Study of RFID Technology Applied to Parts Distribution Center in the Utility Sector

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Abstract

The trend of smart technologies has also impacted the warehousing sector. The technologies including radio frequency identification (RFID) bring the promises of lowering transport cost and bringing visibility to the supply chain. In this research, we investigated the factors impacting the RFID readability, measured by received signal strength indicator (RSSI), in the parts distribution centers of the utility sector. Factors such as horizontal distances and material characteristics were explored and analyzed; horizontal distance levels were assigned at 1, 2, 3 and 4m while commonly found materials in parts distribution centers including paper, wood, plastic and metal were chosen. One-factor and two-factor experiments were conducted according to the procedure of design of experiment. The analysis of variance (ANOVA) and follow-up tests performed on the collected data yielded interesting, valuable results which may be useful for the implementation of a RFID system. Additionally, the practical suggestions for setting RFID environment were provided.

Keywords

Radio Frequency Identification (RFID) Technology, Design of Experiment (DoE), Utility Sector, Warehousing, and Received Signal Strength Indicator (RSSI).

1. Introduction

With the advent of new, smart technologies adopted by various industry sectors, the warehousing sector is without exception pushing for upgrade toward smart warehouses. Zebra Technologies (2020) reported that radio frequency Identification (RFID) was among the ten technologies for helping achieve the vision of smart warehouse by minimizing the delivery time of goods and lowing transportation costs. RFID had its beginning in World War II for preventing the friendly fire by the air force; after the war, the RFID has been used in every walk of life, especially in the modern warehousing. According to Eurostat (2010), about 29% of companies in the European Union (EU) use RFID in the supply chain management and inventory tracking.

Nichols (2020) reported that five benefits RFID may provide to the warehousing operations:

1. Improve accuracy and visibility of asset
2. Enhance the tracking of goods from the warehouse to the destination
3. Heighten security
4. Prevent loss through the integration with the alert system
5. Lower related usage risks associated with equipment

Particularly, the parts distribution centers in the utility sector, with hundreds of maintenance parts in various sizes, makes them good candidates ripe for RFID technology for parts tracking and identification.

RFID technology has been used in years. Not surprisingly, researches related to RFID technology has been massive. Lim et al. (2013) conducted the literary survey of RFID technology in the warehouse from 1995 to 2000. Nevertheless, they did not report on the performance, reading capability and practical guidelines of handheld RFID terminal or tags in their survey. On the other hand, GS1—an organization responsible for standardizing bar codes and labels for the logistics industry around the world did—provide a few recommendations on assigning particular types of RFID reader for certain settings, such as having fixed RFID readers used for the convey belt and warehouse exit. The topics of the performance of equipment or reading capability are not discussed.

When it comes to reading quality of tags, existing literatures discuss mostly about whether the RFID tags are read—rarely have researchers quantify their RFID tag performance research, particularly on levels of *received signal strength indicator* (RSSI). MetaGeek website describes RSSI as a measurement of how well a device may receive an access point or router—a value indicating the relatively quality of a received signal (MetaGeek 2021). Additionally, the indicator does not have neither a unit nor absolute value. The IEEE 802.11 standard specifies that RSSI values range from 0 to up 255, and each chipset manufacturer has their own defined "RSSI_MAX" value (IEEE 2012). For example, the wireless equipment maker, Unitech, set the RSSI values at the range of 0-100.

The guidelines for attaching RFID tags to items seemingly have not existed as far the authors are aware of after checking various industry standards including GS1. The authors of this research believe that even though the topics or discussions of the benefits or advantages of RFID technology are important and conducted by most existing RFID researches, the performance and practical usage of RFID hardware are also concerned by the industry, specifically the reading performance of RFID at the busiest times of warehouse operations. Therefore, the research focuses on simulating the parts distribution center in the utility sector and experimenting with a RFID reader and passive RFID tags. The readability performance of RFID technology then is subject to the verification by the design of experiment (DoE) to determine the potentially influential factors such as material, distance, multiple tagging, etc. Later, the collected data then are analyzed systematically through the Statistical Package for the Social Sciences (SPSS) software. The specific objectives come out of this study include:

a. Understand the factors for influencing the readability of RFID tags
b. Use the design of experiment to analyze those factors
c. Suggest the proper way for using the RFID tags

2. Literature Review

In this section, we present the discussions of existing literatures on topics concerned in this research: RFID technologies with its applications in the warehousing setting and design of experiment with its methodologies and applications for finding significant factors.

