Detecting Hollow Pallets

By

Sheng Zuo, MComp

A dissertation submitted to the

School of Computing and Information Systems

In partial fulfillment of the requirements for the degree of

Master of Computing

University of Tasmania

November 2009

Sheng Zuo
November 2009

DECLARATION

I, Sheng Zuo, declare that this thesis contains no material which has been accepted for the award of any other degree or diploma in any tertiary institution. To my knowledge and belief, this thesis contains no material previously published or written by another person except where due reference is made in the text of the thesis.

....

Sheng Zuo
November 2009

ABSTRACT

Radio Frequency Identification (RFID) technology has become widespread in the supply chain. RFID uses signals transmitted from tags attached to items to track and identify the items. The contents of the items cause weak signal strength and low tag read rate. However, this feature helps to detect whether or not there is a hollow in a pallet. Hollows in pallets are usually caused by the theft of items. This thesis details research that aims to detect the hollow based on a pallet filled with a high water content product. The result suggests that the hollow pallet can be detected by observing the difference in the number of detected tags between the full pallet and empty pallet. Furthermore, by analyzing the data from individual tags, the position of the hollow in the pallet can be determined.

Sheng Zuo
November 2009

ACKNOWLEDGEMENTS

As the deadline for thesis submission is close, I find my thoughts are remembering the year which has just past. Many people deserve my thanks for both assistance with my work and indirect support during this endeavor. I hope this brief token is sufficient to express my gratitude.

My first thanks are to my wonderful supervisor, Mrs. Jacqui Hartnett. Without her help this work would never reach completion. I appreciate her for the time, ideas, books and finances she has contributed to this research.

Continuing with my gratitude, I want to thank my advisor Mr. Luke Mirowski for his suggestions, proof reading and patient handling of questions. He has helped improve my learning ability a lot.

I would like to extend my thanks to Mrs. Louise Oxley and Mrs. Morag Porteous for helping me improve academic writing skills.

I am grateful to all the staff in the School of Computing and Information Systems for their support over the past year. To my fellow students, I thank you for a most interesting and memorable year.

Most importantly, I am deeply indebted to my parents for their continuous support and encouragement over this year and within everything I have undertaken.

Sheng Zuo
November 2009

TABLE OF CONTENTS

Sheng Zuo
November 2009

Figures

Tables

Sheng Zuo
November 2009

1 Introduction

Radio Frequency Identification (RFID) is a technology based on devices using radio signals to identify data. With implementation of RFID, each individual object can be identified by attaching a small *tag* or *label* on it (Thornton et al. 2006). Inspired by implementation of RFID technology, an RFID-based tracking system attempts to detect whether or not there is item loss on a pallet in a transportation and logistics area. The tag receives a radio signal, typically from a reader, and sends back information on it, such as item ID, content and production date. The pieces of information in tags identify the items to which the tags are attached. These processes are similar to asking a question "What are you" and responding with "I am Item Number 00001". By this method, individual items on a pallet can be tracked in transporting processes. This method is known as *item-level tagging*. However, an extended question is that although response information from tags indicates that cartons are on a pallet, it cannot guarantee that the contents of the cartons are there. In this research, a method to detect whether or not the contents are missing will be explored.

Goods in transporting processes, such as from one company to another, or from a company to consumers, may be tracked at item level, case level or pallet level (Brown 2006). Item level refers to the tagging of individual items; while at the case and pallet level, tags are attached on cases and pallets (*RFID Journal Glossary of Terms* 2009). Compared with the case and pallet level, item-level tagging performs better at Ultra High Frequency bands (915 MHz) with the use of low price tags. By tracking goods at item level, shrinkage (a polite term for loss of items usually by fraud of some kind) and time spent on counting items can be reduced (Brown 2006). In addition, item-level tagging provides high quality visibility of individual items in a supply chain (Jung, Chen & Jeong 2007). Therefore, item-level RFID is a valuable method for tracking goods and creating profit in the supply chain. It can effectively detect item loss on a pallet in transit without labor participation. In this research, item level tagging will be used to investigate the hollow pallet problem which is the result of item loss.

Item loss refers to unexpected and unexplainable product shrinkage, which has caused a large amount of retailers to lose significant profit. It is a serious problem in retail and logistic areas as loss has been estimated to reach 1.7% of the sales profit. Nearly 77% of the product reduction was caused by theft (Barua, Mani & Whinston 2006). RFID has been used as an effective means to detect whether a carton is missing on a pallet, so as to address this problem. Large retailers, such as Wal-Mart and Target, plan to implement this technology with all their suppliers. The savings in theft reduction of Wal-Mart was estimated to reach $575 million (Asif & Mandviwalla 2005). The overall saving in product shrinkage in the retail area with the use of RFID was estimated at US$19.06 billion (Barua, Mani & Whinston 2006). Moreover, RFID reduces labor participation in processes, such as data recording and carton inspecting. The labor cost declined by 25%, estimated at US$102.95 billion (Barua, Mani & Whinston 2006). However, although RFID-based item tagging is able to detect carton loss on a pallet, it cannot detect whether or not the contents inside the cartons are missing.

Extending from item loss, a hollow pallet refers to the problem that the cartons are there but contents of a pallet or cartons are missing. It is a real problem when the hollow occurs in the center of the pallet, because it is difficult to visually inspect if the pallet is actually hollow. Finding a method of detecting hollow pallets is necessary, because it costs a large amount of revenue in retail and logistic industry. Traditionally, weighting the pallet is used to find whether or not there are empty cartons on pallets. This is not a good method as it takes more time, requires the use of a weigh bridge, costs more profit, and needs labor participation. On the other hand, RFID technology, which has already been implemented to identify cartons, could be extended to see whether or not the contents of the cartons are there.

The method of identifying hollow pallets in this research is to measure the data produced by passive RFID. In passive RFID, when response signals from tags pass through cartons, the contents inside the cartons affect the signal strength. In other words, the data received at the reader varies according to the contents of the cartons. The assumption is that if the pallet is empty, full or hollow, different data are produced based on the received signal at the reader. By observing the difference in these data, hollow pallets can be detected. Therefore, the hypothesis is that the hollow inside a pallet can be found by evaluating data with passive RFID. If this method works, it means that RFID is able to detect a hollow pallet, in addition to identifying and tracking cartons on it.

Therefore, the aim of this research is to detect whether or not the contents of cartons are missing. The problem to be investigated extends from item tracking. In the experiment of this research, tags will be applied to each carton to find out which carton's content is missing. The results are expected to be applied in the salmon transporting area, in order to investigate if there is salmon missing or not. Thus, the experiment in this research will simulate goods transportation in fish farming. To this end, **Chapter 2** presents an overview of current literature first, bringing a more in depth understanding of RFID system architecture and how it may be used to solve this problem. This also highlights solutions and results from previous researches that investigated similar problems. **Chapter 3** discusses the design and test method used in the experiment. Testing is divided into three phases to investigate the optimized method of solving the problem. Following that, **Chapter 4** presents the outcome of the three phases, and discusses their individual relationship with the hypothesis. Impact of the results from the three Phases in the real world is discussed. The results are simple to observe for summarizing the results, so there is no necessity to analyze them using sophisticated machine learning algorithm. Finally, **Chapter 5** summarizes the finding and explores a discussion of suggested approaches to further research on this topic.

2 Literature Review

This chapter introduces the hollow pallet problem which needs to be detected in this research, and discusses the principles of RFID that can be used to solve this problem. It will firstly present the motivation for this work. Following that, an overview of the basic concept of RFID technology will be given. Then it will discuss the factors which limit the use of RFID technology including the collision problem. The following section will explore how the above factors can be used to solve the problem in this research. In addition, the basic solution that would be used in the experiment will be discussed. Finally, results from previous research in this area will be presented.

2.1 Introduction

The problem to be investigated is the hollow pallet that the contents of the center cartons on a pallet are missing. A pallet is a flat structure which is used to transport goods. It usually consists of many cartons (**Figure 1**). As in shown **Figure 1**, No. 29, 32, 17 and 20 may be empty.

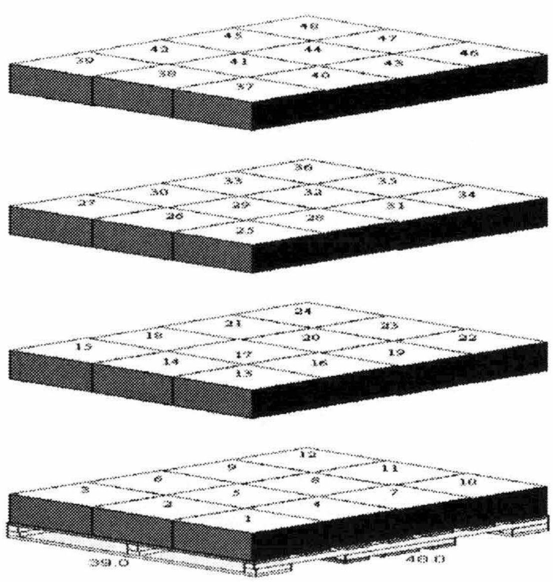


Figure 1 – A pallet with 48 cartons on a board (Clarke et al. 2006)

In many cases it is impossible to find whether there is a hollow by inspecting every carton. Radio Frequency Identification (RFID) system technology will be investigated as the means to address the hollow pallet problem. RFID refers to any system of identification in which electronic devices use radio frequency to communicate. An RFID system basically comprises three components: *tags,* which are the devices attached to items so as to identify and track them; *readers,* which can detect the tags and collect the information stored in them, and *middleware,* which builds up communication between reader and applications (Glover & Bhatt 2006). In general, RFID captures the information from the tags so that people may use the data to track and identify items in transporting processes. However, RFID is not mature as it cannot guarantee 100% read rate. The read rate is affected by a lot of factors. This research will make use of this feature to detect whether there is a hollow in a pallet.

2.2 Transportation Issues in the Salmon Industry

Before presenting the RFID system, which will be used in this research for proving or disproving the hypothesis, attention can be paid to addressing the hollow pallets problem in salmon shipping.

Logistic services provided by carriers were evaluated to determine the most important factors. Item loss, caused by transportation firms, was considered as the second most important problem following reliability (Lu 2000). This research aims to investigate an effective way to detect whether there is any content missing on a full pallet, with the use of RFID technology. The results have benefits in packing and shipping salmon in logistic area.

Salmon aquaculture has become an important global industry. Norwegian salmon production, which amounted to less than 100 tons in 1971, rose dramatically to more than 500,000 tons in 2003 (Asheim et al. 2005). Although Norway contributed the majority of the development, production in other countries, such as Scotland and the Faeroe Islands, also increased. Moreover, Chile is the second most important salmon supplier following Norway. The product is now transported to markets all over the world. In 2000 and 2001, about 66% of the Norway's production was consumed in European Union, 5% were in the US and 13% was shipped to Japan. Problems in transporting processes affect those markets far away from the suppliers. For example, a disadvantage for Chile is the long distance to the European market, and Norway needs to supply fresh salmon to the markets in the Far East (Asheim et al. 2005). Due to this, the salmon industry tends to use ice to keep the salmon in a low degree environment during the long distance transport, to both keep the quality and lower the cost of transportation. However, problems exist and cause profit reduction.

One of the worst problems is inaccurate data. The poor quality of data increases the cost to detect and correct the errors (Redman 1998). Profit was found to be reduced by 25% due to cases where an item was actually available but located in the wrong spot (Basinger 2006). Some causes resulting in data inaccuracy have been identified, including data not updated. If the data are not updated on time, inaccurate status of the storage is produced. Data inaccuracy has negative effects in making decision on inventory. If the items are put in the wrong location, extra labor is expended in correcting the mistakes.

Various methods have been put up for optimizing the accuracy of data. The most simplified way is cycle counting (Donath 2002). It builds up a process to measure the data accuracy by human labor. It also requires other processing to be stopped as the inventory must be stable in the process.

Bar code is also used for improving the data accuracy, but it also brings security issues within the supply chain. Some products were stolen from retail stores such as Wal-Mart as thieves printed their bar code by themselves and pasted it over the top of the bar code on the product. This "name their own price" behavior caused retailers and manufacturers in North America more than $25 billion each year (Schuster, Allen & Brock 2007).

Compared with these two methods above, RFID technology not only improves data accuracy but also saves costs. By applying RFID to pallets, warehouse costs were saved by 3-5% (Basinger 2006). Companies can use RFID tags to detect lost items or track items (*RFID Business Applications* 2009). By implementing RFID tags under carts and readers on the entrances and exits, the budget of Air Canada saves millions of dollars each year. Furthermore, RFID implementation has benefits in adding more information and preventing false information being recorded. An RFID-based tracking system, which aims to track tuna fish in Japan, was expected to make fishermen record fish name, weight, fishing boat ID in an RFID and attach it to the tuna fish before freezing (*Frozen Tuna Gets RFID* 2005).

2.3 RFID Overview

RFID has become a mainstream technology which helps to identify the objects and to speed the work processes in a variety of areas, including retail and logistics (Want 2006). With the use of RFID technology, a retail vendor can provide improved services to customers. For example, RFID technology has benefits in tracking stock efficiently by recording the ID, type, size and color of a product, and some retailers, such as Prada in Europe, have been enhancing the ability to design and stock the latest popular products by monitoring customers' preferences (Koh, Kim & Kim 2006). In addition, RFID started to be implemented in libraries from the late 1990s. It not only detects the books taken out of the libraries without authentication, but also accelerates the querying speed (Boss 2003).

Most RFID system works under one band, as the Radio Frequency (RF) spectrum is divided into a series of band. These bands are governed by local regulatory bodies to decide who has the authority to use the band and how to modulate the signals. For example, in the United States, the authority to use the bands is granted by the Federal Communications Commission (FCC) and it is under the regulation of the European Telecommunications Standard Institute (ETSI) in a number of European countries (Thornton et al. 2006). Based on the spectrum distribution, an RFID system has four frequency bands, such as Low Frequency (LF), High Frequency (HF), Ultra High Frequency (UHF) and Microwave. The use of these frequency bands varies depending on both the local regulations and the surrounding materials. The details of these three frequency bands will be discussed in the following section.

2.3.1 RFID Applications

RFID technology has been used in various applications. Fundamentally, these applications are classified into five categories, as show in **Figure 2**.

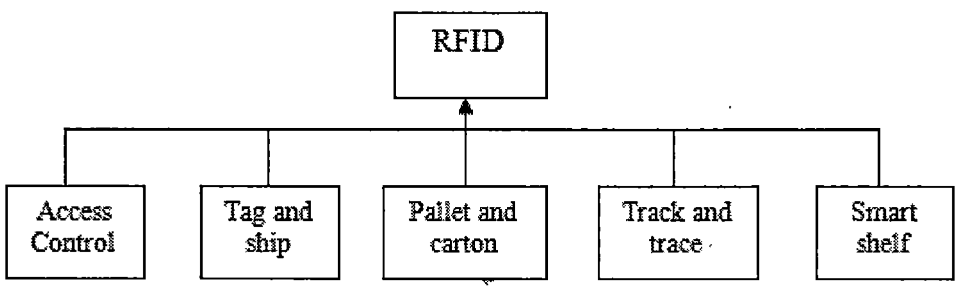


Figure 2 – Relationships among different types of RFID applications (Glover & Bhatt 2006)

These five categories are introduced as follows:

- Access Control: Access control applications are used to grant access authentication in certain areas. In these applications, RFID tags could be integrated into small objects as the size of credit card or key chain attachments that may give access to enter a building or secure area.
- Tag and Ship: Tag and ship applications are systems that enable users to verify whether the tags work properly when they are attached to items.
- Pallet and Carton Tracking: These applications are the most common forms of RFID that are put on one or more individual items on a shipping unit.
- Track and Trace: These applications are used to track animals or pets. Recently, these applications have been widely used to track products in pharmaceuticals, which has critical effects in dealing with public health problems.
- Smart Shelf: These applications are containers which track individual items in them. They keep monitoring the items and update the inventory in real time. A

system using this application can find all expired products by identifying the expiration date (Glover & Bhatt 2006).

This research aims to solve the problem with the use of pallet and carton tracking applications. It has a long list of usage areas which include but are not limited to supply chain and item-level tagging of goods. Assume that each item on a pallet is tagged and the pallet has been moved from the vendor's warehouse to the manufacturer's warehouse, the information tracking every item being shipped can be provided by RFID tags (Thornton et al. 2006). However, because there is no labor component during the transporting process from one company to another, the reader in the manufacturer's warehouse must be compatible with the tags used by the vendor to ensure the system work well.

