

## **Factors Influencing the Accuracy of RFID Systems in Identifying Items in Shopping Carts**

**Yean-Fu Wen**

**National Chiayi University, Taiwan R.O.C.**

**Joolahluk Janpet**

**National Chiayi University, Taiwan R.O.C.**

**Hansen Tan**

**National Chiayi University, Taiwan R.O.C.**

*The efficiency and dynamic data access of RFID systems are major advantages compared to general or even two-dimensional barcodes. As RFID systems become common in daily life, maintaining quality of service provided by such devices, such as issues related to sensing error and data loss, pose considerable challenge. These issues are particularly important in developing a system for the rapid checkout of multiple items in shopping carts. Since these items are located haphazardly in shopping carts: (i) tags are located in various distances and angles relative to the reader; (ii) some items may be blocked by others; and (iii) one RFID reader may interfere with other readers or wireless networks. This paper explores QoS issues related to RFID systems. According to the results of our experiments, we propose a number of suggestions to improve RFID system for the rapid checkout of a large number of items.*

### **INTRODUCTION**

Radio frequency identification (RFID) is a wireless technology with applications in business and industry (Tu & Piramuthu, 2008; Zhou, Ling, & Peng, 2007). RFID is sometimes referred to as wireless automatic identification, representing a system by which objects are identified by codes transmitted at radio frequencies. The concept behind RFID tags is the management of content and the location of objects. Organizations use RFID in a variety of applications: (i) in the management of stock, in which each item in a warehouse can be identified quickly; (ii) in shipping, a large quantity of destinations can be identified quickly and correctly using RFID; (iii) in supermarkets, RFID can help to reduce the human error associated with identifying products in POS systems (Weinstein, 2005). This paper discusses issues related to the use of RFID tags to check out items in shopping carts within a supermarket.

In most RFID systems, a reader transmits a low-power radio signal to a tag, which receives the signal and uses it as a power source to activate an embedded integrated circuit. The data stored on the circuit is then sent back to the reader through an antenna. The information transmitted by the RFID tag includes the identity of the tag and other related information.

Generally, checking stock is a straightforward process; however, identifying a large number of items, using algorithms designed to avoid conflict can lead to errors in tag reading even the loss of information.

Pushing a shopping cart through a checkout quickly often causes interference associated with the identification of items. Many items piled haphazardly in a cart may cause considerable interference resulting from the placement of tags at various distances and angles to the reader or being completely obscured by placement behind barriers such as other items. This can result in an increase in the number of transmissions required, elevated error rates, and the loss of data.

Latency in identification, insufficient bandwidth, reading error, and the loss of data are traditional quality of service (QoS) issues (Li, Chen, Song, & Wang, 2007). Overcoming these difficulties is crucial to the wider application of RFID technology in daily life. This study uses serial experiments to identify the situations that detract from the performance of RFID systems. We then discuss solutions and suggestions to overcome these problems.

Chen & Hsu (2004) focused on a coplanar waveguide (CPW) used to enhance the performance of antennas in the reading of RFID tags. Avoine, Floerkemeier, & Martin (2009) studied a technique called multistate enhancement used to analyze the distance bounding of RFID technology. This study examines the distance at which reader can identify RFID tags correctly.

Sidney, Eric, Lee, & James (2008) rotated the tags along the horizontal and vertical axes to illustrate how the position of the tag can reduce the rate of reading error. Haga, Horikoshi, Tsukamoto, & Hoshino (2007) estimated the position of tags and their angle of rotation by fixing the stage size at  $180 \times 180 \text{ mm}^2$  with the reader set on the circumference of a circle with the tag in the center. They demonstrated that a change in the position or angle of rotation influences the performance of the reader. In this study, we focused on the angle of the tag in relation to the reader and the position of the tag in the shopping cart to determine how varying the angle of the tag influences the rate of error.

