the electromagnetic zone, it detects the reader's activation signal. The reader decodes the data encoded in the tag's integrated circuit (silicon chip) and the data is passed to the host computer [12]. The application software on the host processes the data, often employing Physical Markup Language (PML).

In an RFID-based automatic airport baggage handling system, a tag is attached to each checked-in baggage for identification by tag readers along the conveyor. Robotic arms or mechanical doors control in which direction an identified baggage passes forward along different conveyors. There are several design choices including the use of tag types, the software platform, the hardware platform, and the different system functions to be designed.

3.1: TECHNOLOGY CHOICE

An important issue in baggage identification is determining its location. Barcode identification using infrared technology is serial in nature, however RFID can identify tags concurrently. This advantage becomes a disadvantage in baggage identification because when more than one tag is read, we would not be able to locate a specific baggage for loading and unloading. To solve this problem we have to choose a reader with lower reading range, which allows baggage to be identified one by one. The readers should be able to write and read tags. As mentioned Section 2, the main restriction in widespread adoption of RFID technology is its high cost, thus by choosing readers that can both write and read tags, we can recycle the tags and reduce the cost. For our prototyping, we chose RFID tag readers with a rate of 13.56 MHz, aerial 50Ω (Ext.), read and write distance of 6 cm in average, size dimensions of 30.0(L) * 28.0(W) * 8.7(H) mm, and the data storage size in a card is 4 Kbit.

3.2: SOFTWARE/HARDWARE CHOICES

In this prototype, we wanted to demonstrate how RFID technology can help solve the issues mentioned in Section 2. The system is prototyped as an embedded system [13], which consists of mechanical parts driven by motors, hardware circuits that can drive the motors under real-time constraints, and software programs that can control the system operations. In this subsection, we will first introduce the hardware and software platforms used for prototyping and then describe the architecture of the system prototype in later subsections.

We need to connect RFID tag readers with mechanical arms that can divert baggage along different paths. This connection has real-time constraints because after a baggage is identified we need to drive the motors controlling the mechanical arms such that the baggage is accurately diverted. This is basically a real-time embedded system design [14]. We chose the Creator (S3C2410) motherboard for implementing this embedded system. An RFID tag reader is connected through an RS232 port to the Creator board. Motors driving the mechanical arms are connected to the Xilinx Spartan FPGA chip XC2S30 on a sub-board connected to the Creator board [15]. There is an ARM core on the Creator board for software execution.

Tag information is read continuously by the control software running on ARM. Based on this information, ARM sends control signals to the motor driver circuits running in the FPGA chip. The mechanical arms are thus actuated by the motor drivers, pushing the baggage along correct directions.

3.3: FUNCTION CHOICES

The main function of a baggage handling system is to identify all information related to a baggage including the owner identity and flight details. The amount of data storage space is limited in RFID tags, hence we need to decide which data should be included. Since we are building a prototype, we also need to decide what are all the functions that need to be prototyped in our embedded system. In the following, we will describe the data and functions that we have chosen to design in the proposed prototype.

When a passenger goes to an airline counter to check in, counter agents will stick an electronic label in the form of an RFID tag on the passenger's baggage. The electronic label records the following information.

(1) Passenger's passport number
(2) Flight number
(3) Baggage's serial number
(4) Flight starting point
(5) Flight terminal point
(6) Transfer flight numbers
(7) Unloading passageway of baggage handling system
(8) Cabin rank (including first-class, business-class, and economy-class cabins)

3.3.1: Data allocation in tags

The data space in the RFID tags used in our prototype design consists of 64 blocks, where each block consists of 4 bytes. The data are allocated as follows.