At item-level tagging, each carton is attached with one tag which identifies the carton. When the cartons pass in front of the reader, the reader reads the information stored in the tags and sends it to the middleware to identify the cartons. In passive RFID, power for a tag attached to a carton is supplied by a reader. When signals are transmitted from a tag to a reader, the content of the carton affects the signals. For example, if a carton contains high water content products, signal strength becomes weak, which may cause low read rate, and failure to detect some tags. On the other hand, if a carton is empty, the signal pass through the carton without interference, which can cause much higher read rate and more detected tags. Therefore, by observing the difference in signals between empty cartons and full cartons, whether or not some products on the pallet are missing can be detected. Item-level tagging will be explored in detail in the following section.

In summary, an RFID system has various applications which are used in logistic, retail and other fields. Pallet and carton tracking applications are considered in this research. The basic idea of them is to identify the cartons based on the information contained on the tags read by the reader. However, because there is no labor component in these processes, the reader must be compatible with the tags. The next section will introduce the architecture of RFID system.

2.3.2 RFID Architecture

An RFID system consists of three components: tags, readers, and middleware (Garfinkel & Rosenberg 2005). Tags and readers are the most talked-about devices. Fundamentally, tags are small devices attached to the item which needs to be tracked or identified, and a reader is the device that can detect the tags and retrieve the information stored in the tags. After querying a tag and obtaining its information, the reader transports the information to another system. Middleware is the software which connects the RFID hardware to that existing in the organization. It provides communication between a reader and applications (Glover & Bhatt 2006). These three components and how they work together are introduced as follows. **Figure 3** shows the three components in a typical RFID system.

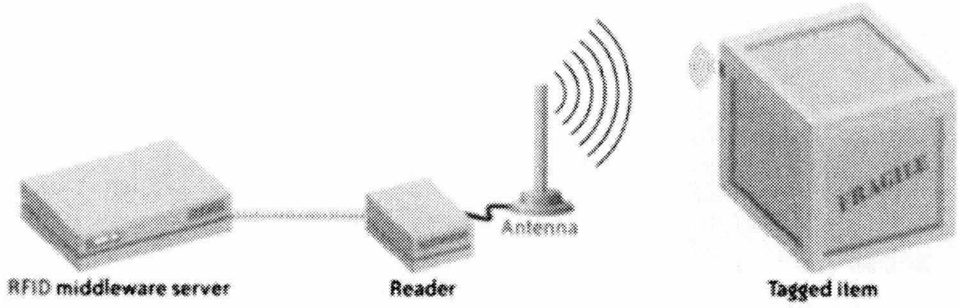


Figure 3 – An RFID system at item level tagging (Glover & Bhatt 2006)

- Tags

RFID tags, also called transponders or labels, are radio device combinations of transmitters and receivers which receive the radio signal of special frequency and send a reply automatically (Thornton et al. 2006). Each RFID tag consists of an antenna and a chip which includes a radio receiver, modulator and a power system as well as memory (Garfinkel & Rosenberg 2005). Based on the different sources of powering, tags can be divided into two categories: passive tags and active tags (Weinstein 2005).

Passive tags are smaller and cheaper than active tags because they have no integrated batteries (Want 2006). It is very easy to affix them into books and small products (Shepard 2005). An RFID reader is the power source of passive tags (Want 2006). The process of obtaining power source is completed through the electromagnetic property *Near Field* which provides energy to tags for transmitting signals (Thornton et al. 2006). However, the name 'Near Filed' implies that tags must be located close to a reader for powering. The advantage of passive tags is that they can be used for many years, while an active tag life is limited by the battery life (Garfinkel & Rosenberg 2005).

In contrast, active tags have their own power source, either from the integrated battery or from a connected power supply. Because they do not need to rely on the energy from 'Near Field', their use is not restricted by distance. Therefore, they can receive energy and send signals over long distance and with high reliability. The read range of active tags can reach as much as 50 feet or more in some situations (Shepard 2005). For example, a 915MHZ UHF tag can be read from more than 100 feet away. In addition, because there is no need of a continuous radio signal to power the tags, their performance can be very stable. One of their drawbacks of is that the battery limits the lifetime in practical use. Other disadvantages include that active tags are always large, and the prices are expensive, which restrict their usage in the real world (Juels 2006).

Moreover, there exist semi-passive tags between the active and passive tags (Garfinkel & Rosenberg 2005). Semi-passive tags have batteries as the power supply for the memory, and rely on the reader to power other components so as to send and receive signals. However, the name "Near Field" implies that the tags must be located close to the reader for powering. In other words, this kind of tags has the reliability of active tags and the transmission range of passive tags.

In the business sector, RFID tags are implemented to track objects in the supply chain, including supplier transport, warehouse storage and retailer (Weinstein 2005). During these processes, the objects' movement information can be added into the database in order to arrange the schedule and prevent theft. The primary application of RFID is to track products in a way which is similar to bar code. In other words, RFID is the next generation of bar code technology. Compared with the traditional bar code technology, RFID has the following advantages:

- Line-of-sight is not necessary;
- A larger read range;
- Simultaneously communication is enabled, thus the RFID reader can detect all the packages on the pallet as it is moved into the warehouse;
- More information, such as position and time, can be stored in a tag throughout the transport process in the supply chain (Gao et al. 2004).

- Readers

In passive RFID system, an RFID reader provides tags with radio energy and receives responses from tags. A tag gains radio energy when it enters the read range of the reader, and sends back a message which contains the serial number and other information on the tag. In some specific RFID systems, the reader can send the radio frequency signal which includes instructions to manipulate tags (Garfinkel & Rosenberg 2005). In these cases, the reader can read or write a tag's memory, or even secure them with a password. On the other hand, in active RFID, tags gain energy from integrated batteries or a connected power supply. They do not need a reader to provide energy to them.

There are various sizes of RFID readers. According to Garfinkel & Rosenberg (2005), the largest reader includes a desktop computer with a special card and some antennas. This kind of reader is typically part of a network and can send the data it reads from tags to other computers in the network. The smallest reader is the size of a postage stamp and is mainly used in cell phones.

An RFID reader consists of three physical components, as it is shown in **Figure 4**:

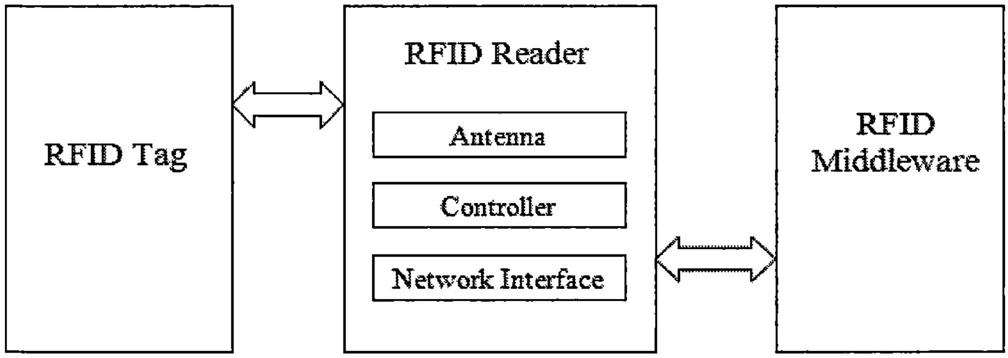


Figure 4 – Physical components of an RFID reader (Glover & Bhatt 2006)

Antennas, which are used to transmit and receive signals, are simple in concept. The number of antennas controlled by a reader varies on different readers. In some cases, one or two antennas are integrated inside a reader; in other cases, a reader can remotely control many antennas.

Controller refers to the device which controls the reader. The controller has three functionalities: controlling tag protocols on the reader side, scheduling time to send information to the network and configuring reader protocols.

Network Interface is the platform which provides the communication between the reader and the network. Moreover, readers communicate with other devices through a variety of interfaces. Historically, most RFID readers had serial interfaces using RS 232 or RS 422 (point to point, twisted pair) or RS 485 (addressable, twisted pair). Recently, more and more readers have start supporting Ethernet and Bluetooth (Glover & Bhatt 2006).

In an RFID system, information is transferred between tags and a reader. Multiple readers can also be used in one system. In a supply chain application there would typically be a reader at the entry and exit to each location in the chain and possibly also on the trucks that transport the items. The radio signals are measured by frequency. Basically the frequency bands can be divided into low-frequency (LF) band at 125-134.2 KHz, high-frequency band (HF) at 13.56 MHz, ultrahigh-frequency (UHF) band at 915 MHz and microwave frequency band at 2.4 GHz. As radio energy is transmitted in waves, it has not only a frequency but also a wavelength. The wavelength of the radio wave multiplied by its frequency is equal to the speed of light, which is $3*10^8$ meters per second. **Table 1** shows the details of the frequency bands.

Band	Frequency	Wavelength
LF	125-134.2 KHz	2,400 meters
HF	13.56 MHz	22 meters
UHF	865.5-867.6 MHz (Europe) 915 MHz (U.S.) 950-956 MHz (Japan)	32.8 centimeters
Microwave	2.4 GHz	12.5 centimeters

Table 1 – RFID frequency band categories (Garfinkel & Rosenberg 2005, p. 21)

Tags at different frequency bands have significant variations of performance when surrounded by water or metal. Among these four bands, LF RFID systems have the best performance when reading tags attached to high water content or metal products. The read ability of HF in this case is slightly worse than LF but better than UHF. UHF tags have limited ability to read tags on items with a high water content or a metal product. The UHF frequency band is the one which has spread in logistics area and is the basis for the Electronic Product Code (EPC) tags. Microwave RFID systems have the highest price, and their use is limited by their possessing the weakest ability to penetrate water or metal products (*Understanding RFID and Associated Applications* 2004).

- Middleware

Middleware describes applications which are responsible for managing data from readers and sending information to the system. It controls the data flow between the readers and the system. In addition, the middleware has extra functionalities, such as filtering and reader integration (Thornton et al. 2006). The system connected to middleware can be commercial databases, such as SQL and Oracle. The database system can work on either a single PC or in a networked system.

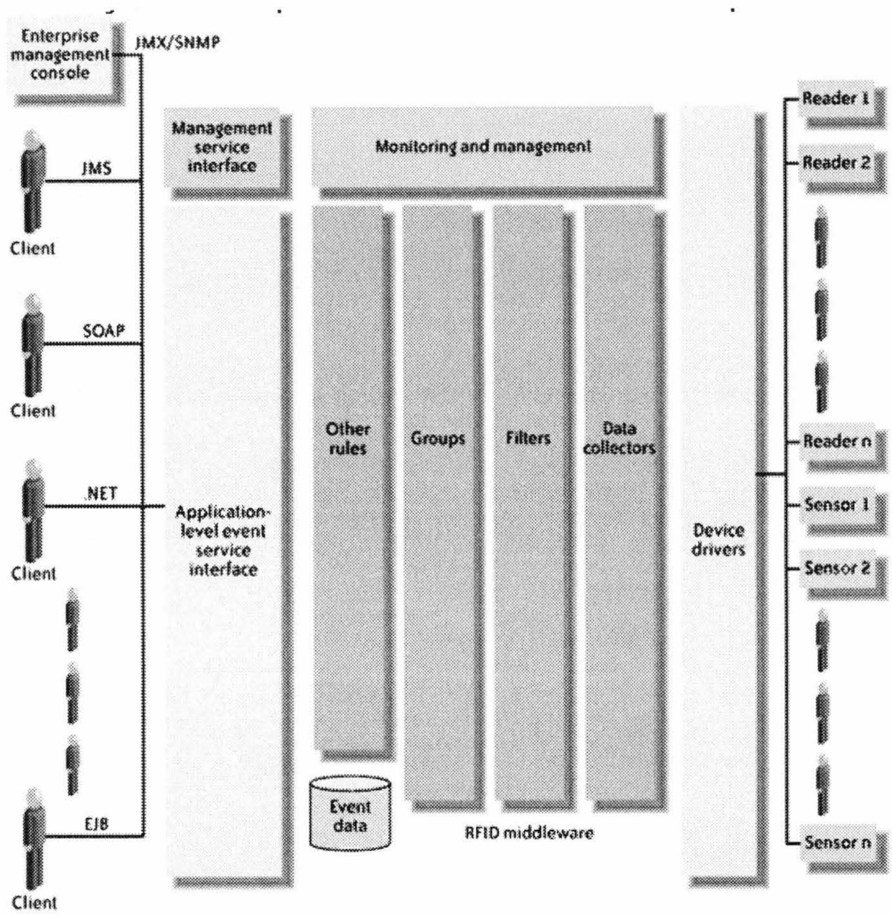


Figure 5 – Conceptual architecture for an RFID middleware product (Thornton et al. 2006)

Middleware acquires raw data from one or multiple sources in the physical world. In the next step, the data are transformed and filtered for the applications. As shown in **Figure 5**, the RFID middleware has many functions to manipulate data, such as monitoring and managing capability, data collection and filtering, and interfaces which provide services using multiple standards.

The raw data from the reader cannot be used directly by the applications. Before an application can use RFID data, it needs to be filtered by the middleware. 'Filtered' means that not all tags are needed by the applications, so some of them are discarded (Cheong & Kim 2005). The filtering aims to remove duplications and false readings from RFID observations, so that the data can be further interpreted by the applications (Bai, Wang &

Liu 2006). Due to the imperfect read rate of RFID, three kinds of undesired data are filtered by middleware:

- False negative readings: The tags are in the read range but not recognized by the reader. This can occur for two reasons: One is tag collisions that occur when tags are read simultaneously and the RF signals interfere with each other. This causes information to be destroyed. The second reason is that the signal from a tag is stopped by metal, absorbed by water or affected by other mediums.

- False positive readings: Unexpected signals are detected by the reader, which produces additional information. This is also known as noise, and can be caused by extra tags in the read range.

- Duplicate readings: Three reasons for duplicate reading have been identified: first, multiple tags within the read range are read more than once; second, multiple readers cover a common area, so tags in the overlapped spaces are detected by multiple readers; third, multiple tags, which are attached to the same items in order to reach a high quality read accuracy, produce duplicate readings (Bai, Wang & Liu 2006).

This filtering process provides precise data to be further interpreted in the applications. It makes the data valuable to the enterprise applications (Cheong & Kim 2005). However, the filter hides the evidence to detect a hollow pallet and the data it removes is essential in solving this problem. For example, since water absorbs the RF signals, the tag read rate of a pallet filled with bottled water should be low. If the read rate is found to be higher than usual, it suggests that there may be a hollow inside the pallet. Therefore, the method in this research is operating at the reader level, before the raw data is filtered by the middleware.

2.3.3 Advantages of RFID

There are many existing methods to identify objects, but these traditional technologies have obstacles to overcome. The bar code, which is probably the most familiar one, has the limitation of "Line of Sight", which means the object needs to face exactly the correct direction in front of a scanner, and anything located between the scanner and the code causes failed reads. ID card, such as credit card, needs to be swiped in the card reader in a particular direction. Biometrics, such as fingerprint recognition and facial scan, have more onerous limitations in alignment. Compared with traditional automatic identification technologies, RFID technology provides effective performance from a distance and has no further requirements in terms of the item alignment. The benefits of RFID have been summarized as following:

- No alignment requirements. "Line of Sight" is not necessary. Items do not need to be placed facing the scanner. Thus no labor assistance is needed in that process.
- High speed in acquiring information. The tags attached on multiple items can be read simultaneously.
- Variety of tag forms. The size of tags varies from as large as a box to as small as a grain of rice, which enables the technology to be used in a wide range of environments.
- Item-level tracking. Tag has large memory which allows for long identification codes and hence a large number of items.
- More information is supported. Compared with bar codes, more types of information beyond ID, such as manufacturer, product type and environmental factors, can be stored on the tags.
- Rewriteable: Certain types of tags can be written more than once. It has advantages when reusable containers are involved. However, when tracking and identifying items in retail area, this type of tags causes potential security issues, so write-once tags are still needed (Glover & Bhatt 2006).

In summary, RFID systems are comprised of three components: tags, readers and middleware. RFID technology has many advantages, such as supporting long distance and high speed readability. In this research, the hollow pallet problem will utilize these components. Tags will be attached to the cartons; the cartons will appear on the pallet. When the pallet is within range of a reader, the tags on the cartons and hence the pallet will be read. The produced information will be used to determine whether there is a hollow pallet. At the same time, there are limitations on the technology, and these limitations will need to be investigated if hollow pallets are to be identified using RFID systems.

2.4 Factors limiting RFID to solve the hollow pallet problem

RFID has many advantages compared with other identification techniques because it does not need the line-of-sight scan and can detect multiple tags simultaneously. However, RFID technology is not a mature technology and some issues have not been addressed. This section introduces the causes of failed tag reads and the factors that affect tag read rate.

2.4.1 Causes of failed tag read

In a multi-tag configuration, the problem of false negative reads occurs .False negative reads refers to the phenomenon that an existing tag is not detected by a reader. This problem can be due to multiple causes, including tag collision on the air interface, tag detuning and tag misalignment.