Dobkin & Weigand (2005) studied the influence of nearby objects on the range of readers, using several types of RFID tags, and determined that metal and water influence the respondent signals of the tags. In a prior study, we focused on short-range experiments interfered by customer's accessories in RFID systems (Tsai, Lai, & Wen, 2009). In this study, we look at obstacles that interfere with transmission. This issue is extended by varying the angle of the RFID tag, the distance, and the speed at which it passes through the reading space.

Most of research in this field has focused on physical issues (Karjoth & Moskowitz, 2005), antennas (Rao, Nikitin, & Lam, 2005), modulation (Chen, Liu, & Lai, 2004), and demodulation in RFID communication systems (Liu, Huang, Min, Li, & Han, 2007; Bae, Choi, Kim, Choi, & Chae, 2009). The main issue is how to control power strength to reduce the failure of RFID tag. A number of researchers (Cichos, Haberl, & Reichl, 2002) have recognized the importance of RFID induction strength, comparing induction of polymers, copper, and aluminum. In general, conductive polymer pastes are suitable for general use and short range applications; and copper or aluminum are suited to high performance applications with maximum reading range.

Currently, Bluetooth and Wi-Fi are widely adopted communication technologies. Wei & Yan (2007) created a mathematical model with which to analyze the impact of 2.4 GHz RFID on Bluetooth and Wi-Fi, comparing the simulation results with theoretical analysis to support the mathematical model. In fact, many types of RFID have been implemented and not all RFID systems transmit at 2.4 GHz (some systems transmit at 135 KHz and 13.56 MHz). In the current RFID system, we do not anticipate interference from Bluetooth or Wi-Fi because we have adopted a transmission spectrum outside the range of these technologies.

Fritz et al. (2010) identified the problem Read-Error-Rate as a key factor in overall system quality. They evaluate the impact of failure mode on the filtering strategies with the maximum allowed BER (bit-error-rate), depending on the specifications of the system and the robustness of the RFID system.

A number of researchers have categorized RFID as a sub-system or middle-ware process. Backend systems monitor and control the status of RFID readers and event and data management systems, such as SUN RFID and RF2ID, are used to ensure reliability (Zhou, Ling, & Peng, 2007; Ju, Wang, & Du, 2010). During the transmission of data between tags and readers, various issues related to reliability need to be explored to avoid or reduce service error. In this study, we explore the factors related to the accuracy of

identification, to obtain information related to errors occurring in the front-end of the system, and as a means to enhance middleware processes.

Based on factors related to identification, we implemented a number of experiments to identify which factors are most important. We then provide suggestions with which to plan the practical implementation of readers. To the best of our knowledge, less researches study the QoS issues for a RFID system. In this work, we focus on issues related to error rate between the tag and reader. The remainder of the paper is organized as follows. RFID architecture is described and various QoS issues are modeled. We then present the details of our experiments, evaluate the performance of the proposed system, and discuss the results.

## **OVERVIEW OF RFID ARCHITECTURE**

RFID systems enable the remote storage and retrieval of data using radio waves. RFID systems comprised of two main components:

- RFID tags are attached to the object to be identified. They carry information in an electronic microchip. Most tags are inexpensive, with only a single coil chip and a single antenna.
- RFID readers are used to detect tags and perform read/write operations. Readers are connected to a backend system via a network (wired or wireless). Devices are becoming increasingly compact, and many are incorporated in handheld devices.

Both components of an RFID system include antennas for sensing and transmitting data. There are three kinds of tags: active, passive, and semi-passive modes. Passive tags are the most commonly used, due to their affordability. Passive tags do not require attached batteries, and the energy required by the tag is supplied by the reader transformed from reader's signal. As a result, the identification range of passive tags is short, the reading rate is reduced and read error rate is elevated due to variations in environmental factor. In addition to the RFID tag and reader, each RFID system requires back-end applications combined with a database, computer network, and firewall. With such systems, it is possible to control the operation of readers to ensure automatic, safe, and convenient real-time applications.