(1) The passenger's passport number is stored in the first block to the fourth block, totally 16 bytes.
(2) The flight number is stored in the fifth block to the sixth block, totally 8 bytes.
(3) The baggage serial number is stored in the seventh block to the fifteenth block, totally 36 bytes.
(4) The flight starting point is stored in the sixteenth block to the seventeenth block, totally 8 bytes.
(5) The flight terminal point is stored in the eighteenth block to the nineteenth block, totally 8 bytes.
(6) The transfer flight numbers are stored in the twentieth block to the twenty-first block, totally 8 bytes.
(7) The unloading passageway of baggage handling system is stored in the twenty-ninth block to the thirty-third block, totally 20 bytes.
(8) The cabin rank is stored in the thirty-fourth block to the thirty-seventh block, totally 16 bytes.

An example is shown in Figure 1 for a passenger called John Wang, with details as follows.

(1) Passenger's passport number: K1234567,
(2) Flight number: A0003,
(3) Baggage's serial number: 000001,
(4) Flight starting point: Kaohsiung (code number: 001),
(5) Flight terminal point: Taipei (code number: 003),
(6) The transfer flight numbers: Z2007,
(7) The unloading passageway: 06,
(8) The cabin rank: First class (code name 01).

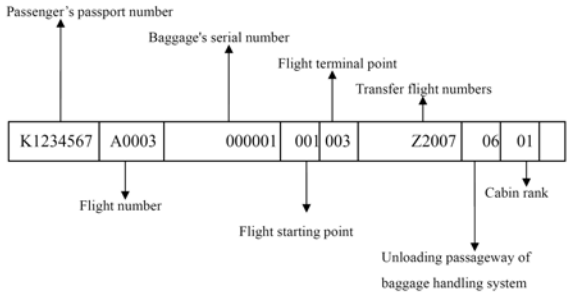

Figure 1: Tag sector allocations

3.3.2: System functions

After paying an in-depth visit to the CKS International Airport in Taiwan, we discussed, with the main technical person in charge of the two automatic baggage handling systems in CKS Terminal 2, about the issues that they currently face and would like to solve. All the issues identified were related to the locating of baggage both along the conveyors and in the baggage container to be loaded into the cargo area of an airplane.

To solve the above two issues, we decided to develop a system prototype implementing solutions proposed by us for the two issues. The solutions included the following.

(1) An RFID-based flight-specific baggage routing system that can locate and route bags easily with high success rate.
(2) An RFID-based cabin-specific baggage sorting system that can load bags into containers for easy retrieval later.

The overall system functions are shown in Figure 2. After a baggage is loaded onto a conveyor, the baggage will go through two kinds of junctions for sorting. The first is a junction for routing to the correct unloading passageway (another conveyor) and the second is a junction for sorting into the correct container.

At the first junction, called *routing junction*, the baggage is routed along the designated unloading passageway. This junction consists of a mechanical arm and a tag reader. The mechanical arm acts as a pusher that can allow a baggage to move along the conveyor or push (divert) it onto another conveyor that is the designated unloading passageway. The tag reader acts as a baggage identifier that reads the baggage information from the electronic label on the baggage and sends this information to the monitoring software running on a microprocessor. On receiving baggage information, including the designated passageway, the monitoring software decides whether the baggage should be diverted along the unloading passageway in this junction or not. If it belongs to the unloading passageway in the current junction, the pusher is actuated immediately. When a single processor controls several junction pushers, real-time constraints have to be considered for a correct system design.