- Collision on the air interface

A passive RFID system is mainly used to identify the items which are expected to be detected by the reader simultaneously. A problem is caused by collisions in identifying multiple tags when they are presented in the read range of the reader. If tags transmit their signals in the same time slot, the reader cannot separate the information of one tag from that of another. Thus, the information sent by multiple tags is destroyed. This often happens in laundry services and warehouses (Vogt 2002).

In order to make the tags be detected successfully, multiple protocols have been introduced to avoid collisions. Vogt (2002) pointed out two methods to solve this problem. One approach is to mute the other tags in the collision. In other words, only one tag is allowed to send information at a time. After one tag has sent its message, it is disabled to resend and other tags will be activated to send their message by repeating this process. The other method is to give each tag a stochastic time slot. Since the communication is based on the shared medium, it is usual to assign each tag a different time slot based upon an Aloha-like protocol (Slotted Aloha). Only one tag can send the information to the reader in a specific time slot. Traditionally, three commands are used to control tag read by Slotted Aloha: REQUEST, SELECT, and READ. When REQUEST command is sent by a tag, the protocol provides the tag with one specific slot. This slot is randomly selected and a tag has to wait for this until it can send a response to the reader. After that, the tag broadcasts its ID. In a particular time slot, the reader sends SELECT command containing the correct tag ID. Only the tag with the correct ID is allowed to send its response. Then the reader issues the READ command to obtain the information from that tag. After the conversation is completed, the read sends another REQUEST command and repeats the previous steps to obtain the information of each tag (Glover & Bhatt 2006). **Figure 6** shows the state transition from the reader side.

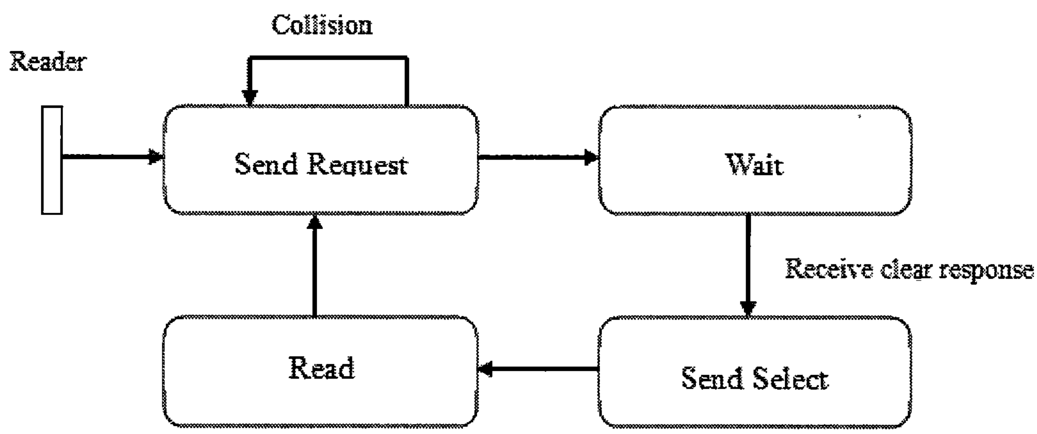


Figure 6 – Slotted Aloha protocol (Glover & Bhatt 2006)

For EPC Class 1 UHF tags, a more complicated approach, called an Adaptive Binary Tree procedure, is used to solve the collision problem. This approach uses two separate nodes, one is "1" and the other is "0", for each representing tag responses. In applying this protocol, the reader finds a tag by the bits in the tag's ID. For example, the reader first asks the tags whether their IDs start with "1". The tags answering "0" will be ignored, whereas other tags answering "1" will be asked a question about the next bit. Repeating this step forms a binary tree. The deeper the tree becomes, the fewer tags send the responses. This step keeps repeating until only one tag is left. This protocol is more complex than Slotted Aloha, but in most cases, it does not need to read the entire IDs of all tags, which means it is more efficient (Glover & Bhatt 2006).

- Tag detuning

Tag detuning refers to the fact that the tag read rate can be easily affected by detuning effects. In inductively couple RFID systems, a tag microchip is powered by the induced voltage in the antenna coil of the tag. A parallel resonance circuit is created by adding a capacitor in parallel to the antenna coil. The resonance frequency is adjusted to the frequency of the RFID system. Therefore, at resonance, tag read range is enlarged as the induced voltage increases (Floerkemeier & Lampe 2004).

However, the tag can easily be affected by environmental detuning effects, which significantly reduce read range. There are two kinds of factors causing tag detuning: nearby tags and materials, such as metal and dielectric mediums, present in the environment. These factors make tags receive weaker signals and produce a lower read rate. In an experiment, reported by Floerkemeier & Lampe (2004), 10 playing cards were configured in four different arrangements in front of an antenna: in a heap, spread out, stacked and held in a hand. **Figure 7** shows the read rate results of these four arrangements. Stacked arrangements produce low read rates, because each tag is detuned due to other tags close by, and tags held in a hand produce relatively low read rates, which is a result of the combination of the dielectric medium (hand) and tag detuning of other tags close by (Floerkemeier & Lampe 2004).

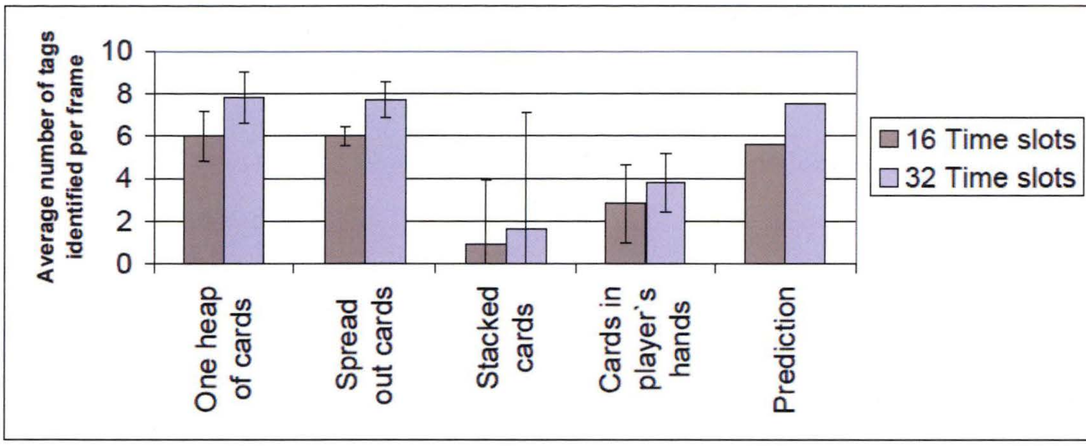


Figure 7 – Average number of tags identified per frame (Floerkemeier & Lampe 2004)

- Tag misalignment

The misalignment of the tags is an important factor which causes failed reads. In the magnetic field of the reader, tags receive the maximum power supply when the plane of the tag coil is vertical to the field lines. If the tag is rotated, the received energy becomes weak (Floerkemeier & Lampe 2004).

In summary, tag collision, detuning and misalignment are causes which lead to failed reads. Tag collision is the most important problem. The collision avoidance algorithms have been used to effectively address this problem. For EPC Class 1 UHF tags, Adaptive Binary Tree is used to solve collision problems. Tag detuning and misalignment also need to be noticed as they produce low read rate by changing the read range and weakening supplied energy to tags. Besides these causes, tag read rate is affected by multiple factors. These factors will be introduced in the next section.

2.4.2 Factors affecting tag read rate

Tag read rate is influenced by many factors. Tag position and the content of a carton were considered to be two of the most important factors (Jo, Lim & Zimmers 2007). Some factors can be controlled by setting values on a reader. Some other factors, such as the radio signals transmitted by mobile phones and mediums interfering with signals of tags, are hard to control. In this research, a Faraday cage will be used to build up an isolated experiment environment. A Faraday cage has a radio shield to prevent external factors from interfering with the tags and the reader inside it. Thus, the factors can be controlled. The influences of other factors are excluded and the effect of individual factors inside the Faraday cage can be evaluated. Faraday cages will be introduced in the next section.

The following factors will be evaluated in the experiment:

- Tag position: This refers to the location and orientation of a tag on an item. The tag can be put either in a horizontal orientation or in a vertical orientation. In previous research done by Singh et al. (2007), RF performances based on three different products were tested to find the optimal tag position: bottled water, paper towels and carbonated beverages. For the case of bottled water or paper towels, in order to achieve an accurate read rate, the most appropriate tag position was on the front of the package in a vertical orientation. and for carbonated beverages, the best location was on the front of the package in a horizontal orientation (Singh, J et al. 2007).

- Content of cartons: when identifying and tracking tags in transporting pallets, RF signals are affected by the contents of the cartons on the pallet. Especially, low read rate is produced when a carton has a high water content product, such as fruit or fish, because water absorbs RF signals (Myerson 2007, p. 42).

- Distance between an RFID reader and tags: The distance between an RFID reader and tags determines whether or not tags can be detected by the reader. In order to achieve sufficient read rate, tags should be placed within the read rage of the reader. Otherwise, tag read rate will decrease because the tags cannot receive enough power supply. **Figure 8** shows the read rate based on an experiment completed by Buettner & Wetherall (2008). According to this figure, only a few tags are missing at two feet; however, the read rate drops off when the distance increases.

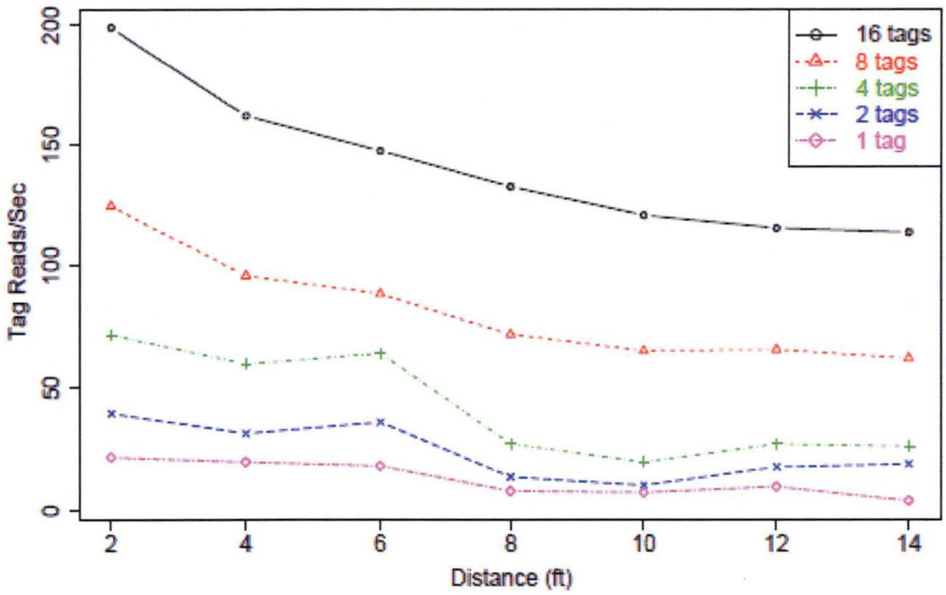


Figure 8 – Tag read rate when distance increases (Buettner & Wetherall 2008)

- Acquire Mode: It refers to protocols under which the reader reads the responses from the tags. For the Alien Reader, which will be used in this research, there are two alternative acquire modes: *global scroll* and *inventory*. The reader searches for information from the nearest tags quickly when the acquire mode is set to *global scroll*, while it looks for all tags within the reader's read range when the mode is set to *inventory* (D'Mello et al. 2007). Fundamentally, the difference between these two modes is that inventory mode enables collision avoidance while global scroll mode does not.

- Attenuation: With Radio Frequency, attenuation refers to the amplitude reduction of an RF signal. It occurs if the signal is absorbed or dispersed when traveling from the sender to the receiver (Sanghera et al. 2007, p. 44). The value of attenuation is the reduction in the reader's transmitting power. Attenuation is the basic factor in evaluating read performance when water is the content of the cartons (Ramakrishnan & Deavours 2006). The reason is that water is remarkably good at absorbing RF radiation, so the tag read rate can be influenced significantly by the content (Kitsos & Zhang 2008, p. 119).

- Persist time: Persist time determines the amount of time a tag stays in reader's memory after it is detected by the reader (*Reader Interface Guide All Fixed Readers* 2008). If persist time is set to a low value, for example, the default value which is "1", the reader memory contains only a small amount of tags information from those which were read a short time ago. When the value is set to "0", the information of detected tags will not be stored in the readers' memory at all.

In summary, tag position and content of carton were considered to be significantly important in previous research. They affect RF signal strength and influence tag read rate. Factors, such as acquire mode, attenuation and persist time, have effects in determining and recording tag read rate. These factors are worthwhile to be evaluated in the experiment of this research. When a carton contains high water content products, any RF signal passing through it, is absorbed by the water and the signal becomes weak. This has negative effects in detecting all the tags on a pallet. However, it can be used to detect whether or not some cartons on a pallet are empty, because the interference will be reduced if some high water content products are missing. The next section will introduce other factors which limit tag read rate.

2.4.3 Other factors

Usually other factors, which influence a tags ability to identify itself, exist in the environment in which the read process occurs. The read rate of RFID tags is also influenced by other factors in the environment, such as metal, building structure and other equipment which uses radio frequency. According to Schuster, Allen & Brock (2007), the communication between tags and readers is processed in radio frequency fields which are invisible. Therefore, the read performance is hard to evaluate as it is difficult to determine the electromagnetic properties. Presence of mediums, such as metal, in the tag vicinity leads to failed reads, because the mediums reduce the energy supplied to the tags by changing the magnetic flux. If tags are attached to the surface of a metal, they cannot be detected at all. These mediums can detune the antenna when placed close to the reader, which leads to reduction of the read range. In experiments, read range of a reader was found to decrease significantly when the reader was placed on a metal frame table (Floerkemeier & Lampe 2004).

Errors in manufacturing and usage cause failure in detecting tags as well. According to Elisabeth (2006), a number of tags have been damaged during usage. Reader malfunction is also a factor which causes the read failure. As it is difficult to predict and avoid the malfunction, an alternative reading method is important if an accident occurs. Furthermore, other electronic devices may interfere with the read procedure. A survey based on a hospital in Taiwan presented that equipment which also uses radio frequency caused tag read failure (Wang et al. 2006). Radio waves may also be influenced by the layout and materials of the building. Finally, besides the technique issues, some users resist implementation of the RFID technology and giving training to them is important when an RFID system will be implemented in a company or institution.

In summary, tag read rate faces potential challenges from various causes and factors. The main causes include collision, tag alignment and the content of the carton. Attenuation, distance, acquire mode and product content are factors which need to be identified in implementation of RFID. A high water content product causes significant low read rate, as water absorbs RF signals. Furthermore, other factors such as surrounding media also need to be considered. Since there are many factors interfering with the read rate, it is essential to control these factors in order to evaluate the effect of each individual factor. The next section will discuss Faraday cages, which will be used to control some of the environmental factors in this research.

2.5 Faraday Cages

A Faraday cage is an isolated environment which is enclosed by electronically conducting shields (Hashemi 2009). A conducting shield can effectively stop RF signals from passing through it. Therefore, RF signals inside a Faraday cage cannot leave the enclosed space, and signals outside the Faraday cage cannot enter it, as shown in **Figure 9**. It ensures that RF signals are sent and received in a clean space, without being interfered with by external noise. In one report, a thin layer of metal within paper was used to make a Faraday cage (Xiao & Pan 2007, p. 158). In the real world, Faraday cages have been embedded in items which need to be tracked or identified with the use of RFID. For example, a Faraday cage works perfectly when it is used in a wallet in which multiple tags in credit cards and other identification need to be protected. However, location is a limitation for Faraday cages. They do not work well when a tag in integrated in a watch, or somewhere a faraday cage is hard to construct.

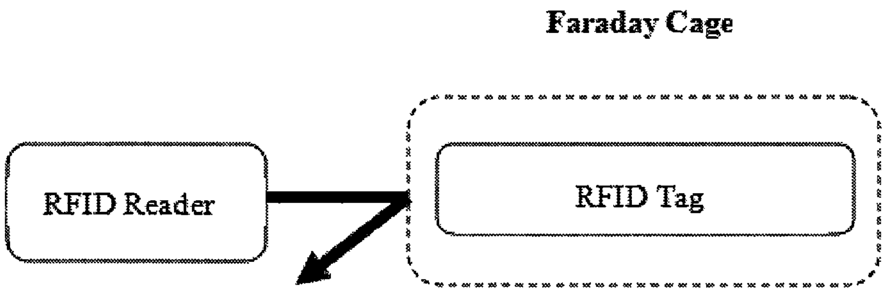


Figure 9 – RF signals are blocked by a Faraday cage (Xiao & Pan 2007)

In a laboratory environment, aluminum foil is an effective material for stopping signals. Hashemi (2009) did a test with the help of a Faraday cage which was made of cardboard boxes covered with aluminum foil. The RF signal was sent by an oscillator outside the cage and received by an RF spectrometer inside it. When the distance between sender (the oscillator) and receiver (the spectrometer) was 5 meters, the foil box gave 28 dB attenuation, which meant that aluminum foil significantly reduced the RF signal in this case. In this research, layers of aluminum foil will be used as the material to build up a Faraday cage.