## **ACCURATE IDENTIFICATION OF RFID TAGS**

The RFID system shown in Figure 1 has a number of issues that must be investigated. Due to the haphazard manner in which items have been loaded into the shopping cart, the tags are turned at different angles, they are positioned at varying distances, and many obstacles threaten the integrity of the system. To evaluate the performance of this kind of system, we consider error rate as well as transmission latency. High transmission latency resulting from the movement of the cart prevents the system from identifying tags and leads to reading errors. Therefore, it is necessary to evaluate issues related to error rate.

- Position: When items are placed in a shopping cart, the angles of the items vary. In this work, we also considered obstacles, because some items might be located between other items and the reader. When QoS is considered, the interference between tag-to-tag, reader-to-reader, and two parallel readers are the most common issue. Therefore, when deploying an RFID system, we have to consider factors, such that interference can be reduced maximally.
- Distance: Identifying distance is a matter of balancing the medium and the distance between the tag and reader. Because the power range is limited (particularly with passive tags), the distance between the tag and the reader is a major cause of transmission error. Sensing distance differs between tags and readers and this can lead to further interference. If the distance is too long, the reader is unable to receive the signal, resulting in a loss of data. Even when the tag remains within the range of the reader, the ability to sense the tags may vary, resulting in latency and error.
- Direction: Because the coil circuit is printed on a card, any variation in the directions of the tag related to the reader may cause interferences or fluctuations in the strength of the reflected signals. Most of the time, items are placed randomly in carts, resulting in different tags set at different transmission angles. This causes latency in the system and increases error rates. The issue of direction is considered a major issue.

- Obstacles: When items of different size and shape are placed in a cart, some of the items face the reader, but most of them are enclosed by others. These surrounding items may be metal, plastic, water, or other material. When masked by metal, RFID tags cannot be read; therefore, overcoming the issue of obstacles is crucial.

**FIGURE 1  
ARCHITECTURE OF AN RFID SYSTEM**



- Induction strength: each reader and tag possesses different induction strength. Devices with higher induction strength can provide high sensing rate with reduced interference. Signal to noise ratio (SNR) is an important factor and materials must be tested to identify materials that can be distinguished from neighboring tags and readers.

## RFID QOS EVALUATION

In this section, we perform various experiments to evaluate issues related to QoS.

### Experimental Environment Setup

This study used two kinds of readers installed on a computer with 10 tags for the serial experiments. As shown in Figure 2, the plate reader does not indicate whether data has been read successfully, nor the time required performing the reading. We recorded the furthest distance for each tag to each reader. Each experiment was repeated 20 times, and the error rates were averaged.

### Experimental Cases

- Case A: Varying the distance between the tag and reader. This was the initial experiment, to determine the maximum sensing distance between the tag and reader. This data provides insight into the effects of signal strength and power loss.
- Case B: We varied the angle of the RFID tags, setting them parallel, at 45 degree, and with the vertical face to the readers to test whether the structure of the tags influences the accuracy of identification.
- Case C: We overlapped readers to test whether one reader causes interference with other readers.

Case D: Various obstacles, such as plastic water bottles, aluminum foil bags, body, plastic bags, cartons, plastic plates, books, styro foam, aluminum cans, were placed between the tags and readers to test whether the materials influence the accuracy of detection.

Case E: Interference from Wi-Fi and Bluetooth: RFID identity tags were operated in the vicinity of a Wi-Fi or Bluetooth system to test the influence on RFID signals, in which the tag angle is also considered a control variable.

**FIGURE 2  
EXPERIMENT SETUP**



(a) Obstacles placed between the tag and reader



(b) Interference between readers



(c) Tags angled toward the reader

### Experimental Results

Based on these cases, the experimental results are shown as follows:

Case A: Based on the results shown in Figure 3, the reader read tags at a distance of 0 cm, 2.5 cm, 5 cm, and 7 cm. The delay in the RFID reading was minimized at 0 cm; therefore we assumed that the delay increased with an increase in the distance between the tag and reader. Figure 4 shows that the reader was capable of reading tags that are parallel and at 45 degrees at distances between 0 cm and 7 cm; however, it was unable to identify tags beyond 7 cm. The reader was unable to read vertically oriented tags (error rate of 100%), even at a distance of 0 cm. This means that both the angle of the tag and distance from the reader influence the accuracy of identification, particularly when the tag is situated at 90 degrees to the reader. This is an important issue when adopting RFID systems to identify items oriented at various angles.