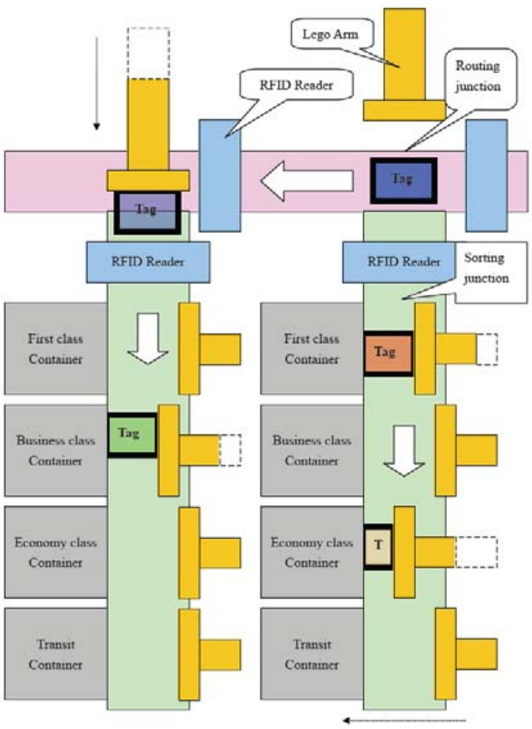

Figure 2: Simulation of tags pushed to another conveyor by mechanical arms

At the second junction, called *sorting junction*, the baggage is sorted into cabin-specific containers. This junction also consists of pushers and a reader. After a baggage is diverted onto the unloading passageway at the routing junction, the reader in the arched door of this sorting junction will read the tag for information again. Based on the cabin information, the monitoring software pushes a baggage into the proper container using different pushers.

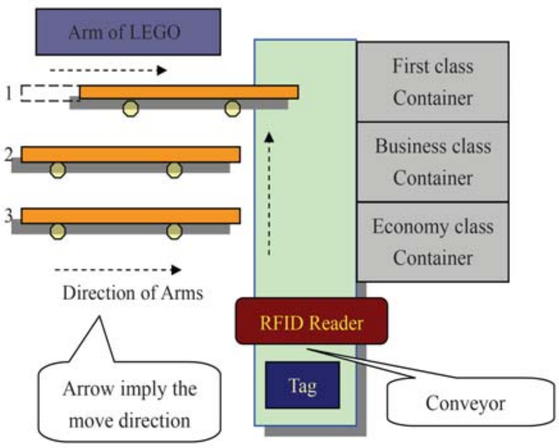

Figure 3: Simulation of tags pushed to luggage container by mechanical arms

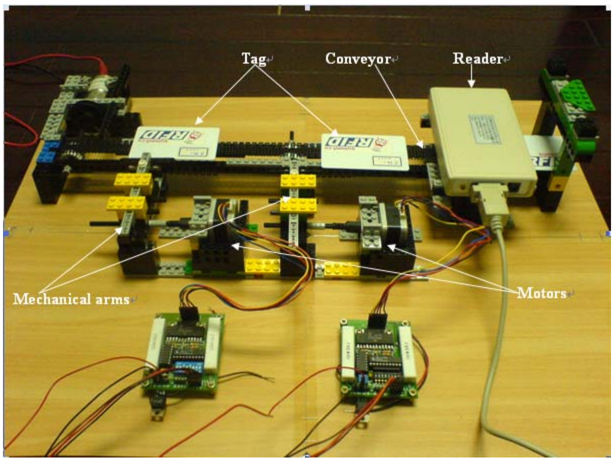

Figure 4: Snapshot of the sorting junction prototype

4: SYSTEM DESIGN

The system prototype was developed mainly to solve the two issues encountered in the CKS airport and not to develop a full prototype. We thus implemented the routing and sorting junctions based on the decision choices made in Section 3. Figure 4 shows a snapshot of the sorting junction prototype.

Given the data allocation in tags and the system functions as described in Section 3.3, we designed the system prototype using the platform and technology as described in Sections 3.1 and 3.2. The overall system prototype architecture is illustrated in Figure 5, where the embedded system development platform, Creator, connects the tag reader and the motors controlling the pushers and the conveyors. We designed three parts of the system including (1) the mechanical emulation of the pushers, conveyors, and junctions using the Lego Mindstorm systems, (2) the monitoring software, and (3) the motor driver hardware circuits.