2.1 RFID Technology

Naohisa et al. (2006) introduced the device of "smartLocator", which was an indoor location management system consisted of RFID and infrared red (IR) technologies to improve warehousing efficiency of receiving and delivery. It worked by allowing mobile devices such as personal data assistant (PDA) with IR receivers to receive the location ID signals from IR transmitters installed on the warehouse ceiling. When a worker scanned RFID tags on the incoming items using his or her PDA, the PDA linked the asset IDs with the location ID received from the IR transmitter and registered the information wirelessly with the assets location management server. In other word, the storage location of each item was automatically input into the warehouse management system thanks to the technology.

Golding and Tennant (2010) reported the performance testing of RFID through the evaluation of DoE in the setting of a RFID library system. Their contributions include a methodology to investigate the performance of RFID library inventory reader; the methodology includes a DoE approach for analyzing four decision variables—read angle, read distance, tag location and shelf material—and one response variable, read rate. Their findings indicated that read angle, read distance and tag location significantly impacted the readability performance of a RFID reader.

Wang et al. (2010) proposed a digital warehouse management system (DWMS) based on the RFID system for the tobacco industry. In the system, they defined a set of basic events and storage/retrieval rules to improve the feasibility and flexibility of DWMS. Their contribution was that the DWMS, with integration of RFID, computer and communication technologies, enabled a warehouse to automate storage/retrieval management, provide real-time inventory management and achieve accurate shelf management.

Hassan et al. (2012) conducted the research to evaluate the reading performance of all types of RFID tags in a warehouse environment with the contributions of (1) providing an overview of the existing real-time data management techniques in resource tracking, (2) proposing an overall conceptual framework for helping warehousing management to choose the RFID technology and (3) designing an experiment for reading performance evaluation of semi-passive RFID tags.

Cruz and Pedrasa (2019) evaluated a RSSI-based localization technique on an emulated active RFID system. They discovered that RSSI based distance estimation was linear in short range and became unstable in long range with variance of 1.33m.

Park et al., (2020) developed an inventory localization method for indoor RFID system used in the small and medium enterprises (SMEs). The method was particularly designed for multi-stacking racking (MSR). To achieve the inventory tracking, the authors introduced reference tags and performed the measurement calculation for the distance between the RFID reader and reference tag to improve the accuracy of locating items. In the research, they verified their concept through a case study of an electronic device manufacturing company. From their findings, their idea achieved the same efficacy and applicability as the existing active RFID-based method but at a relatively lower cost, making it attractive and suitable to SMEs.

2.3 Design of Experiment

According to Durakovic (2017) and Guo and Mettas (2012), the design of experiment can be used in various situations. The commonly usage of DoE include the following:

1. Comparison
2. Variable screening
3. Transfer function identification
4. System Optimization
5. Robust design

Abdul Hamid et al. (2018) presented a dual band RFID system embedded with glucose meter by integrating a passive interrogator with an active tag to enable automatic patient detection. They discovered that the embedded RFID system in the multihop wireless sensor network was able to keep the integrity of the glucose data. They also relied on the design of experiment to determine the influential factors on the performance of throughput of the system. Three factors were investigated: packet length, number of hops and type of RFID. The analyzed results indicated that the larger packets increased the throughput while the number of hops contributed to the decreasing effect of the throughput.

Okati et al. (2016) conducted the design of experiment to investigate different parameters that influenced the humidification-dehumidification cycle of a solar desalination system in terms of fresh water production. They reported that those parameters of inflowing air cross-section, velocity, relative humidity, temperature of the air flowing into the cycle as well as the still water temperature all significantly influenced the performance of the humidification-dehumidification cycle.

From the literatures surveyed above, we can tell even though RFID technology and design of experiment have been extensively researched and applied in a wide range of fields, the related research articles on both topic are relatively few in numbers.

3. Methods

The research follows the steps delineated by Montgomery (2013), which include (1) Recognition of the problem, (2) Selection of the response variable, (3) Choice of factors, levels and range, (4) Choice of experimental design, (5) Performing the experiment and (6) Statistical analysis of the data. By carrying out those steps, we may systematically come up with the conclusions based on unequivocal, unbiased evidences and thus provide practical recommendations.