Case B: Based on results shown in Figure 5, we observe a significant difference according to the reading angle. No error was observed in the following five situations: (i) parallel tags within 1 cm of the reader; (ii) tags parallel to the reader at a middle distance of approximately 10 cm; (iii) parallel tags situated between two readers close to the active reader; (iv) tags situated at 45 degree within 1 cm of the reader; and (v) tags at a 45 degree angle between two readers, close to the active reader. Parallel tags no further than 20 cm with a 45 degree angle to the reader demonstrates no error in identification. Regardless of other parameters, the reader was unable to identify tags facing vertically (with a horizontal reader), resulting in a high rate of error.

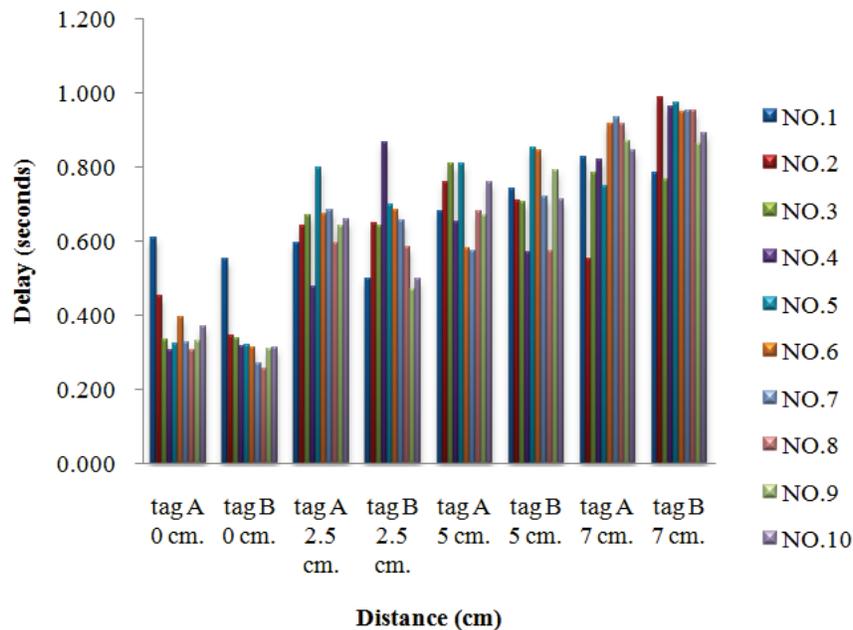
Case C: Experimental results are shown in Figure 6 in which tags are located above, below, and to one side of the reader. The reader was able to read tags in all orientations except vertical to the reader. Again, we summarize that the reader was able to read tags at 45 and 180 degrees; however, it was unable to read tags at 90 degrees.

Case D: The results in Figure 7 indicate a significant correlation between tag angle and obstacles. First, we determined the appropriate distance for RFID tags by performing the 3 times for each tag. Second, we set barriers and angled the tags relative to the reader, and added barriers including plastic plates (PP), sheet metal (SM), thick metal plates (TMP), customer's hands, wood, mobile phones (MP), plastic water bottles (empty) (EPWB), plastic water bottles (full of water) (WPWB), styrofoam, aluminum cans (AC), aluminum foil bags (AFB), books, and cartons. The result shows