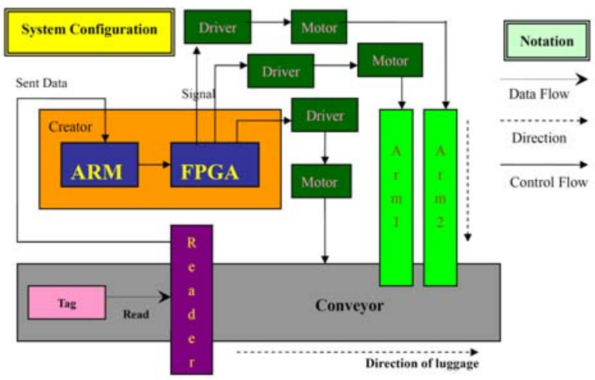

Figure 5: System prototype architecture

As shown in Figure 6, the control/data flow of the system prototype is as follows. The monitoring software runs on the ARM processor on Creator, which requests readers to read tag information and actuates the motor drivers based on tag information. The driver circuits for the motors are configured into the Xilinx FPGA chip on Creator, which drives the different motors based on inputs from the monitoring software. The motors in turn drive the pushers (Lego arms).

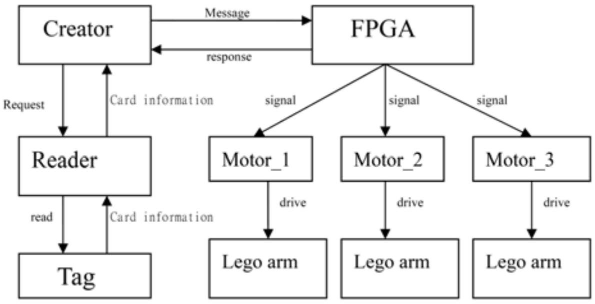

Figure 6: Component diagram

As far as non-functional requirements of the system are concerned, we mainly focused on reducing the overall cost of the system and to satisfy real-time constraints. To reduce the cost of the system, we allocated only one reader at each of the sorting junctions, and then put the pushers that sort baggage into different cabin-specific containers equidistant from each other. Depending on the speeds of the conveyors and pushers, we calculated the precise time when the motor driver in FPGA should be signaled by the ARM software so that it can drive the motor to actuate the correct pusher that can then push a baggage into the correct container.

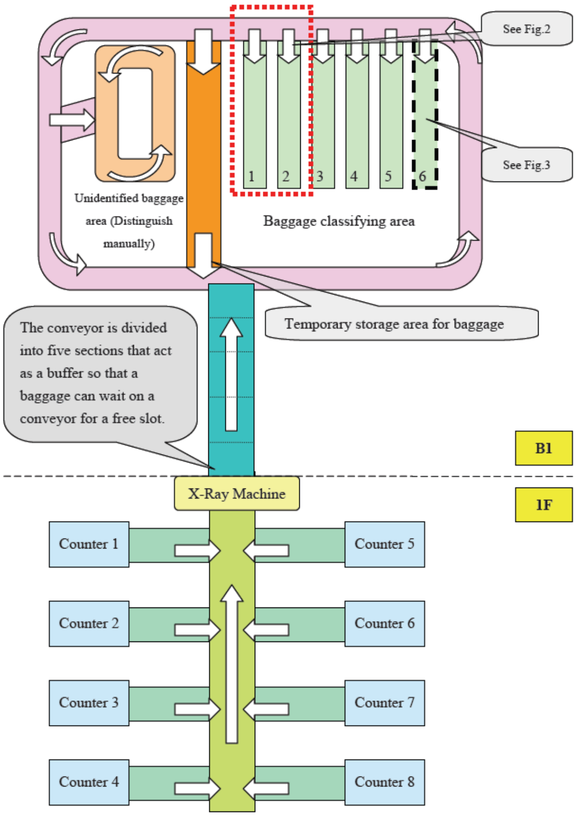

Figure 7: Deployment in airport baggage transportation system

5: IMPLEMENTATION AND ANALYSIS

The system prototype design proposed in Section 4 must be deployed in a real airport. We now show how such a deployment can be implemented. As shown in Figure 7, we try to make this deployment, while striving not to induce major changes to the existing airport baggage transportation and handling system, because major changes will not only require re-training of technical and security personnel, but also incur higher development costs.