3.1 Experiment Setting and Constraints

The research was carried out at the National Kaohsiung University of Science and Technology with all attempt to simulate the environment of a parts distribution center. The experimental setting was shown below in Figure 1. The ambient temperature were kept constantly around 25-27°C.

Figure 1: Experiment setting for this research

In addition to the constraint of being a simulated environment instead of the real environment at the parts distribution center, other constraints also existed:

1. With so many varieties of RFID readers and tags, we have chosen handheld RFID terminal and passive tags to conduct the research.
2. The data values presented in the research are not exact values since the deviations exist even for tags at the same frequency.
3. We have selected items for the experimentation with same material characteristics as similar as those found at the parts distribution center since we cannot obtain the exact items from the parts distribution centers.
4. The experiment only focuses on small items rather than large items.
5. So many factors may potentially impact the readability of UHF RFID tags. Therefore, the research chooses those common factors that may likely to be encountered by the warehouse personnel.

3.2 Tools, Equipment and Items Used in the Experiment

As mentioned earlier, the equipment used in the research include handheld a RFID handheld reader and passive tags. The specifications and appearance of the RFID handheld reader and passive tags are displayed in Table 1, Figure 2 and Table 2, respectively.

Table 1. Specification of RFID handheld terminal (Unitech 2020)

Unitech HT510 RFID Rugged handheld Terminal		
OPERATION SYSTEM	OS	Android 7
	CPU	1.45GHz Quad Core
	Memory	2GB RAM/16GB Flash
	Language support	Multi-language
RFID TECHNOLOGIES	UHF	Frequency : 865~868MHz, 902~928MHz Protocol : EPC global Class 1 Gen 2 ISO 18000-6C/6B Antenna gain : 3dbi Output Power : 1-30dbm adjustable Data Capture Range : 6~8 meters
	HF	Frequency 13.56Mhz ISO14443A/B, ISO15693 standard, NFC, MIFARE, Felica
COMMUNICATION	WLAN	IEEE 802.11a/b/g/n/ac

Figure 2: Unitech HT510 RFID rugged handheld Terminal (Unitech 2020)

Table 2. Specification of UHF RFID tags

Chipset	Characteristic	Tag Size	Range	Figure
Higgs 4	Generic type	98x50 mm	6 m	
Alien Higgs-3	Anti-metal	75x15x1 mm	2 m	

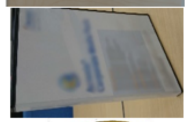
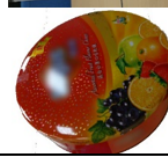
The experiment requires the following tools: a stop watch, a tape measure and a glow tape shown in Table 3.

Table 3. Tools required in the experiments

Tool	Number of Unit	Explanation
Stop Watch	1	Timing
Tape Measure	1	Measuring horizontal distance
Glow Tape	1	Specifying horizontal positions

The materials investigated in this research with respect to the readability of RFID tags include: paper box, wooden board, plastic box and metal box. Those were commonly found materials in parts distribution centers in the utility sector, corresponding to boxes, wooden crates, cables with plastic coating and transformers. The detailed description of those are listed in Table 4 below.

Table 4. Materials investigated in the experiment

EXPT. MATERIAL	UNIT	DETAILED INFORMATION	FIGURE
Paper Box	1	Dimensions:26cm×20.5cm×16.5cm	
Wooden Board	1	Dimensions: 50cm ×29.5cm × 0.5cm	
Plastic Box	1	Dimensions:19cm × 13.5cm× 1.5cm	
Metal Box	1	Dimensions: diameter 23cm; thickness 7cm	

3.2 Procedures and Types of Experiments

Two types of experiments are discussed in this paper: (1) horizontal distance (one-factor experiment) and (2) horizontal distance and material (two-factor experiment). The experiment procedures are presented in the following two sub-sections.

3.2.1 Horizontal Distance Experiment (One-Factor Experiment)

The objective of horizontal distance experiment is to determine the RSSI values at different distances, which are those levels in the one-factor experiment, and ensure they are significantly different from one another. The experiment procedure is listed below.

1. The experimenter initially uses the RFID reader to determine the maximum distance that RFID tags may be detected as the reference point for setting the levels. The experimenter found that the maximum distance was around 6m; therefore, the interval between levels was set at 1m, with factor levels at 1m, 2m, 3m and 4m. For each round, the experimenter measures a RFID tag for a time interval of 1 minute.
2. The experimenter holds a regular RFID tag at the chest level and stands still at a particular location while the other experimenter stands at one particular distance and holds the RFID reader about the same height as that of RFID tag.
3. The experimenter with the RFID reader presses the **Scan** button to conduct the tag reading/data collection for 1 minute as shown in Figure 3.