Overall, a Faraday cage is an isolated environment with radio shields which RF signals cannot penetrate through. By using a Faraday cage, factors in the environment that influence tag read rate can be controlled. Aluminum foil has been proved to be effective in stopping RF signals in previous research. This material will be used to build up a Faraday cage in this research. This research simulates a tagging scenario in the supply chain and focused on item level tagging. In the real world, items are packaged in cases which are stacked on a pallet. In the tracking procedure, tags can be attached to each individual item, case or the pallet. The next section will discuss the pallet configuration and item level tagging.

2.6 Pallet Configuration and Item Level

2.6.1 RFID Tagging levels on a pallet

RFID tagging occurs at three levels: pallet level, case level and item level, as shown in **Figure 10**. Pallet-level tagging is wildly used in the supply chain. In pallet-level tagging, a tag which contains purchase order information is affixed to a pallet before it is shipped. When the pallet arrives at the shipment destination, information stored in the tag can be read (Jung, Chen & Jeong 2007, pp. 31-32). This helps to make the supply chain become more productive and brings clear economic profits (Vickery 2006, p. 249). In case-level tagging, tags are attached to cases. Compared with pallet-level tagging, case-level tagging achieves more detail tracking, including clearer inventory visibility. In addition, it can count cases automatically so as to save labor cost (Jung, Chen & Jeong 2007, pp. 31-32). Finally, item-level tagging has been used to track retail goods (Vickery 2006). In item-level tagging, tags are affixed to either the product box or the item itself. This tagging level achieves the highest visibility (Jung, Chen & Jeong 2007, pp. 31-32).

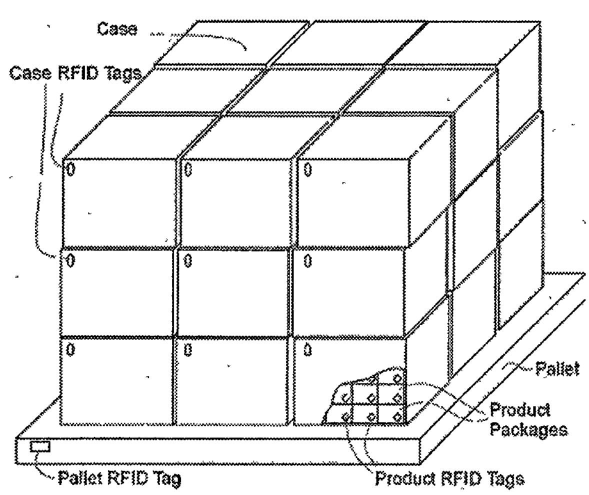


Figure 10 – Three levels of tags on items, cases and the pallet (Lindsay & Reade 2003)

Item-level tagging is expected to produce potential profit for the retailer (Gaukler, Seifert & Hausman 2007). It has been widely used and more companies are planning to use it. This research focuses on item-level tagging. However, although item-level tagging has been used identify items, it has not been considered to identify the contents of the items on a pallet. There are some problems influencing tag read rate at item level, as mentioned in previous sections. When tags are placed on the item level, in this case on the cartons, the problems affecting tag read rate are exacerbated. It is therefore important to solve these limitations at the item level in order for organizations to introduce RFID into their applications. The following part introduces the examples of item-level tagging used in the real world.

2.6.2 Item-level Tagging in the Real World

Item-level tagging has been widely spread in the logistic and retail area. Most companies use UHF passive tags to track the items, because of their low cost and small size. EPC Global tested different frequency bands in seven item-level tagging scenarios and tried to find which frequency band is appropriate for tagging items. Based on this test, they found that if the read time is too short, the antenna cannot obtain enough energy from the reader and if tags are allocated too close together, potential issues may arise. Furthermore, they found that no one frequency can work in all situations (O'Connor 2006).

Dillard's Gear tried passive UHF Generation 2 EPC (EPC Gen2) tags on 50 items in August 2008, to compare the performance of RFID and traditional bar-code technology. It was proved that RFID could help the company to save cost by decreasing shrinkage, reducing labor, and improving sales (O'Connor 2007a).

Falabella, a department store, used EPC Gen 2 to test 2000 tagged items at the point of manufacture. The whole process comprised shipments, passing the items to the sales floor, generating a daily inventory and measuring the shrinkage. It also attached a mobile reader to a cart and used it to record the daily inventory. The antennas were fixed to maximize the reader's read range. The staff removed the tags from the items after they were purchased so as to determine how many tagged items were lost. According to the test, the accuracy reached 98.4% (O'Connor 2007b).

Furthermore, An RFID-based system has been developed by Global Technology Resources (GTR), to track food, such as fish and vegetables. GTR also considered developing the RFID readers and tags to facilitate this system. According to GTS, this RFID-based system was expected to track and identify the food by real time monitoring during transporting processes. If some products are found to be tainted in the supply chain, information on both the origin and the destination will be retrieved automatically, in order to identify these products (Collins 2003)

Overall, the ability of an approach to detect hollow pallets will need to consider the tradeoffs between usability and technical limitations of RFID. If hollow pallets are to be detected, it will be important to know how these factors will limit its feasibility in the real world. The following section will discuss previous research exploring the influence of factors on tag read rate.

2.7 Previous Work

Previous research tested the tag read rate by a variety of factors, such as tag orientation and carton content. Clarke et al. (2006) used read rate to RFID efficiency based on different products and tag orientations. If the tags are placed outward on the boxes, only the center tags are not directed to the antenna; if the tags are inward or downward and none faces the antenna in a direct line, only a few tags are detected. The boxes also have different contents inside, such as rice, water or nothing. Clarke et al. (2006) found that the cases with water-filled bottles only have 25.02% read rate while the empty box can reach almost 100%. In addition, tag orientation has more significant interference on rice and water cases than empty cases. Tags which are put outward can reach 100% read rate for empty cases, but almost no tag can be read when it is put inwards or downwards with the water-filled bottles.

Furthermore, another experiment was done for observing the readability based on different carton content. These items include paper product, powder, liquid and metal. Twenty seven items were put on the pallet in three columns with nine in each column, and all the tags were attached on the exposed sides, as shown in **Figure 11**. The pallet was moving on a conveyor belt in front of the reader at two speed rates, 0.625 mph and 5 mph(Singh, SP et al. 2008).

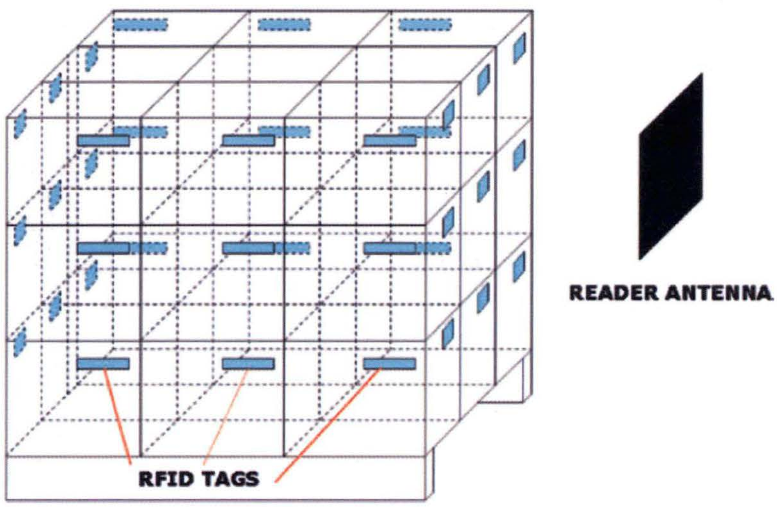


Figure 11 – Tags and reader orientation (Singh, SP et al. 2008)

The conclusions of this experiment are drawn based on the results as follows:

- Product content is most important factor. When the results were analysed, paper product was found to contribute the best read rate, especially as it was almost 100% under the moving speed of 0.625 mph. The cases with liquid product, and powdered product in aluminium foil wrapped cartons had low read rates.
- Distance between the tags and the reader has influence on the readability. The tags which were close to the reader or placed at the same height as the reader were detected better.
- High speed produces weak readability. In the case of paper, the read rate reached 100% at 0.635 mph but only 20% at 5 mph.

This detecting system does not handle the situation in which the cartons contain more than one kind of product inside (Singh, SP et al. 2008).

Furthermore, some important results of detecting the tag read rate based on fresh fruits were published by McCartney (2005) and Singh et al. (2008):

- Metal has a critical effect on read rate.
- Products with high percentages of water have low read rates.
- Speed of transporting during detecting processes has a critical effect.

Some additional factors which were considered to affect the final read rate were identified (McCartney 2005). Especially, external electromagnetic fields and the orientation of tags influence the read rate. The former usually occurs because of signals that are transmitted by electronic devices such as mobile phones, and the latter indicates that the tags have better readability when put close to the reader or face outward.

In summary, previous research identified the factors which have influence on the readability. These factors, such as pallet moving speed, tag position, material of the carton content and distance between tags and readers, play critical roles in the final results. Therefore, it is important to use a Faraday cage to prevent external interference and deal with the other factors in order to get a reliable read rate in the experiment.

2.8 Summary

Hollow pallets are a problem of transport in the warehouse. Many companies have implemented RFID system to identify items. It can help to speed inventory process, decrease item shrinkage and save cost. An RFID system consists of three components which are tags, readers and middleware. However, RFID is imperfect as it cannot reach 100% read rate.

In passive RFID, antennas integrated with the reader provide power to the tag, and the tag sends back the information stored in it back to the reader. The information is retrieved by the middleware and then analyzed and recorded by applications on PC. However, the content of the carton which is attached with the tag affects the signal strength. This may cause low tag read rate, but it can help to detect whether or not the content is missing or not by observing the data, because the read rate produced from a hollow pallet is supposed to be better than the full pallet. Before investigating this problem, factors which influence tag read rate need to be evaluated. Low read rate is caused by tag collision, tags alignment and detuning, and factors such as product content, attenuation, acquire mode and distance. Also building structure and other equipment can affect this. This research will focus on item-level tagging, at which each carton is attached with a tag, to solve the hollow pallet problem. It will also illustrate the practical constraints, such as how the intervening media the signal must travel through can affect whether or not a tag can be read. Similarly, this research will examine the problems associated with reading tags placed on individual cartons stacked on a pallet. It is a new area as RFID data has been used for identifying items, but not used to detect whether the item contents are there. The next chapter will present the experiment methods in this research.

3. Methodology

3.1 Introduction

The aim of this research is to determine whether there is a hollow pallet by using Radio Frequency Identification (RFID). Before determining a method with which to prove the hypothesis above, the requirements should be specified clearly. The experiment consisted of three phases. Each phase tested different factors in order to find the unimportant factors which were not tested in the next phases, and the optimal values for the important factors. In testing individual factors, only the factor which was evaluated varied while the values of other factors were kept constant. This helped to observe the influence of each individual factor on the final results in the testing period. Otherwise, it would be difficult to tell whether increasing one factor's value made the read rate better or not, as other factors might influence the results. In this chapter, the first section will introduce the experiment environment including hardware and software. Following that, the proposed evaluation factors in each phase of the experiments will be discussed. Finally, the methods used to ensure the validity of the experiment results will be described.

3.2 Environment and System Architecture

The equipment in the experiment was provided by the School of Computing in the University of Tasmania. It included of bottles attached with tags (a pallet), a reader and a PC. Fundamentally, there were four processes in each replication of the experiment. The PC was a terminal controller which set the values of factors and sent the commands to the reader. According to the transmitted values, the reader sent signals to the tags on the pallet and received the response information from the tags. Following that, the application on the PC retrieved the data from the reader and saved them into logs. Finally, values of factors were altered on the computer and the next replication could start.

3.2.1 Experiment Environment

In order to control the factors in the experiment environment, the reader and the pallet were put inside a Faraday cage which was constructed by the author. A Faraday cage is a container which is usually made of metal mesh or foil. Because RF signals cannot pass through the Faraday cage, the signals transmitted between the reader and the tags inside are isolated (Juels, Rivest & Szydlo 2003). Therefore, the results retrieved by the PC were not interfered with by external radio devices, such as laptops, mobile phones and other tags. The Faraday cage in this research was made of three layers of foil, which was proved to provide an effective radio shield in the preparation of the experiment. Before each test, only the reader will be placed in the faraday cage so as to test whether there are extra tags in the experiment environment. If no tag is detected, it indicates that the space is clean, and the following tests can be started. The following subsections will introduce the facilities used in the laboratory environment.

3.2.1.1RFID Reader

An Alien 9650 Gen2 RFID reader with integrated Antenna (ALR- 9650), which is the product of Alien Technology Corporation, was used for this research. The ALR-9650 supports EPC Gen2 RFID tags and can be connected to a computer using RS-232 or LAN TCP/IP interconnection. In addition, it provides an extra antenna port to support 2-antena applications. Java libraries are provided as well, in order to control the reader by customized development (*Product Overview* 2007).

3.2.1.2 RFID Tags

The 32 tags used in this research were ALN-9640 Squiggle. They were UHF, passive and EPC global Class 1 Gen 2 tags, with a 512-bit memory.

The tags were attached to bottled water in this experiment, as shown in **Figure 12**. Tag read rate is slightly better when the tag is vertically attached to the bottle. However, because of the size of the Faraday cage used in this experiment, the bottles were horizontally placed. The initial aim of this research was to investigate the hollow pallet problem in transporting fish. In the laboratory environment, some substitutes were used instead of real fish as a simulation. Fundamentally, the main component of fish is water. According to Gardiner & Geddes (1980), generally the water content of fish is 84.7% but the percentage varied in different seasons. For example, it reduced to 77.6% in late September and increased to 80.7% in early April. Based on this result, bottled water was used in this experiment instead of real fish.

Figure 12 – A bottle attached with a tag used in the experiment

3.2.1.3 RFID Applications

Alien provides packages so users are enabled to set up a reader's parameter values. In this research, the application project developed with the packages was already written by Mirowski (Advisor of this thesis) and this was used. The project was run on Eclipse 3.4. It had the following main functionalities:

- Setting up or changing the values of the parameters, such as protocol type, attenuation and persist time, on the reader;
- Printing out the result of each individual replication and the average value of the replications;
- Saving the results, both individual and average values, into the log folder.

3.2.2 Experiment Structure

The overall experiment system is a local network which consists of three components: a PC, a reader and tags attached to the pallet. The reader and the pallet with tags were placed inside the Faraday Cage that was made of foil so as to avoid external interference. The experiment process is described as following:

- Preparation: The reader was fixed in the Faraday Cage. The pallet was configured and also put into the Faraday Cage. The values of parameters were set up via PC.

- Obtaining data: When the project started on Eclipse, the reader sent the signal according to the parameter values to the tags. Tags sent back data including their IDs to the reader. Then the reader transferred the received data to PC;

- Recording: Programs on PC collected the data of each replication from the reader and calculated the results, such as the number of cycles, the number of unique tags and the number of all detected tags based on the information of each tag. The programs also averaged the values and saved all the records into a log folder.

It is necessary to ensure that there are no extra tags detected during the preparation step. In other words, the system should be kept in a "clean" environment. Further data analysis was undertaken in Microsoft Excel and diagrams were drawn to observe the results.

3.3 Experiment Methods

There are multiple factors influencing the results in the experiment. These factors exist in both internal environments, such as parameters of RFID reader, and external environments, such as other electronic devices. Since the Faraday cage has the ability to isolate the experiment from the interference of other external factors, only internal factors were considered. This section introduces the test methods in this experiment.

3.3.1 Three Phases

In order to evaluate the hypothesis, the experiment was done in three phases. Each phase evaluated different factors and influenced the next phase. Phase One was to determine which of the evaluated factors were important, and whether the system worked effectively. The results of Phase One determined the values of the evaluated factors in Phase Two. Phase Two was to determine whether the hollow pallet can be detected. Phase Three improved the test method of Phase Two to achieve a more accurate result. Based on the results of previous phase, some factors were kept as constant, optimal values in the following phases. In addition, some factors were found unimportant in solving this problem, so they were not tested in the following phases.

The factors which were tested in each phase are introduced as following:

Phase One: The distance between the reader and tags on the pallet, acquire mode and content of cartons were tested in this phase. Testing the content of cartons in this phase helps preliminary determination of whether this system can tell the difference between an empty pallet and a full pallet.