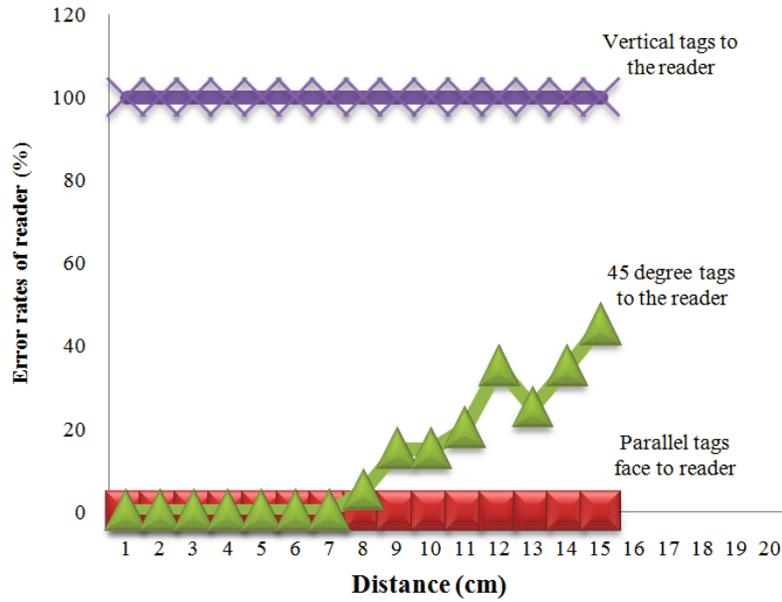
that the reader was unable to read vertical tags, regardless of the obstacles; however, the reader was able to read parallel tags with any of the barriers except sheet metal, metal plate and aluminum foil bags. With the tags angled at 45 degrees, the reader was able to identify tags to a limited degree through books and cartons, mobile phones and plastic water bottles (full of water).

Case E: This experiment addresses data transmission, with simultaneous use of Bluetooth (Figure 8). The reader was able to read only tags parallel to the reader. After comparing the results of tags angled at 45 degrees to the reader, it was observed that Bluetooth and Wi-Fi did not influence the RFID reader in our experiments. The reason was that the frequencies used by RFID are different from Wi-Fi and Bluetooth, regardless of the distance to the reader or network employed. Thus, according to these results, we have to select an appropriate RFID system operating at a frequency different from that of Wi-Fi and Bluetooth, because these wireless networks are widely deployed and ubiquitous.

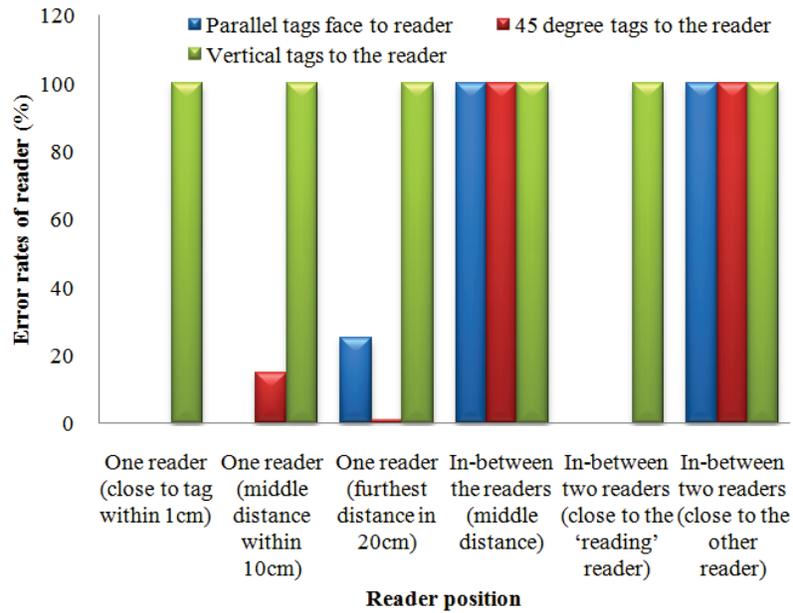
**FIGURE 3  
TRANSMISSION DELAY IN CASE A.**