In Figure 6, we see that there are 8 counters used by different airlines to help passengers check in. Counter agents weigh the checked-in baggage and attach an electronic RFID tag label on each baggage, which records all related information including the passenger's passport number, the flight number, the baggage number, the flight starting point, the flight terminal point, the transfer flight numbers, the unloading passageway, and the cabin class. The baggage is then placed on a conveyor that carries it through an X-ray machine for security inspection. A baggage with illegal articles such as explosives will be removed and will not enter the baggage handling system.

The main baggage routing system is depicted by a circular ring in Figure 7. Before a baggage enters the main baggage routing system, it is on a conveyor leading into the main system. The conveyor is divided into five sections that act as a buffer so that a baggage can wait on the conveyor for a free slot in the main routing system. When there is a free slot on the main routing system a baggage waiting on the conveyor can be placed precisely into that slot. This is important because we need to exactly locate each baggage and also to avoid baggage to collide with each other by maintaining a safe distance between consecutive baggages. After the baggage enters the main routing system, its location is continuously sensed using RFID tag readers because the baggage control room of the airport would like to know where exactly a baggage is located, just in case there is a congestion or interruption in the main routing system.

In the main routing system, a baggage passes through one or more routing junctions where a routing machine may divert the baggage along its correct unloading passageway. Each unloading passageway represents a different flight number. Our RFID-based flight-specific baggage routing system solution as described in Sections 3 and 4 will be deployed at these routing junctions.

After a baggage has entered an unloading passageway, it will pass through a sorting junction, where we will also deploy a tag reader and several pushers. Each pusher represents a different cabin class, including first class, business class, economy class, and transfer flight. Our RFID-based cabin-specific baggage sorting system solution as described in Sections 3 and 4 will be deployed at these sorting junctions.

After deploying the two system solutions to an existing baggage handling system, we expect the following benefits. The baggage identification success rate will increase from the current 85 ~ 90% to more than 99.8%, which means the additional person in-charge of manually scanning the unidentified baggage (around 15% to 10% bags), will not be required to remain in the main routing system the full day waiting to scan bags [1]. In our newly proposed baggage routing system, whenever a bag is unidentified an alarm will be sent to the control room where a person can then be assigned to identify the bag. Thus, there is no need of an extra person waiting for unidentified baggage in the main routing system. Further, the newly proposed baggage sorting system will have also automated the classification of bags into different cabin-specific containers, which is currently done manually in the CKS airport. This not only saves manual efforts but also reduces the amount of human errors in misplacing a baggage into a wrong container, for example, a first-class passenger's bag is placed into an economy-class container would make passengers unhappy.

There are still some limitations in our proposed prototype. Our proposed solutions have not automated the tedious task of locating the exact baggage for retrieval from a container when a passenger has failed to board a flight. According to international rules, a passenger's baggage should not be transported if he/she is not on the plane, thus before a plane takes off, it always becomes troublesome to lay out all the baggages from a container to search for and remove those belonging to the passenger missing the flight. We will work on solving this problem in the future by integrating locating techniques with RFID technology.

6: CONCLUSION

We have proposed and analyzed a prototype for RFID-based automatic baggage handling system that can be implemented for deployment in the CKS airport. We are confident that the system will help resolve the two issues posed to us by the technical persons of CKS baggage handling system. There are still several issues to be resolved in transforming an existing baggage handling system into RFID systems, including static electricity generated on the conveyors make RFID tag reading difficult, the cost of RFID tags, security leak, and privacy issues, etc. We hope to also investigate on such issues in the future. Developing RFID middleware for baggage handling systems will also be a future research direction. We also plan to extend the VERTAF [16] framework to support embedded software development for RFID-based systems.

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