In this phase, the testing was undertaken by the following method:

1. Structure of the pallet: The pallet consisted of 30 boxes facing 1 reader. One tag was attached to each box. The structure of the pallet was 5 boxes per column by 6 columns. All the tags were horizontal and facing toward the reader. The size of the pallet was 40.6cm*15.2cm*13.2cm. The size of each box is 6.5cm*15.2cm*2.7cm.

2. Distance between the RFID reader and the pallet was progressively changed from 50 cm to 200 cm using 25 cm intervals.

3. Acquire mode, attenuation and run length: Both global scroll and inventory were tested. The RF attenuation was equal to 0 dB and the run time was 30 seconds.

4. Empty, full and hollow pallets were tested. In the hollow pallet, two pen boxes were empty, and the full boxes were filled with 12 plastic pens.

5. Each test was replicated five times and the value was averaged.

6. These data were input into Microsoft Excel and a diagram was generated in it so as to determine if the hollow pallet could be detected.

Distance between the reader and tags on the pallet was evaluated in this phase. It was important because it determined from how far away a tag can be detected. In this phase, distance between the RFID reader and pallet was progressively from 50 cm to 200 cm using 25 cm intervals. By increasing the distance, the number of detected tags was reduced, which indicated that distance from the reader was an important factor in determining the potential percentage of tags that can be detected. By keeping the distance from the reader constant, tag readability can be set at an optimal value and hence the influence of distance as a variable factor removed. Therefore, the question was to find a proper distance to optimize tag readability.

Changing the value of distance was equivalent to changing the attenuation (Ramakrishnan & Deavours 2006). An experiment, done by Ramakrishnan & Deavours (2006), evaluated the influence of distance in detecting UHF tags, by measuring the *response rate*, which refers to the number of successful reads in each attempt. As shown in **Figure 13**, the response rate reaches almost 100 % when the distance varies between 2.9 feet and 11.7 feet. This region is called 'strong-in-field', but it decreases dramatically when the distance increases and no tag can be detected when the distance is between 18.5 feet and 29.3 feet. The X-axis in the figure shows the attenuations value which are equivalent to the effect of the distance values at the top of this figure. In the laboratory environment of this research, the distance between the reader and the pallet was set to 20 cm, which, as shown in the Results chapter, can guarantee a reliable tag response rate (Section 6.1).

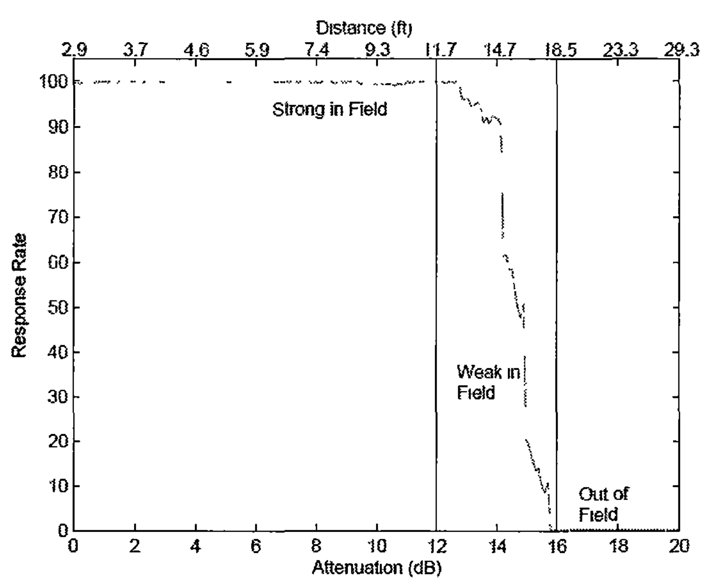


Figure 13 – Tag response rate versus distance between readers and tags (Ramakrishnan & Deavours 2006)

Acquire Mode, which controls whether collision avoidance is enabled, determines the protocol within which the reader reads the signals from the tags. In Phase One, when acquire mode was set to global scroll, which disabled collision avoidance algorithms, the numbers of detected tags in the different pallet situation (empty, full and partially full) were almost the same. Whereas, then acquire mode was set to inventory, which enabled collision avoidance algorithms, there were significant difference in the empty pallet situation and the full pallet situation. This result indicated that global scroll protocol was unimportant in influencing the results, whereas inventory protocol produced significant difference. Therefore, acquire mode was set to inventory in the following phases.

The contents of the cartons in Phase One were plastic pens. Three situations, such as empty pen boxes, full pen boxes, and partially full boxes (1 box was empty), were tested to find whether there was significant difference to detect the hollow pallet problem.

Phase Two: This was a formal experiment to determine whether the hollow pallet could be detected with the use of bottled water. Tests in Phase Two were based on different factors such as attenuation and persist time, because the factors tested in Phase One were set to constant values. From the experience of Phase One, the results of Phase Two were expected to be clarified in a graph. In the graph, three lines, which represent the full pallet, empty pallet and hollow pallet, were expected to be clearly distinguishable, and the line representing hollow pallet was expected to be located between the other two lines. If this assumption was finally proved to be correct, then the hollow pallet could be detected in this system.

In this phase, the testing was undertaken using the following method:

1. Structure of the pallet: Bottled water was used as the content on a pallet. The number of bottles was doubled each time, from 1, 2, 4, 8, and 16 to 32.

2. Attenuation and persist time: attenuation was set to two values: the high value was 120 dB, which produced weak RF signals, and the low value was 0 dB, which produced strong RF signals. The persist time was set to 0 seconds and 30 seconds.

3. When testing the hollow pallet of this phase, the number of empty bottles was kept at 1 while the size of the pallet increased.

4. Average number of running cycles, unique tags and all detected tags were calculated by the program and then recorded.

Attenuation is the reduction in the reader's transmitting power. When attenuation is high, the signal becomes weak. In this phase, the difference between the full pallet and the partially full pallet was hard to tell when attenuation was set to 0 dB, whereas the difference was easy to find when attenuation was set to 120 dB. This result indicated that high value attenuation (a weak signal) was more useful in detecting a hollow pallet problem.

Persist time is the duration between the time a tag was last read and the time it was removed from the reader memory. A low value of persist time indicates that the reader only contains the tags it detected recently, whereas a high value, for example, 3600 seconds indicates that the tag list in the reader contains all the tags being detected in the last hour. In this phase, persist time was found to be an unimportant factor. Changing the value from 0 seconds to 30 seconds did not have a significant variation in the final results.

Phase Three: This phase extended from Phase Two. The difference was that in Phase Three, the size of pallet was kept constant while the number of empty bottles increased. In other words, the results of this phase were based on increasing the percentage of the hollow in a pallet instead of increasing the total number of bottles. In addition, in this phase, the position of each individual bottle remained the same in each replication, and the tag ID number was recorded. Therefore, after the results were analyzed in Microsoft Excel, not only could the hollow pallet be detected, but also the positions of the hollow were expected to be found.

In this phase, the testing was undertaken by the following method:

1. Size of the pallet: the number of bottles was kept constant at 20. The bottles were placed into two sides with 10 bottles on each side.

2. The number of empty bottles increased while the size of pallet did not change.

3. Attenuation and persist time were tested as factors in this phase. Attenuation was set to 0 dB and 120 dB, and persist time was set to 0 seconds and 30 seconds.

5. Average number of running cycles, unique tags and all detected tags were calculated by the program.

In summary, the above factors were considered throughout the experiment. Although these factors had their individual contributions to the experiment results, some were set to constant values in order to achieve accurate results, and some were found to be unimportant. After analyzing the results of Phase One, distance and acquire mode were set to constant values, and the system was proved to work effectively. In Phase Two, attenuation was considered as the factors influencing the final results, and persist time was unimportant. In Phase Three, the method of configuring the pallet was optimized to detect the hollow pallet.

Besides these factors in the three phases, there were other methods in testing need to be considered. This research used statistical tools to determine the number of replications and the 2^k factorial design method to test the influences of factors.

3.3.2 The Number of Replications

Replication refers to repeating the tests. The aim of replication is to ensure that sufficient output data have been obtained to achieve a high accuracy when evaluating the system performance (Robinson 2004, p. 151). In addition, by replicating the test a number of times, the errors which exist among the average results could be reduced. Moreover, it is useful in estimating the error variance, which would be reduced in a stochastic experiment. For these reasons, repeating the experiment has benefits in optimizing the precision of the results (Hoshmand 2006).

In this research, it was important to determine a replication number because the experiment needed to be large enough to ensure that the difference between the results was significant to distinguish the hollow pallet. In Phase One, the number of replications was set to five as it was a magic number used in a previous experiment design (Gomez 1984). In order to achieve optimized and more accurate average results, the number of replications was determined based on a statistic tool known as the confidence interval method in Phase Two and Phase Three.

A confidence interval is a means for evaluating the accuracy of the average value in simulation (Robinson 2004). It indicates that the narrower the interval is, the more accurate the result. A common method to get a narrow interval involves more sample data in input. If the confidence is too large, tests should be further replicated until the size is satisfactory (Banks 1998).

The confidence interval is calculated using the following formula:

$$CI = \bar{X} \pm t_{n-1,\alpha/2} \frac{S}{\sqrt{n}}$$

Where: $\bar{X}$ is the mean value calculated from all the replications ($\bar{X} = \frac{X_1 + X_2 + \ldots + X_n}{n}$);

S is standard deviation from all the replications ($S = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{n-1}}$, X_i is the value in replication i)

n is the replication number

$t_{n-1,\alpha/2}$ is from Students' t-distribution, n-1 is the freedom degree and $\alpha/2$ is the significance level

The most common significance level is 5%. It provides 95% probability that the correct value distributes within the confidence interval. On the other hand, the probability that the true value does not distribute in the confidence interval is 5%. As the confidence interval has an upper limit and a lower limit, the significance level is divided by 2. So in this case, 2.5% is used in the formula (Robinson 2004).

Previous work for 20 replications from a user help desk with 95% confidence interval has benefits in determining the number of replications in this research.

Table 2 shows part of the results, from replicating four times to eleven times. From the table, the number of replications can be selected based on the acceptable deviation value. Because 5% is required in this experiment, so from the table, the number of replications should be set to at least six. In addition, in order to get reliable average results, not only is the narrow confidence interval essential, but also the cumulative mean line should be flat enough. **Figure 14** shows the plot of cumulative mean for this example. When the number is larger than eight, it brings both a reasonable narrow confidence interval and a flat cumulative line (Robinson 2004). Therefore, tests will be replicated 10 times, which is a sufficient number, in Phase Two and Phase Three.

	95% Confidence Interval		
Replication	Lower interval	Upper interval	% deviation
4	2166.58	2549.79	8.13%
5	2219.84	2481.95	5.57%
6	2224.98	2442.19	4.65%
7	2252.87	2458.91	4.37%
8	2273.92	2448.02	3.69%
9	2259.32	2428.48	3.61%
10	2277.18	2447.91	3.61%
11	2286.15	2438.27	3.22%

Table 2 – Confidence interval results from 4 replications to 11 replications (Robinson 2004)

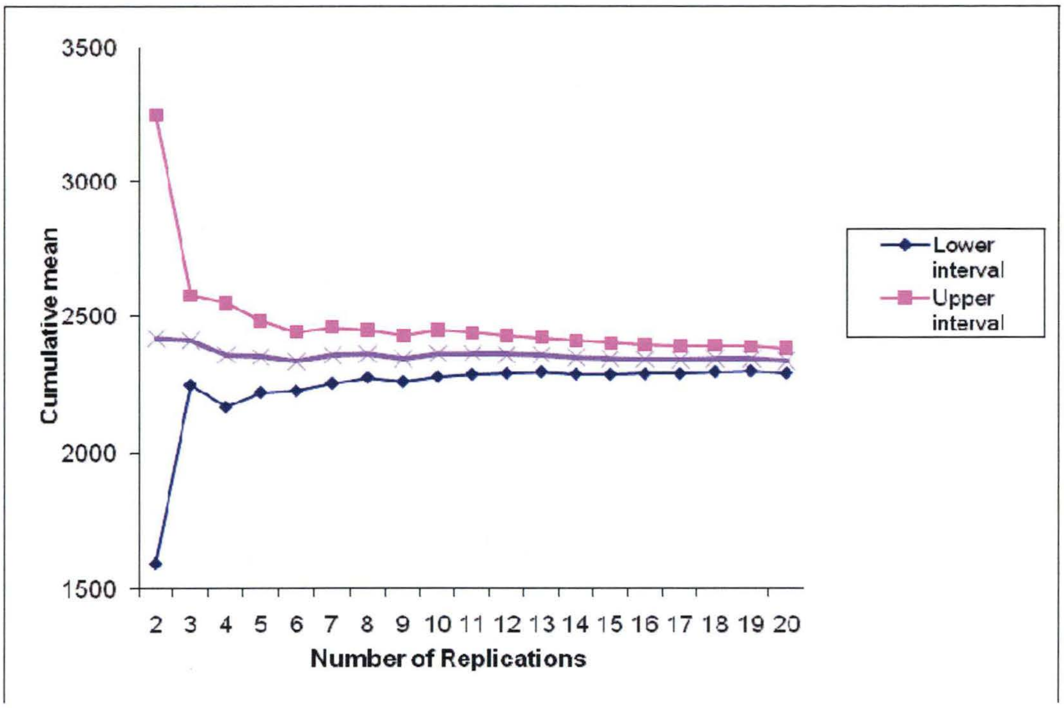


Figure 14 – Plot of cumulative mean for 95% confidence interval (Robinson 2004)

After the 10 replications, the results were analyzed to obtain the moving averages. This helped to determine whether the output data were smooth. In calculating the moving averages, the initial window size is set to 5 (Robinson 2004). If the results are not smooth, the number of replications will increase to get more accurate output data. In this research, the output data had no significant variance, because they were tested in a clean experiment environment (the Faraday cage) within which the factors were controlled. According to this, the results from the 10 replications can be simply averaged.

3.3.3 The 2^k Factorial Design

Traditionally, experiments used sensitivity analysis to investigate whether a response was apportioned to different factors (Santner, Williams & Notz 2003). In computing, "response" refers to the output and "factor" refers to the input. In other words, sensitivity analysis is to observe the degree of the output change when the inputs are changed. Specifically, sensitivity analysis provides methods to identify which factors have dominant influence on the output variation and which factors produce limited effects.

However, in this research, a less complicated design method, 2^k factorial design was used. Experiments based on the 2^k factorial design have simplified statistical analysis (Kumar 2006).

The simplest example in 2^k design is 2^2. In this case, if there are two factors, such as A and B, and each factor has two values, which are assumed as low value and high value, an experiment based on these two factors consists of four runs in the design, as shows in **Figure 15.**

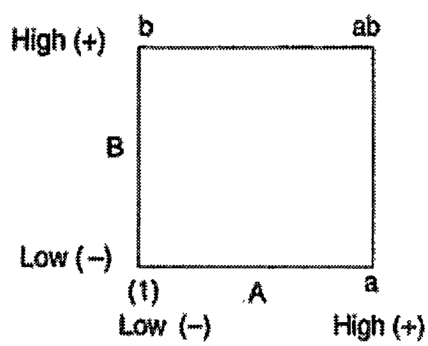


Figure 15 – A 2^k factorial design example when k is 2

In this figure, the lower case letters represent the high values of each factor. For example, a represents the high value of factor A, b represents the high value of factor B and 1 represents the low value of each factor.

The 2^k factorial design is a greatly simplified method, with only two variable values, high and low, in each factor. In this research, a linear relationship between the values of the factors (high and low) was expected to be found, instead between the degree changes in output caused by input. Therefore, the 2^k factorial design was selected instead of the sensitivity analysis.

3.4 Summary

This experiment used an Alien 9650 Gen2 RFID reader and UHF tags attached to bottled water to evaluate the performance of the system detecting hollow pallets. In order to conduct the evaluation, the experiment was divided into three phases. Phase One was a trial with pen boxes. Phase Two was a formal experiment. Phase Three extended from Phase Two but the method was improved. Each phase evaluated different factors to determine whether they were important. The important factors were set to constant values that can achieve a high read rate in the next phases. For achieving accurate results, the interference of noises should be excluded and the effects of individual factors should be distinguished. To this end, a Faraday cage, which was made of Aluminum foil, was used so the factors evaluated in the three phases were controlled.

This experiment used the 2^k factorial design because a linear relationship between the values of the factors was considered in this research. There was no necessity to use the sensitivity analysis as the degree changes in output data were not expected. Confidence interval, a statistical tool, was used to determine the number of replications. The number of 10 was proved to be a remarkably sufficient number to guarantee an accurate output data. The results from the 10 replications were found to have no significant variance, so they were simply averaged. The average results were put into the figures which are discussed in the next chapter.

4. Results

This chapter examines the results from the three phases above. Linear graphs are produced to determine whether the hollow pallet can be detected, based on the average number of detected tags in this experiment system.