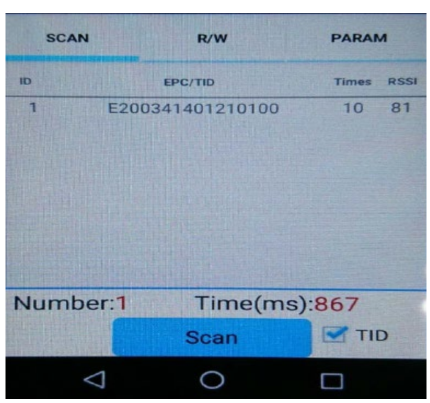


Figure 3: Scanned RFID tag information are recorded in RFID handheld terminal

4. The experimenter with the RFID reader presses the Scan button to stop recording when the "Time" reaches 60,000ms or 1 minute.
5. The experimenter then transfers the collected data to the desktop computer through the built-in Bluetooth wireless device.
6. The experimenter holding the RFID tag remains still while the other experimenter holding the RFID reader moves to the next distance/level. The experimenter repeats Step 2 to Step 5 until all data are collected for various levels.

3.2.1 Horizontal Distance and Material Experiment (Two-Factor Experiment)

The objective of horizontal distance and material experiment is to determine the RSSI values with respect to two factors— distance and material. For this experiment, the *anti-metal* RFID tag was used since a metal material was involved. The experiment procedure is listed below.

1. The experimenter determines the different levels for horizontal distance (factor 1) and for materials. The horizontal distance levels were set at 1m, 2m, 3m and 4m while the material levels were assigned as paper box, wooden board, plastic box and metal box.
2. The two-factor experiment procedure is almost the same as the *one-factor experiment* with the exception that the experimenter repeats the procedure steps for *each* material.

4. Results and Discussion

The data results from the one- and two-factor experiments—horizontal distance and horizontal distance- materials, respectively— are discussed in this section. The data analysis was conducted through the statistical software used in the SPSS.

4.1 Numerical Results

The analysis of regular RFID tags' RSSI at various horizontal distances is shown in Table 5. From the results we can tell that RFID reader recorded the strongest mean value of RSSI at 67.30, while the weakest mean value, 44.00, was recorded at 4m. The results of homogeneity of variance test indicated the variability among the sample means. Further testing—Brown-Forsythe and Welch—still indicated results as significant at significant level 0.05. We discovered that the post hoc analysis of Games-Howell at the significant level of 0.05, the mean value at level of 1m was still the largest in relation to other distances. Hence, to have the best readability in terms of RSSI, the distance of 1m between the RFID tag and reader was the most suitable.

Table 5. Simple main effect analysis of RSSI at various horizontal distances and materials

Horizontal Distance (m)	Sample Size (N)	Mean	Std. Dev.	homogeneity of variance (Levene/ p^* value)	ANOVA (F value/p value)	Post hoc (Mean difference)
1	1911	67.30	2.67		Variability	1m >2m,3m,4m
2	1533	44.09	3.59		among the	Significant
3	1650	45.65	4.13		sample	Difference
4	1761	44.00	2.89		means	3m > 2m,4m
				1159.76/<.001	Brown-	Significant
					Forsythe	Difference
					20843.01/0	(Games-
					Welch	Howell)
					28874.75/0	

$P^* < .05$

Tables 6 and 7 contain the two-factor analysis results of various horizontal distances and materials. The strongest and weakest RSSI values were specified with the **boldface** type. Peculiarly, from Table 6 the overall strongest RSSI mean value,73.14, was recorded at 1m and with RFID tag attached to the plastic box; the overall weakest RSSI mean value, 42.48, at 4m was also recorded for the plastic box. In regards to the material being paper, the horizontal distance at 1m yielded the strongest RSSI value, 69.83; however, the distance at 3m yielded the weakest RSSI value at 52.87, even weaker than RSSI (53.23) at 4m. In regards to the material being wood, unsurprisingly, the strongest and weakest

RSSI were recorded at 1m and 4m, respectively. The readability of the metal with respect to RSSI was probably the most unexplainable. In regards to the material being metal, the strongest RSSI was recorded at 3m while the weakest RSSI was recorded at 4m.