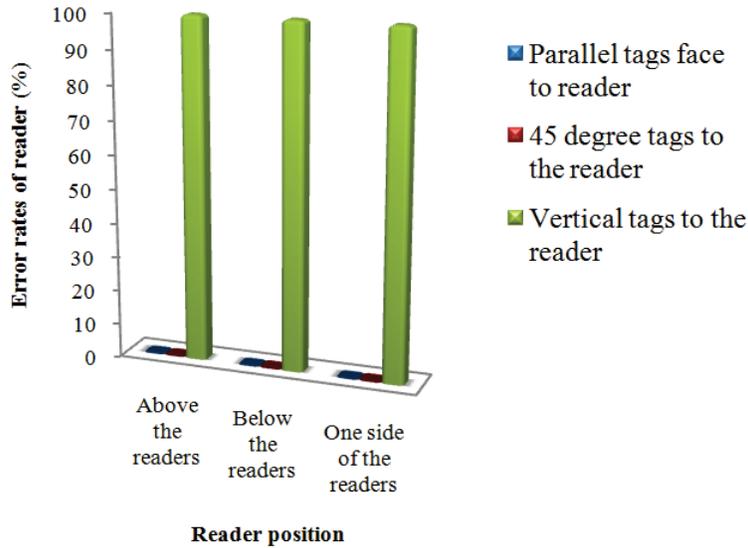
**FIGURE 4  
BIT ERROR RATE IN CASE A**



**FIGURE 5  
BIT ERROR RATES IN CASE B**



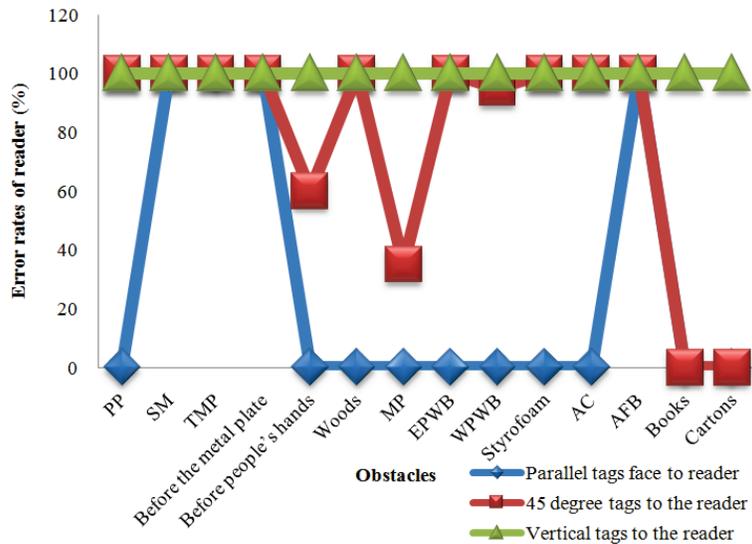
**FIGURE 6  
BIT ERROR RATES IN CASE C**



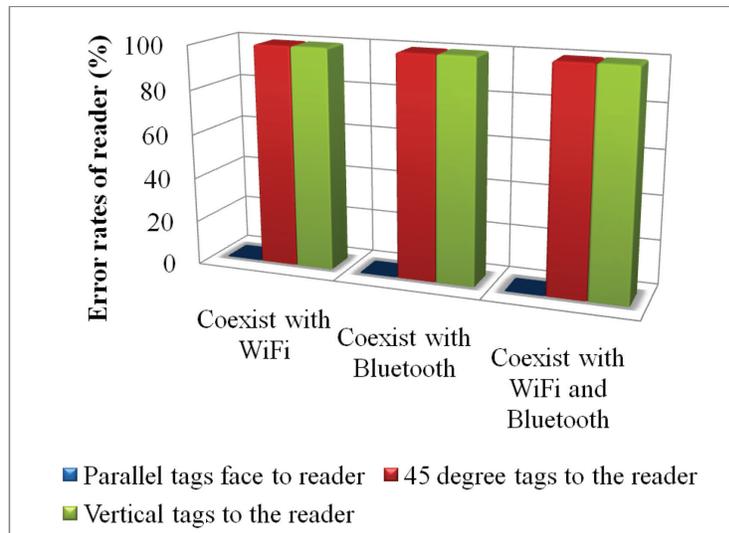
**Discussion**

All of the experiments in this study indicated that RFID signal quality depends on the variables related to the shopping carts, which may influence the ability of the reader to identify RFID tags on products. The packed material of the merchandise is verified to evaluate whether it is caused by items and angles. In addition, RFID tags cannot be attached to all items. For example, items packed with aluminum (e.g., soft drink buttons) can make some disturbances in reading the RFID signal. If the distance between the RFID tag and reader is too great, the reader is sometimes unable to read the tag or reads the tag incorrectly.