4.1 Phase One Results

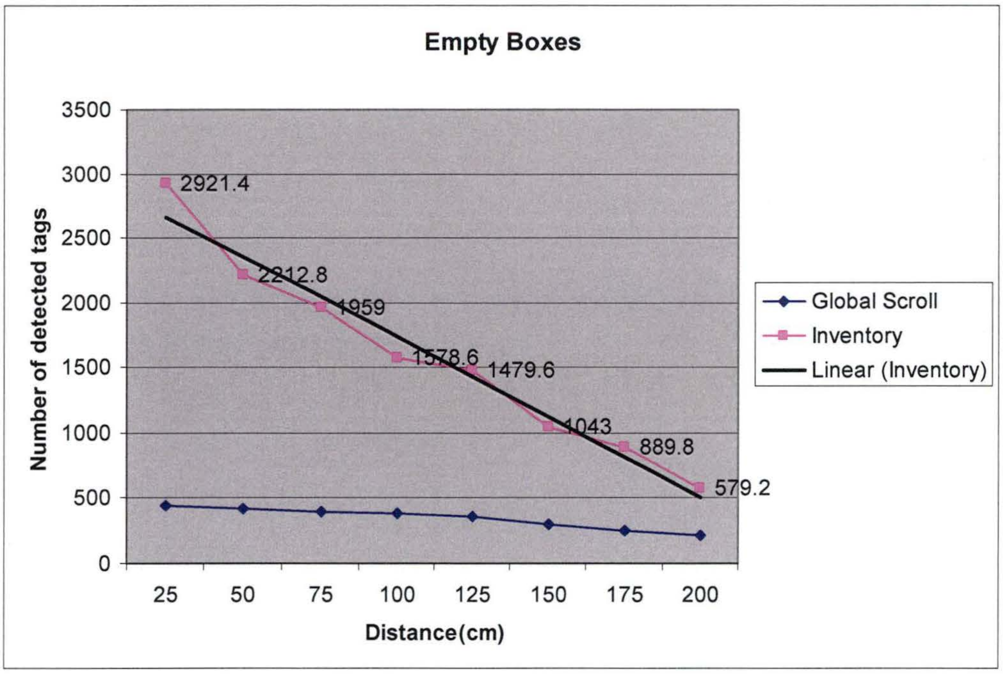
The outcome of Phase One showed the line trend when changing values of parameters. There were 30 pen boxes in total in the pallet with one tag attached to each box. Each box had the capacity of 12 plastic pens. Each test in Phase One replicated five times and the raw data were recorded into Excel.

Table 3 shows the example of empty boxes using Inventory protocol.

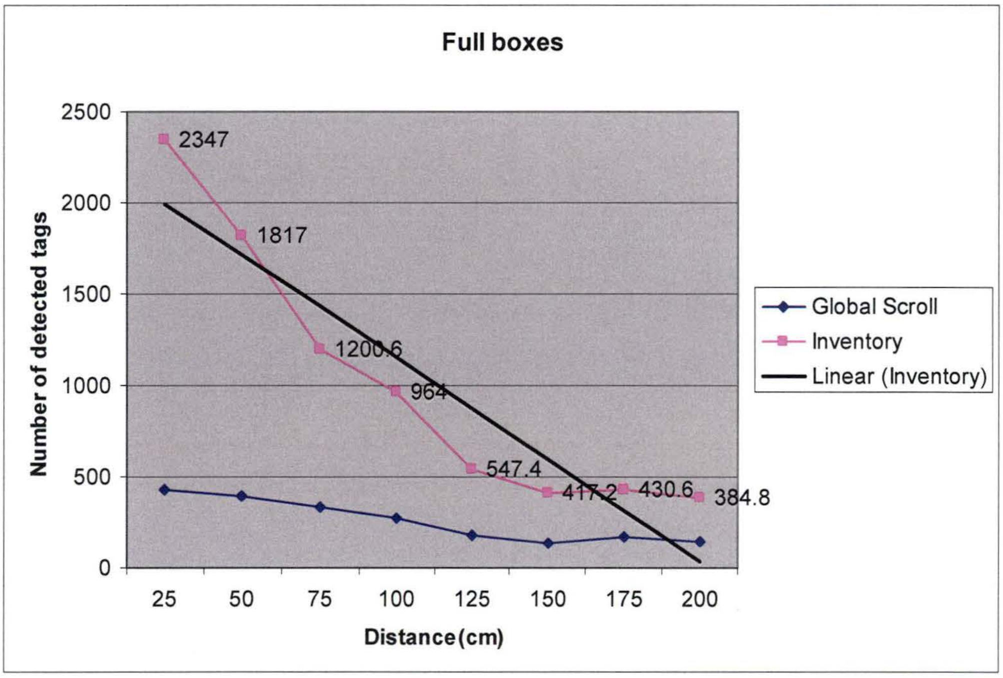
Content	Acquire Mode	Distance (cm)	#1	#2	#3	#4	#5	Average
Empty	Inventory	25	2924	2944	2951	2869	2919	2921.4
		50	2176	2181	2244	2232	2231	2212.8
		75	1907	1981	1977	1986	1944	1959
		100	1551	1579	1600	1584	1579	1578.6
		125	1499	1460	1492	1473	1474	1479.6
		150	1039	1051	1016	1073	1072	1043
		175	853	897	880	905	914	889.8
		200	561	660	625	515	535	579.2

Table 3 – The results of empty boxes using inventory protocol

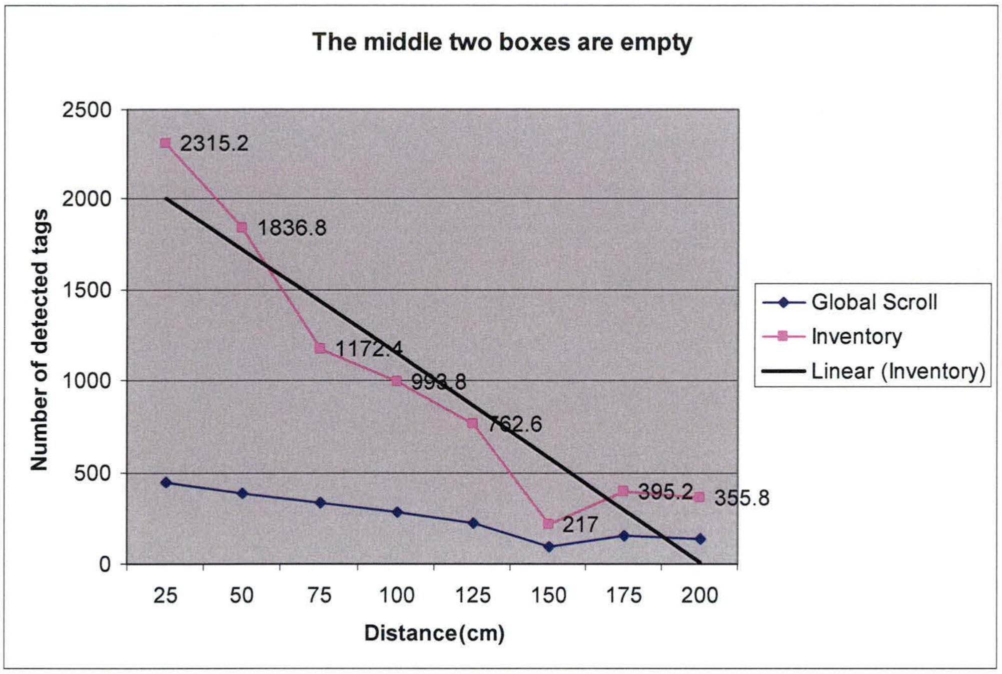
As shown in the table above, the numbers were averaged to get a final value which would be used in the graphs. **Figure 16** shows the results of empty, full and hollow pallets in graphs.



(a) Phase 1: Empty pallet (all boxes are empty)



(b) Full pallet (all boxes are full)



(c) Hollow Pallet (two empty boxes)

Figure 16 – Results of Phase One

In **Figure 16**, the X-axis in each graph refers to the distance factor, and the Y-axis refers to the number of detected tags. The purple line refers to the results in inventory and the blue line refers to the global scroll protocol, respectively. Each value in these graphs (the points), are averaged from 10 replications. As shown in **Graph (a)**, the empty boxes situation, the blue line is relatively flat. When the distance varies from 25 cm to 200 cm, the values in blue line changed from 441 to 215. On the other hand, the purple line decreases dramatically, ranging from 2922 to 580. Therefore, the slop of the purple line is much higher than the blue line, which means that when collision avoidance is enabled, tags are read more frequently, and when the distance increases, the number shrinks more quickly. **Graph (b)** shows the situation of full boxes. In this graph, the blue line is raging between 434 and 145, which is very similar to **Graph (a)**. The difference between these two lines is insignificant. On the other hand, the value potted in the purple line decrease a lot, ranging from 2347 to 384.8 with a slightly more gradual changing trend. Therefore, when the acquire mode was set to inventory, observing the difference from the graphs became easier, as the difference between the empty pallet and the full pallet is significant.

Graph (c) shows the hollow pallet, within which there were two empty boxes. In this graph, both the blue line and the purple line are similar to those in **Graph (b)**. The blue line varies from 443 to 140 and the purple line varies from 2316 to 355.8. Therefore, when the acquire mode was set to inventory, the hollow pallet can be told from the empty pallet, but the difference between hollow pallet and the full pallet is insignificant. This was due to the limitation of the pallet size. If the pallet size increased with a larger hollow, the difference between the hollow pallet and the full pallet was estimated to be clearer.

In summary, when the acquire mode was set to global scroll, the average number of detected tags did not change a great deal in the three pallets. On the other hand, when the acquire mode was inventory, the number reduced dramatically since the distance increased. The results indicated that inventory mode is more critical in investigating this problem while global scroll mode has little effect. In addition, the number of tags decreased in all the three diagrams when the distance increases. It decreased more dramatically in inventory protocol. This indicated that distance is an important factor which can effectively influence tag read rate. In order to achieve a high read rate, the distance should be less than 25 cm. Therefore, acquire mode was set to inventory and distance was set to 20 cm which ensured that all the tags were in the read rage and an optimal read rate was achieved. The results of Phase One also indicated that method was effective. However, Phase One had limitations. First, tag read rate in a water product should be far worse than that in plastic. Therefore, the data from Phase One were not sufficiently accurate for analyzing the problem. Second, the results were restricted by the size of the pallet which is 40.6cm*15.2cm*13.2cm. The tests with the use of water bottles to investigate this problem were undertaken in Phase Two and Phase Three.

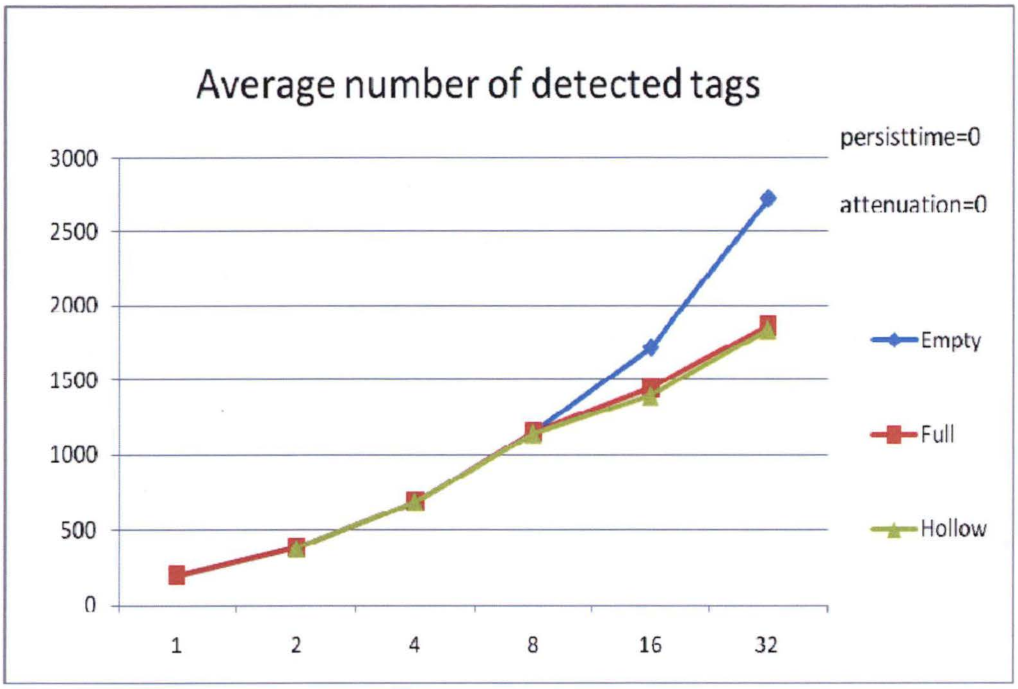
4.2 Phase Two Results: using bottles of water

The outcome of Phase Two was from the tags attached to bottles of water that were placed in a Faraday Cage. In this phase, bottles of water were placed on the pallet, and one tag was attached to each bottle. The number of the bottles was doubled each time, from 1 to 32. The factors tested in this phase were attenuation and persist time. **Table 4** shows the example of empty pallet when persist time is 0.

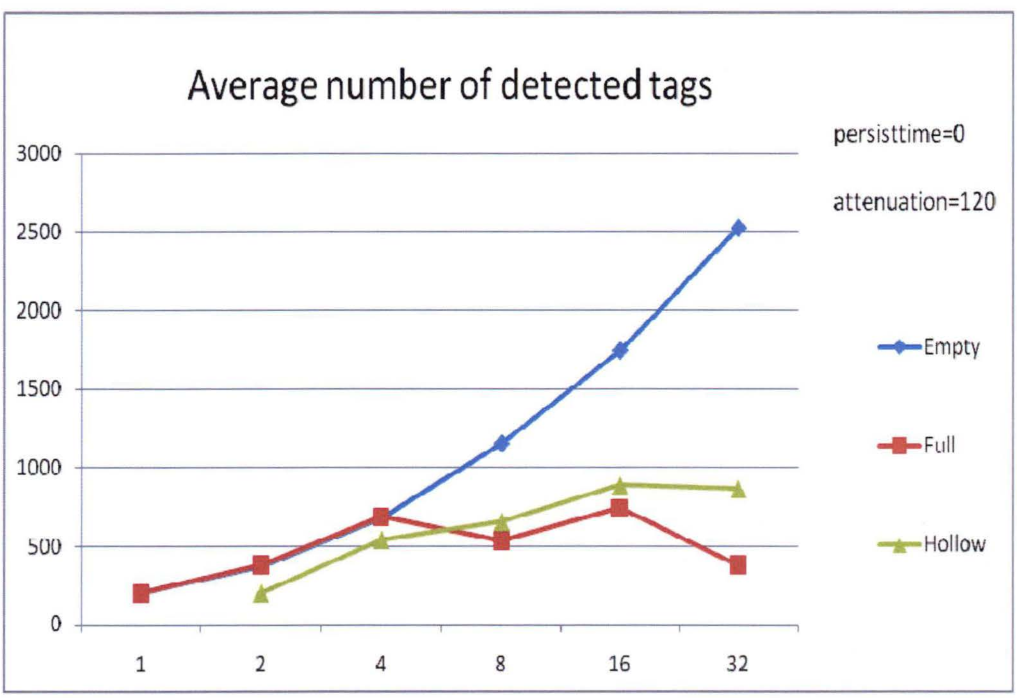
Content	Persist time	Number of box	Attenuation	Cycles	Unique tags	Detected tags
Empty	0	1	0	200.3	1	199.3
			120	201.5	1	200/5
		2	0	190.3	2	378.5
			120	188.7	2	375.3
		4	0	196.1	4	684
			120	196.2	4	684
		8	0	244	7.9	1149.4
			120	246.8	8	1154.4
		16	0	266.3	15.8	1715.7
			120	266.7	16	1743.1
		32	0	372.1	32	2721.9
			120	348.5	29.5	2522.5

Table 4 – Empty pallet when persist time is 0

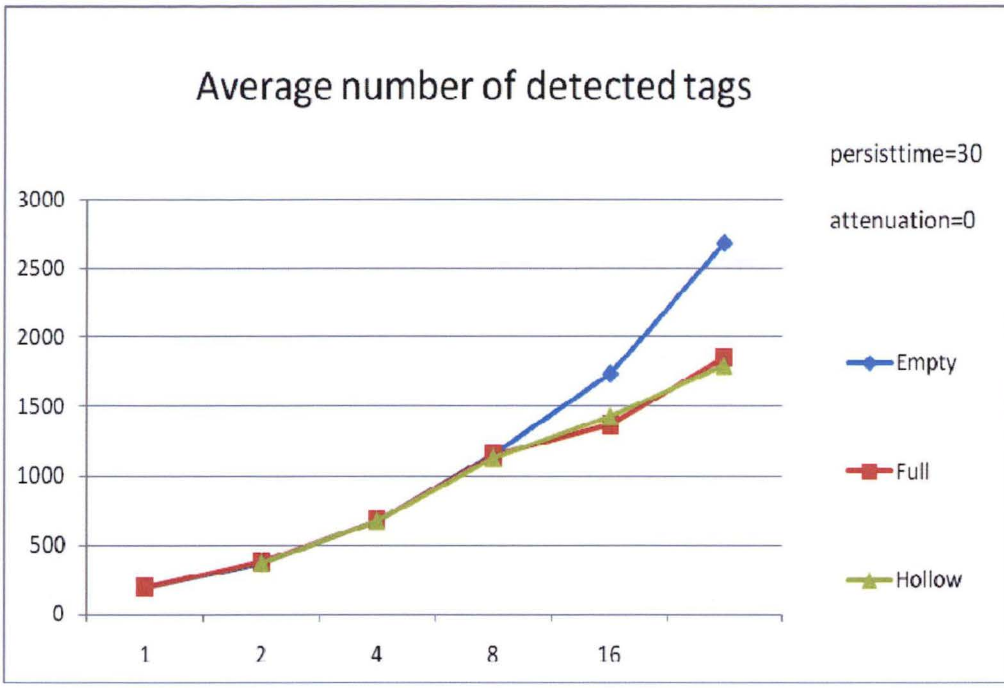
Figure 17 shows the results of four situations, where attenuation is 0 dB and persist time is 0 second, attenuation is 120 dB and persist time is 0 second, attenuation is 0 dB and persist time is 30 seconds and attenuation is 120 dB and persist time is 30 seconds.



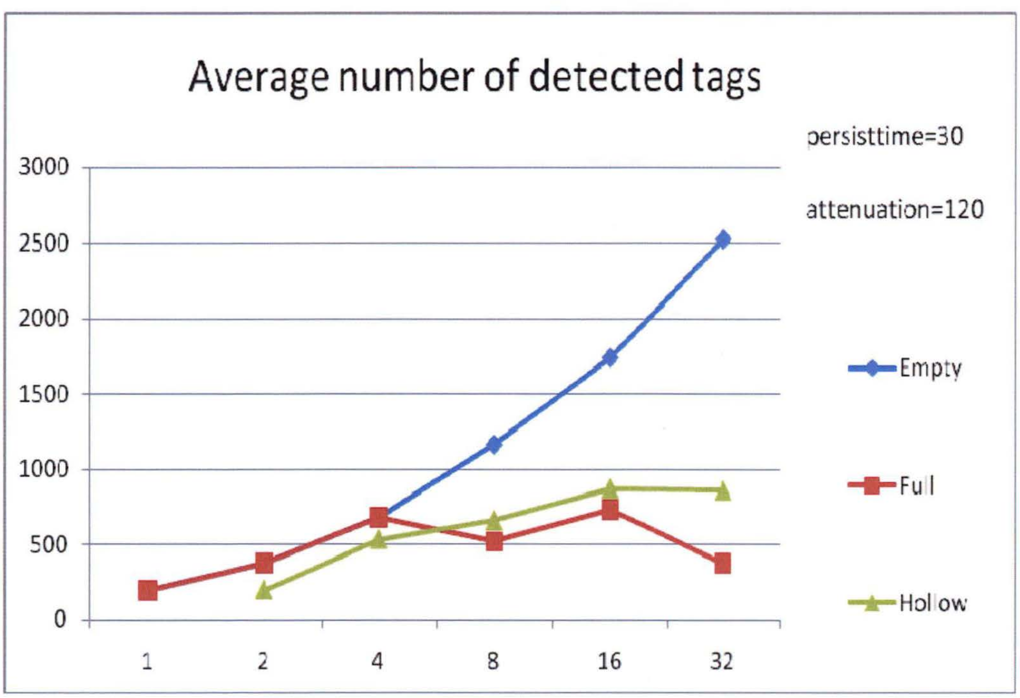
(a) Average number in all replications when persist time is 0second and attenuation is 0dB



(b) Average number in all replications when persist time is 0second and attenuation is 120 dB



(c) Average number in all replications when persist time is 0second and attenuation is 120dB



(d) Average number in all replications when persist time is 30seconds and attenuation is 120dB

Figure 17 – Results of Phase Two

In the graphs of **Figure 17**, the X-axis refers to the number of bottles on the pallet, and the Y-axis refers to the number of detected tags. The blue line represents the empty pallet. The red line represents the full pallet. The green line represents the hollow pallet in which there was one empty bottle. In this phase, two factors were tested and each factor was set to a high and a low: attenuation was set to 0 dB and 120 dB, and persist time was set to 0 seconds and 120 second. The results in these graphs were produced and averaged from 10 replications. According to (Robinson 2004), when the number reaches 10, it brings a reasonable narrow confidence interval. Therefore, the results in these graphs are statistically significant.

In this figure, **Graph (a)** shows the results when attenuation was set to 0 dB and persist time was set to 0 seconds. In **Graph (a)**, the three lines almost coincide when the bottle number is less than 8. The empty pallet (blue line) can be told from the other two situations when the number is greater than 8, but the green line and red line still almost coincide, which means that when both the attenuation and the persist time are in low values, it is difficult to distinguish the hollow pallet and the full pallet. **Graph (b)** demonstrates the results when attenuation changed to 120 dB while persist time kept at 0 seconds.

In **Graph (b)**, the red line and the blue line coincide, and the hollow line is below the other two lines when the number of bottles is less than 4. When the number is greater than 8, the difference of the three lines starts becoming more and more significant. The result of blue line (empty pallet) increases much faster than the other two lines, which have the similar increasing rate, when the number of bottles is between 8 and 16. However, when the number of bottles is greater than 16, the blue line keeps increasing, whereas the green line (hollow pallet) and the red line (full pallet) start shrinking. In this space, the slope of red line is much steeper than that of the green line, which makes the difference of the three lines become significant. Therefore, from these results at this stage, the hollow inside a pallet can be found when the attenuation is set to 120 dB and the persist time is 0 seconds.

In the following two graphs (**Graph (c)** & **Graph (d)**), persist time was changed to 30 seconds and the previous operations were repeated. The results of these two figures are extremely similar to the above results. This indicates that persist time is an unimportant factor which would not influence the read rate. Therefore, persist time has no effect in detecting a hollow pallet problem.

To summarize the above results, when the attenuation was 120 dB, the difference between the three situations was sufficiently significant if the number of bottles was greater than 8. It seems that under these conditions, the system can successfully detect the hollow pallet. However, when the number of empty bottles was changed, which means the size of the pallet remained stable and the hollow increased, the change of the line was not the same as expected, as shown in **Figure 18**.

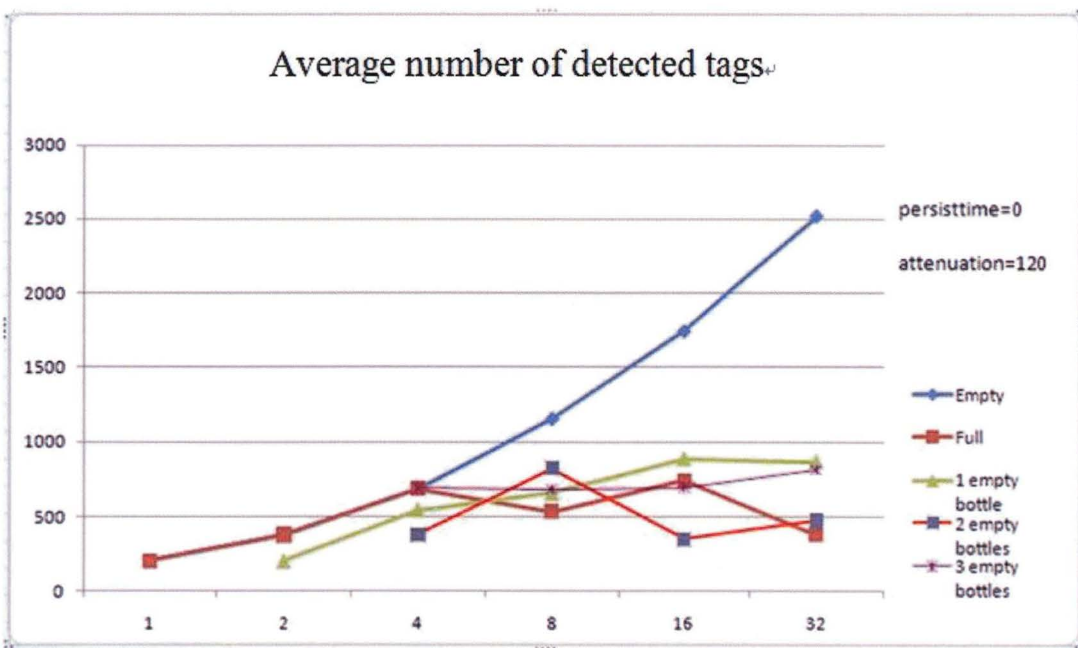


Figure 18 – Increasing size of the hollow

Figure 18 extends the results of **Graph (b)** in **Figure 17**. Two extra tests were involved. As shown in **Figure 18**, the pink line refers to the situation that 2 empty bottles were inside the pallet and the purple line refers to 3 empty bottles were inside. Ideally, the trends of the overall five lines were expected to be shown in order that the blue line (empty pallet) would have the highest number of detected tags, following by the purple line (3 empty bottles). The pink line (2 empty bottles) was expected to appear in the middle, and below it, the green line (1 empty bottle) would have better read rate than the red line (full pallet). However, the results in Figure 13 shows that when the number of bottles was greater than 8, the values of the pink line (2 empty bottles) and the purple line (3 empty bottles) were lower than the green line (empty pallet). The pink line (2 empty bottles) value is even worse than the red line (full pallet). This indicates that the method in Phase Two, which kept the hollow size stable and increased the pallet size, was not effective in detecting this problem.

In summary, the method used in Phase Two was to keep the size of the hollow stable and increase the size of the pallet. Attenuation and persist time were the variable factors. Attenuation was found to be important, while persist time did not have significant influence on the final results. Although this method can detect the hollow pallet problem under certain conditions, it cannot be used in a general situation. Therefore, an optimized method was used in Phase Three.

4.3 Phase Three Results: changing method

In this phase, the size of the pallet was kept stable while the number of empty bottles changed. In other words, the percentage of the hollow varied. 20 bottles were placed on the pallet in this case. The data shown in **Table 5** is an extract of Phase Three when persist time is 0. **Figure 19** shows how the line changes when the percentage of empty bottles is between 0 and 100.

Persist time	percentage	hollow	full	attenuation	cycles	Unique tags	Detected tags
0	0%	0	20	0	223.6	17.8	1478.2
				120	187.1	5.1	491.1
	5%	1	19	0	231.6	14	1498.3
				120	192.3	4.9	643.9
	10%	2	18	0	250.2	18	1659
				120	198.7	5.2	685.3

Table 5 – Phase Three data when persist time is 0

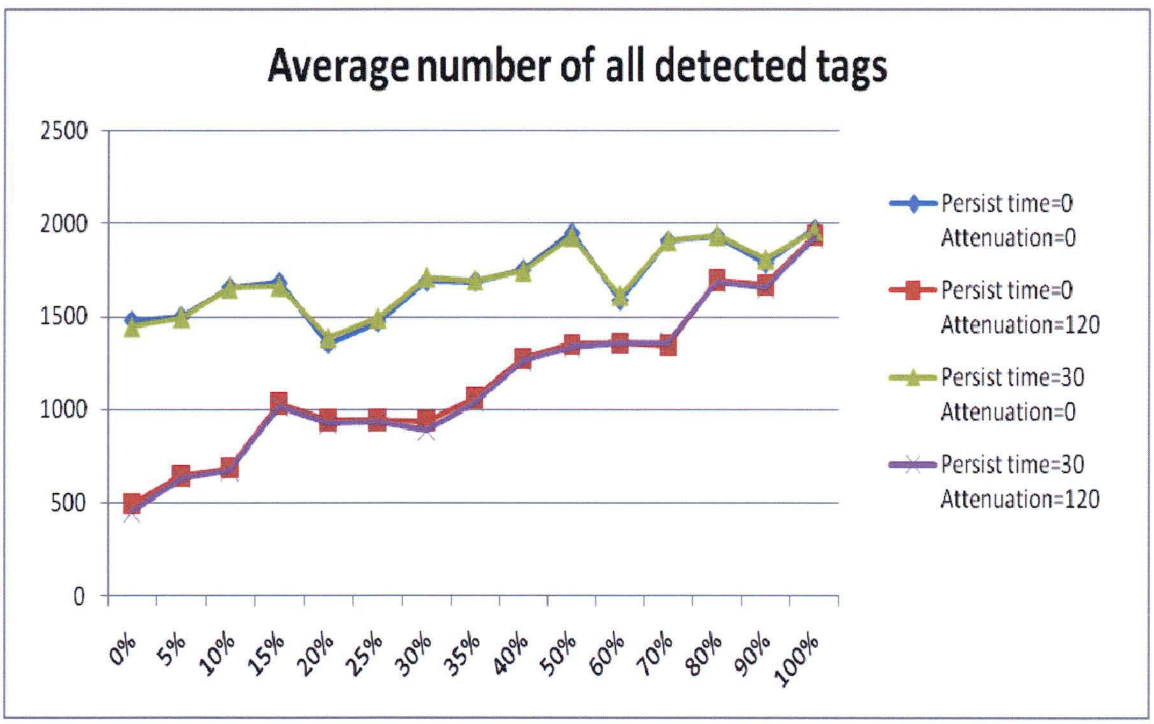


Figure 19 – Results of Phase Three

In this figure, the X-axis refers to the percentage of empty bottles in the pallet. Within this, 0% represents all bottles are full, 5% represents only one bottle is empty, and 100% represents that all bottles are empty. The Y-axis refers to the number of detected tags. The upper two lines refer to the results when attenuation was 0 dB. The lower two lines refer to the results when attenuation was 120 dB. As shown in this figure, persist time does not influence the final results, because as the two lines, which have the same attenuation value but different persist time values, almost coincide. When the attenuation is 0 dB, the point of the empty pallet is only 500 higher than the full pallet. This varying difference is not sufficient to distinguish the hollow pallet. On the other hand, when the attenuation is 120 dB, the difference between 0% (all full) and 100% (all empty) is quite large, and the values which refer to the hollow pallet situation, can be clearly found in this case. According to this result, rules can be summarized to find out the proportion of the hollow inside a pallet. For example, if the number of detected tags is 600, it indicates that 10% of the contents inside a pallet are missing.

In addition, because the position of each tag is kept stable in this phase, it becomes possible to find which bottle(s) is (are) empty. For example, when there were two empty bottles on the pallet, the results can be analyzed in the Microsoft Excel and shown as **Figure 20**.

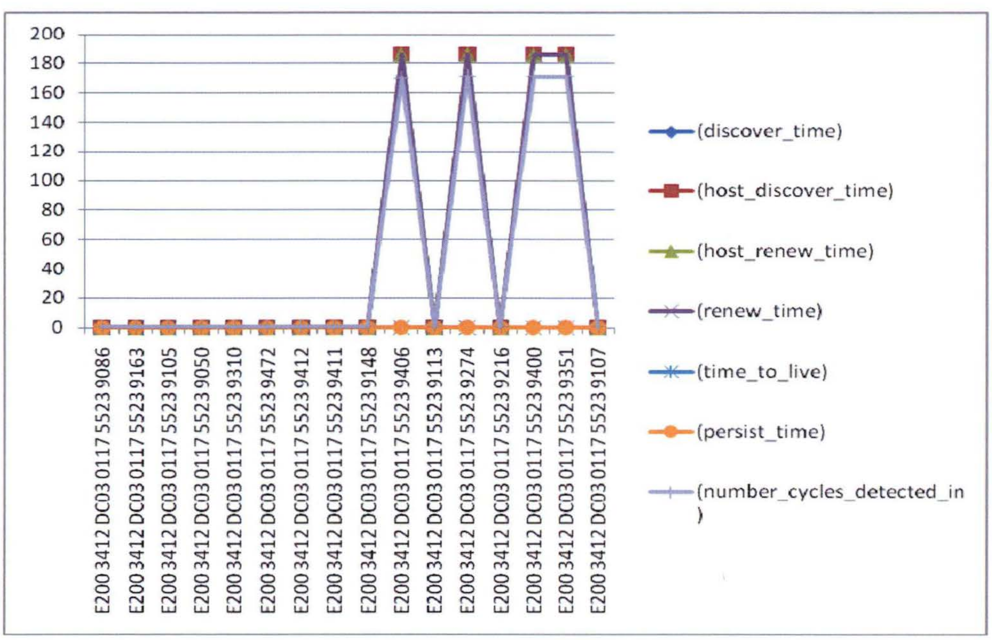


Figure 20 – Locating positions of empty bottles

In **Figure 20**, the X-axis refers to the tag ID, Y-axis refers to the frequencies of tag responses. There are four peaks in this figure, which means that four tags were found to be read more frequently than others. The reason of that is an empty bottle has less interference as a bottle of water. The tags attached to emtpy bottles can be detected more times than others in the same period. Therefore, the position of the hollow inside a pallet can be located by finding out where these four tags are. In addidtion, an empty bottle did not only influnence the tag attached to it, but also caused the neighbouring tags to be read more frequently than other tags. In this case, four tags were found, although there were only two empty bottles. The extra tags were under and behind the empy bottles. The signals emitted from these neighbouring tags also reached the reader much faster than any other tags in the farady cage.