**FIGURE 7  
BIT ERROR RATES IN CASE D**



**FIGURE 8  
BIT ERROR RATES IN CASE E**



The angle of the RFID tag is an issue that cannot be overlooked because it influences the reader, and when the tag is at a 90 degree angle to reader, it cannot be read at all. Tags were situated at 45 degrees to the reader in cases C, D and E, in which it was observed that Bluetooth and Wi-Fi influence the reader, but not in all situations. The reason is that the experiment results of 45 degree tags to reader in case D, some obstacles caused higher error rate. However, the experiments in case C did not result in any error. In case E, the read error rate was only influenced by the angle of the tags, and Bluetooth and Wi-Fi did not interfere with the reader. Overall, it was determined that distance results in more reading errors than angling the tag within 45 degrees to the reader. In Cases B and D, the issue of angle influenced the effectiveness of reading the tags.

Obstacles located between the tag and reader and behind the tag reduce signal strength and obstruct the transmission of the signal to the reader. The materials used in the experiments provide a better understanding of the factors influencing the read performance of RFID with regard to interference. During the testing process, we simulated barriers of different materials used for in the packaging of items in supermarkets. According to our experiment results, we found that as long as the distance between the RFID reader and tag was within 7 cm, none materials, except metal or a divergence radio items, are interfered by the transmission. It would be necessary to operate the RFID system at different frequencies and signal strengths to avoid interference caused by these materials.

In theory, interference from metallic items should be greater than the interference from books; however, the results of this experiment indicate that the interference from books and packages was greater than the interference from aluminum foil packaging. We believe that this is because these two kinds of items covered a larger area, effectively blocking the tag from the reader, preventing the reader from reading the label.

Our experimental results show that error rates are influenced by distance and the angle of the tags. An increase in distance results in a higher error rate, but an increase in power could improve reading results. Angling the tags away from the reader led to an increase in error rate; however, shortening the distance or increasing the power could improve this situation. However, two additional problems occurred: (i) The use of passive tag limits the acceptable distance between the tags and reader; (ii) high powered readers cause more interference. To overcome these problems (i), we need to improve the response distance of the tags or reduce the cost of active tags; (ii) the disadvantage of RFID sensing is that it cannot transmit through metal

plates. Thus, it would be possible to use these obstacles for each checkout lane to enable the use of higher power readers, while avoiding the problem of interference between them. In addition, a large angle of the tag leads to large tag antenna directivity that makes the reader cannot identify well. Thus, we suggest a circular reading device in to identify tags at different angles.

## CONCLUSIONS

Items in supermarkets come in many shapes and packaged using various materials. This inevitably leads to the possibility that tags will not be read by the reader. Readers are unable to read tags attached to various materials, such as sheet metal, thick metal plating, and aluminum foil bags. In addition, we must consider distance and angle of the tag relative to the reader, because both of these variables influence the accuracy of the reader. We suggest designing a circular reader, increasing the strength of the signal, and separating checkout lanes with obstacles to prevent interference among multiple readers.

## ACKNOWLEDGMENT

This work was supported in part by National Science Council (NSC), Taiwan, under Grant Number NSC 99-2220-E-415 -001.