In summary, the results of Phase One helped to ensure the effective acquire mode and the optimal distance between the reader and the pallet, thus the optimal factors for these could be determined in the next phases. Phase One also proved that the system can be used to investigate th problem. Phase Two found that under certain condition, the hollow pallet problem can be detected. But the test method did not work effectly in gerenal situations. An optimized method was used in Phase Three, which successfully detected whether there was a hollow or not. In addition, the location of the hollow inside the pallet can be found by analyzing the outcome of individual tags. In this research, the tags in the above graphs were verified by visual inspection of the graphs. In future work, a 3D model of a pallet can be used to automate the visualization of the hollow as well.

4.4 Results Discussion

The overall results in the three phases proved the hypothesis posed in this thesis. The conclusion can be easily summarized according to the graphs which were generated from the data in Microsoft Excel intuitively. The experiment was based on a pallet of bottled water. The results indicate that when a pallet is located within the read range, and the RF signal is not strong and collision avoidance algorithm is enabled, the hollow inside a pallet which hold bottled water can be detected. Although there is no sophisticated machine learning algorithms involved in this research, the results clearly tell the difference between an empty pallet, full pallet and hollow pallet.

This experiment was a simulation of transporting fish in the real world. The results can now be applied to detect a hollow pallet in transporting fish. However, it is important to customize the method in supply chain, because it cannot detect the fake product. For example, it would be possible for an attacker to remove the fish inside a carton and replace it with bottled water. Therefore, it is necessary to achieve an accurate data by testing real fish.

5. Conclusion and Further Work

This research began by presenting a hypothesis regarding detecting the missing carton content on a pallet with the use of RFID technology. Following an introduction to RFID system architecture, results from previous research were explored in order to find the factors which would take effect in this work. After building up the experiment, some factors were determined to be variables which were tested in the next phases, while some were set to be constant. The motivation was the selection of an appropriate method to verify the hypothesis. After comparing with the sensitivity analysis method, the 2^k factorial test method was selected. The experiment consisted of three phases. Each phase was initialized to find or optimize results based on the results from previous phases. Results were summarized intuitively without the necessity of using sophisticated machine learning methods. Finally, results were presented and the usage of tracking and transportation area in the real world was discussed.

In the design of this experiment, a Faraday cage was used to build up an isolated environment to control the factors which influenced tag read rate. Therefore the results from the testing replications were ensured not to be interfered by external environment and the effect of each individual factor can be evaluated. The results were summarized from comparing the three curve lines of the graphs based on different parameter values. The three curve lines represented the number of tags being detected in three kinds of pallet, the empty, the full and the partially full.

The most essential improvement from Phase Two to Phase Three is the method of changing the percentage of the hollow on a pallet, instead of the number of empty bottles. Ultimately, by keeping the tags in a stable position, the results can not only detect whether there is a hollow on the pallet, but also tell where the hollow is. By observing the data of individual tags, some tags were found to be detected for much more times than others, which indicates that a bottle with one of those tags attached was either empty or close to the empty one.

This research has explored the feasibility of using the RFID based detecting system to find the empty cartons on a pallet. By using the above passive RFID system, it is possible to detect a hollow pallet problem, as well as find the position of the hollow. The use of RFID has been extended by analyzing the data before it is filtered. Advanced computing analysis of the output data, such as machine learning algorithms, was not necessary in this research, because by observing the output data, the results are really obvious. The results in this research were initially aimed to be used in fish transporting section. Therefore, it is worthwhile doing more investigation to improve the results from laboratory environment to the real world. To this end, performance of the system would be optimized and several directions for further investigation would be identified. This chapter presents some of the directions upon which the future work would be established.

As noted in the result discussion part, the detecting system should perform well in the real world. Therefore, the experiment environment should involve more factors, especially those from external environment, such as other radio frequency devices and metal equipment. As covered in the literature review, metal has the ability to block the signal but in some cases it is the main material in the warehouse. Effective methods for exploring the influence of more factors could be explored in future work.

The results from this research aimed to detect item loss on a pallet in salmon transportation. As mentioned in methodology, the experiment was undertaken with the use of bottles of water instead of salmon, because the water percentage of a salmon reaches higher than 80%. Although this simulation has achieved an excellent performance, it is worthwhile repeating the experiment with salmon, so as to improve accuracy of the results. In addition, it can help to prevent attackers from replacing fish with bottled water.

Finally, the pallet model used within this experiment had limited size. Because the pallet was placed in a Faraday cage along with the reader, the size of the pallet was restricted by the Faraday cage. As described in the results section, the pallet consisted of 32 bottles in Phase Two, and 20 bottles in Phase Three. The impact of hollow pallet might be more significant and more easily to be observed if the pallet was in a larger size. Therefore, the pallet would be configured to have a similar size in the retail area, so as to achieve an accurate result.

6. References

Asheim, LJ, Lien, G, Richardson, JW, Tveteras, R & Weggeland, F 2005, 'Modelling Risks in the Salmon Industry and Markets', *proceedings of 95th EAAE Seminar*, Rome, Italy, 9-11 December.

Asif, Z & Mandviwalla, M 2005, 'Integrating the supply chain with RFID: A technical and business analysis', *Communications of the Association for Information Systems*, vol. 15, no. 24, pp. 393-426.

Bai, Y, Wang, F & Liu, P 2006, 'Efficiently filtering rfid data streams', *The First International VLDB Workshop on Clean Databases*, Citeseer.

Banks, J 1998, *Handbook of simulation*, Wiley, New York.

Barua, A, Mani, D & Whinston, A 2006, 'Assessing the Financial Impacts of RFID Technologies on the Retail and Healthcare Sectors', *Center for Research in Electronic Commerce, Department of IROM, McComb School of Business*, The Univerity of Texas at Austin.

Basinger, KL 2006, 'Impact of inaccurate data on supply chain inventory performance', Ph. D. thesis thesis, Ohio State University.

Boss, RW 2003, 'RFID technology for libraries', *Library Technology Reports*, vol. 39, no. 6.

Brown, DE 2006, *RFID implementation*, McGraw-Hill, New York.

Buettner, M & Wetherall, D 2008, 'An empirical study of UHF RFID performance', *Proceedings of the 14th ACM international conference on Mobile computing and networking*, ACM New York, NY, USA, San Francisco, California.

Cheong, T & Kim, Y 2005, 'RFID data management and RFID information value chain support with RFID middleware platform implementation', in *On the Move to Meaningful Internet Systems 2005: CoopIS, DOA, and ODBASE*, Springer, Berlin, vol. 3760, pp. 557-575.

Clarke, RH, Twede, D, Tazelaar, JR & Boyer, KK 2006, 'Radio frequency identification (RFID) performance: the effect of tag orientation and package contents', *Packaging Technology and Science*, vol. 19, no. 1, pp. 45-54.

Collins, J 2003, *Safeguarding the Food Supply*, RFID Journal, viewed 28 October 2009, <http://www.rfidjournal.com/article/articleview/691/1/1/>.

D'Mello, SK, Choudhary, D, Chari, S, Markham, J & McCauley, L 2007, 'RFID Tag Characterization in a GHz Transverse Electromagnetic Cell', *IEEE International*

Conference on Service Operations and Logistics, and Informatics, Philadelphia, PA.

Donath, B 2002, *The IOMA handbook of logistics and inventory management*, Wiley, New York.

Floerkemeier, C & Lampe, M 2004, 'Issues with RFID Usage in Ubiquitous Computing Applications', in *Pervasive computing*, Springer, Berlin, pp. 188-193.

Frozen Tuna Gets RFID, 2005, Textually Org, viewed 11 October 2009, <http://www.textually.org/textually/archives/2005/08/009621.htm>.

Gao, X, Xiang, Z, Wang, H, Shen, J, Huang, J & Song, S 2004, 'An approach to security and privacy of RFID system for supply chain', *IEEE International Conference on E-Commerce Technology for Dynamic E-Business*, Beijing, 15 September.

Garfinkel, S & Rosenberg, B 2005, *RFID: Applications, security, and privacy*, Addison-Wesley.

Gaukler, GM, Seifert, RW & Hausman, WH 2007, 'Item-level RFID in the retail supply chain', *Production and Operations Management*, vol. 16, no. 1, pp. 65-76.

Glover, B & Bhatt, H 2006, *RFID Essentials*, O'Reilly, Beijing.

Gomez, AA 1984, *Statistical procedures for agricultural research*, Wiley, New York.

Hashemi, K 2009, *Faraday Cages*, Open Source Instruments Inc.

Hoshmand, AR 2006, *Design of experiments for agriculture and the natural sciences*, Chapman & Hall, London.

Jo, M, Lim, CG & Zimmers, EW 2007, 'RFID tag detection on a water content using a back-propagation learning machine', *KSII Transactions on Internet and Information Systems*, vol. 1, no. 1, pp. 19-32.

Juels, A 2006, 'RFID security and privacy: A research survey', *IEEE Journal on Selected Areas in Communications*, vol. 24, no. 2, pp. 381-394.

Juels, A, Rivest, RL & Szydlo, M 2003, 'The blocker tag: Selective blocking of RFID tags for consumer privacy', *Proceedings of the 10th ACM conference on Computer and communications security*, pp. 103-111.

Jung, H, Chen, FF & Jeong, B 2007, *Trends in supply chain design and management: technologies and methodologies*, Springer, London.

Kitsos, P & Zhang, Y 2008, *RFID security: techniques, protocols and system-on-chip design*, Springer Verlag, New York.

Koh, CE, Kim, HJ & Kim, EY 2006, 'The impact of RFID in retail industry: issues and critical success factors', *Journal of Shopping Center Research*, vol. 13, no. 1, pp. 101-117.

Kumar, D 2006, *Six Sigma Best Practices: A Guide to Business Process Excellence for Diverse Industries*, J. Ross Publishing, Ft. Lauderdale, FL.

Lindsay, J & Reade, W 2003, *Cascading RFID Tags*, viewed 26 October 2009, <http://www.jefflindsay.com/rfid3.shtml>.

Lu, CS 2000, 'Logistics services in Taiwanese maritime firms', *Transportation Research Part E*, vol. 36, no. 2, pp. 79-96.

McCartney, M 2005, 'Keynote retail panel: meeting technology challenges and succeeding', in *Presentation at RFID retail Seminar by Michigan State University* East Lansing, MI.

Myerson, JM 2007, *RFID in the supply chain: a guide to selection and implementation*, Auerbach Publications, Boca Raton, FL.

O'Connor, M 2006, *EPCglobal Puts Item Tagging to the Test*, viewed 30 October 2009, <http://www.rfidjournal.com/article/view/2225/1/1/>.

O'Connor, M 2007a, *Dillard's Gear Up for Item-Level Pilot*, RFID Journal, viewed 20 October 2009, <http://www.rfidjournal.com/article/view/3574/1>.

O'Connor, M 2007b, *Falabellla Plans Second Item-Level RFID Pilot*, viewed 20 October 2009, <http://www.rfidjournal.com/article/articleview/3585/1/1/>.

Product Overview, 2007, Alien Technology Corporation, viewed 29 October 2009, <http://www.alientechnology.com/docs/products/DS_ALR-9650.pdf>.

Ramakrishnan, KM & Deavours, DD 2006, 'Performance benchmarks for passive UHF RFID tags', *Proceedings of the 13th GI/ITG Conference on Measurement, Modeling, and Evaluation of Computer and Communication Systems*, Citeseer, Nuremberg, Germany.

Reader Interface Guide All Fixed Readers, 2008, Alien Technolgy.

Redman, TC 1998, 'The impact of poor data quality on the typical enterprise', *Communications of the ACM*, vol. 41, no. 2, pp. 79-82.

RFID Business Applications, 2009, RFIDJournal, viewed 11 October 2009, <http://www.rfidjournal.com/article/articleview/1334/1/129/>.

RFID Journal Glossary of Terms, 2009, RFID Journal, viewed 23 October 2009, <http://www.rfidjournal.com/glossary/205/>.

Robinson, S 2004, *The Practice of Model Development and Use*, John Wiley, Chichester.

Sanghera, P, Thornton, F, Haines, B & Fung, FKM 2007, *How to Cheat at Deploying and Securing RFID*, Syngress, Rockland, Mass.

Santner, TJ, Williams, BJ & Notz, WI 2003, *The design and analysis of computer experiments*, Springer, New York.

Schuster, EW, Allen, SJ & Brock, DL 2007, *Global RFID: The Value of the EPCglobal Network for Supply Chain Management*, Springer Verlag, New York.

Shepard, S 2005, *RFID: radio frequency identification*, McGraw-Hill Professional, New York.

Singh, J, Deupser, C, Olsen, E & Singh, SP 2007, 'An Examination of the Variables Affecting RFID Tag Readability in a Conveyer Belt Environment', *Journal of Applied Packaging Research*, vol. 2, no. 2, pp. 61-73.

Singh, SP, McCartney, M, Singh, J & Clarke, R 2008, 'RFID research and testing for packages of apparel, consumer goods and fresh produce in the retail distribution environment', *Packaging Technology and Science*, vol. 21, no. 2, pp. 91-102.

Thornton, F, Haines, B, Das, AM, Bhargava, H, Campbell, A & Kleinschmidt, J 2006, *RFID security*, Syngress, Rockland, Mass.

Understanding RFID and Associated Applications, 2004, Psion Teklogix Inc, viewed 29 October 2009, <http://www.expertek.com/pdf-files/Understanding_RFID_and_Associated_Applications.pdf>.

Vickery, G 2006, *OECD information technology outlook: information and communications technologies*, OECD, Paris.

Vogt, H 2002, 'Multiple object identification with passive RFID tags', *IEEE International Conference on System, Man and Cybernetics (SMC '02)*, Hammamet, Tunisia, October 2002.

Wang, SW, Chen, WH, Ong, CS, Liu, L & Chuang, YW 2006, 'RFID Application in Hospitals: A Case Study on a Demonstration RFID Project in a Taiwan Hospital', *Proceedings of the 39th Annual Hawaii International Conference on System Sciences*, vol. 08, p. 184.

Want, R 2006, 'An introduction to RFID technology', *IEEE Pervasive Computing*, vol. 5, no. 1, pp. 25-33.

Weinstein, R 2005, 'RFID: a technical overview and its application to the enterprise', *IT professional*, vol. 7. no.3, pp. 27-33.

Xiao, Y & Pan, Y 2007, *Security in Distributed and Networking Systems*, World Scientific, Singapore.

7. Appendices

Appendix A - Statistical Java code

The following Java code is an extract out of the hollow pallet detection project. It was used to calculate the mean, standard deviation and the confidence interval based on Student's t-distribution.

```
public class Confidence_Interval
{

     public static void main(String[] args) {

          double
a[]={99.3,98.7,100.5,101.2,98.3,99.7,102.1,100.5,99.5}; //
input the data here
          double sum=0; // Initialize sum of the data
          double avg=0; // Initialize average of the data
         double powsum=0; // Initialize the sum of power
deduction
         double Sn=0; // Initialize the standard deviation
         double t=2.31; // the value of t when Confidence
Degree is 95% and N=5
         double Ch=0; // Initialize the max value of
Confidence Interval
         double Cl=0; // Initialize the min value of
Confidence Interval


     // Calculate average
     if(a.length!=0){
       for(int i=0; i<a.length;i++){
       sum += a[i];
       }
      avg = (sum/(a.length));
       //System.out.print(a);
       System.out.print("Avg is " + avg);
       System.out.println();
     }
     else{
          System.out.println("Error");
     }
```

```
    // Calculate standard deviation
    for(int i=0; i<a.length; i++)
    {
        powsum += Math.pow((a[i]-avg),2);
    }
    Sn=Math.sqrt((powsum)/a.length);
    System.out.print("Sn is " + Sn);
    System.out.println();

    // Calculate Confidence Interval
    Ch=avg+Sn*t/(Math.sqrt(a.length-1));
    Cl=avg-Sn*t/(Math.sqrt(a.length-1));
    System.out.print("The confidence interval is between
"+ Cl+ " and " + Ch);
  }
}
```

Appendix B – CD-ROM

The following items are available on the accompanying CD-ROM:

- Phase One results
- Phase Two results
- Phase Three results
- Source code
- Log data