## REFERENCES

- Avoine, J., Floerkemeier, C., & Martin, B. (2009). RFID Distance Bounding Multistate Enhancement. *Lecture Notes in Computer Science*, 5922, 290-307.
- Bae, J. H., Choi, W., Kim, J., Choi, G. Y., & Chae, J. S. (2009). Study on the Demodulation Structure of Reader Receiver in a Passive RFID Environment. *Progress in Electromagnetics Research*, 91, 243-258.
- Chen, P., Liu, Z., & Lai, S. (2004). The Analysis and Design of a Novel Passive Reflection Modulation Tag. *4th International Conference on Microwave and Millimeter Wave Technology*, (pp. 402-405). Guangzhou, China.
- Chen, S. Y., & Hsu, P. (2004). CPW-Fed Folded-Slot Antenna for 5.8 GHz RFID Tags. *Electronics Letters*, 40 (24), 1516–1517.
- Cichos, S., Haberl, J., & Reichl, H. (2002). Performance Analysis of Polymer Based Antenna-Coils for RFID. *Polymers and Adhesives in Microelectronics and Photonics*, (pp. 120-124). Technische Univ. Berlin, Germany.
- Dobkin, D. M., & Weigand, S. M. (2005). Environmental Effects on RFID Tag Antennas. *Microwave Symposium Digest*, (pp. 135-13). Enigmatics, Sunnyvale, CA, USA.
- Fritz, G., Berouille, V., Nguyen, M. D., Aktouf, O., & Parissis, I. (2010). Read-Error-Rate Evaluation for RFID System On-Line Testing. *IEEE Mixed-Signals, Sensors and Systems Test Workshop (IMS3TW)*, (pp. 1-6). La Grande Motte.
- Haga, T., Horikoshi, Y., Tsukamoto, S., & Hoshino, H. (2007). Two-Dimensional Location and Direction Estimating Method. *6th International Special Topic Conference on ITAB*, (pp. 296-297). Tokyo, Japan.
- Ju, S., Wang, D., & Du, B. (2010). Research and Development of QoS for RFID Middleware. *2010 Second International Conference on Computer Modeling and Simulation*, (pp. 397-402). Sanya, China.

- Karjoth, G., & Moskowitz, P. A. (2005). Disabling RFID Tags With Visible Confirmation: Clipped Tags are Silenced. *Workshop on Privacy in the Electronic Society*, (pp. 27-30). Alexandria, Virginia, USA.
- Li, Y. J., Chen, C. S., Song, Y. Q., & Wang, Z. (2007). Real-Time QoS Support in Wireless Sensor Networks: A Survey. *7th IFAC Int Conf on Fieldbuses & Networks in Industrial & Embedded Systems (FeT'07)*. Toulouse, France.
- Liu, Y., Huang, C., Min, H., Li, G., & Han, Y. (2007). Digital Correlation Demodulator Design for RFID Reader Receiver. *Wireless Communications and Networking Conference*, (pp. 1664-1668). Shanghai, China.
- Rao, K. V., Nikitin, P. V., & Lam, S. F. (2005). Antenna Design for UHF RFID Tags: A Review and a Practical Application. *IEEE Transactions on Antennas and Propagation*, 53 (12), 3870-3876.
- Sidney, D. M., Eric, M., Lee, M., & James, M. (2008). Impact of Position and Orientation of RFID Tags on Real Time Asset Tracking in a Supply Chain. *Journal of Theoretical and Applied Electronic Commerce Research*, 3 (1), 1-12.
- Tsai, M. H., Lai, Y. H., & Wen, Y. F. (2009). On Studying on Short-Range RFID Interference with Customer's Accessories. *In Conf. of TANET*.
- Tu, Y. J., & Piramuthu, S. (2008). Reducing False Reads in RFID-Embedded Supply Chains. *Journal of Theoretical and Applied Electronic Commerce Research*, 3 (2), 60-70.
- Wei, J., & Yan, M. (2007). Bit Error Rate Analysis of Wi-Fi and Bluetooth under the Interference of 2.45 GHz RFID. *The Journal of China Universities of Posts and Telecommunications*, 14, 89-93.
- Weinstein, R. (2005). RFID: A Technical Overview and Its Application to The Enterprise. *IT Professional*, 7 (3), 27-33.
- Zhou, S., Ling, W., & Peng, Z. (2007). An RFID-Based Remote Monitoring System for Enterprise Internal Production Management. *The International Journal of Advanced Manufacturing Technology*, 33 (7-8), 837-844.