Table 6. Two-factor descriptive statistics of horizontal distance and material

	Plastic		**Paper**		**Wood**		**Metal**	
	n	*M(SD)*	*n*	*M(SD)*	*n*	*M(SD)*	*n*	*M(SD)*
1m	2112	**73.14(3.90)**	1515	**69.83(2.44)**	1560	**54.85(4.57)**	1422	51.50(4.15)
2m	2151	53.33(3.08)	1692	59.60(1.69)	1593	54.47(2.64)	1110	49.31(2.99)
3m	1713	56.05(2.71)	1461	**52.87(3.75)**	1494	50.08(2.89	1110	**55.09(4.03)**
4m	1572	**42.48(3.42)**	1776	53.23(2.70)	1578	**47.66(3.69)**	1299	**46.34(2.58)**

Note: the bold numbers represent the strongest and weakest RSSI for each material

From Table 7, we also knew that the horizontal distance-material interaction is *significant* because the *p* value (0.00) is much smaller than the significant level at 0.05. Therefore, the follow-up test—simple main effect— was performed and analyzed results was collected in Table 8.

Table 7. Two-factor variance analysis of horizontal distance and material

Source of Variance	*SS*	*df*	*MS*	*F*	p^*	η^2
Horizontal Distance	709623.77	3	236541.26	22085.02	0.00	.725
Material	267177.61	3	89059.20	8315.14	0.00	.498
Horizontal Distance * Material	484503.81	9	53833.76	5026.27	0.00	.643
Error	269282.98	25142	10.71			

$p^* < .05$

The analyzed results of simple main test was recorded in Table 8. The simple effect test is a follow-up test when the interaction is significant. The test examines the difference between groups within one level of one of the independent variables to explore the nature of the interaction (Newsom 2021).

In Table 8, we can tell that RFID tags attached at various materials and distances were all significant. Additionally, the post-hoc (follow-up) comparison indicated that the a RFID tag attached at the surfaces of plastic, paper and wood and at the distance of 1m generated the significantly strongest RSSI than other combinations. At 3m, the reader recorded the strongest RSSI for the metal material. Overall, the reader recorded significantly *strongest* RSSI values for plastic material at distances of 1m and 3m and for paper material at distances of 2m and 4m.

Table 8. Variance analysis of simple main effect for horizontal distance and material

Source of Variance	**SS**	***df***	***MS***	***F***	***p****	**Post-hoc (Tukey HSD)**
Factor A (Horizontal Distance) vs. b_1(Plastic)	911415.32	3	303805.11	27483.23	0.00	1m>2m,3m,4m 2m>4m 3m>2m,4m
vs. b_2 (Paper)	292001.82	3	97333.94	13250.85	0.00	1m>2m,3m,4m 2m>3m, 4m 4m>3m
vs. b_3(Wood)	57325.67	3	19108.56	1534.23	0.00	1m>2m,3m,4m 2m>3m, 4m 3m>4m
vs. b_4 (Metal)	48832.37	3	16277.46	1315.17	0.00	1m>2m, 4m 2m>4m 3m>1m,2m,4m
Factor B (Material) vs. a_1(1m)	578165.03	3	192721.68	12953.59	0.00	plastic > paper, wood, metal paper > wood, metal wood> metal
vs. a_2 (2m)	76839.73	3	25613.24	3626.72	0.00	plastic > wood paper > plastic, wood, metal wood > plastic, metal
vs. a_3 (3m)	31960.82	3	10653.61	968.00	0.00	plastic >paper, wood, metal paper> wood Metal > paper, wood
vs. a_4 (4m)	99472.44	3	33157.48	3366.88	0.00	paper > plastic, wood, metal wood > plastic, metal meatal > plastic

$p^*<.05$

4.2 Graphical Results

The interaction effects of various horizontal distances and Materials are displayed in Figures 4 and 5. We can tell from the figures that the interaction effects existed between horizontal distances and materials since all curves of horizontal distances intersected with those of materials. Additionally, the strongest RSSI values all recorded at 1m for all materials with the exception of metal. Moreover, in contrary to our intuition, the strength of RSSI did not get weaker as the distances got further away; therefore, we may conclude that materials did play roles in influencing the readability of a RFID tag.

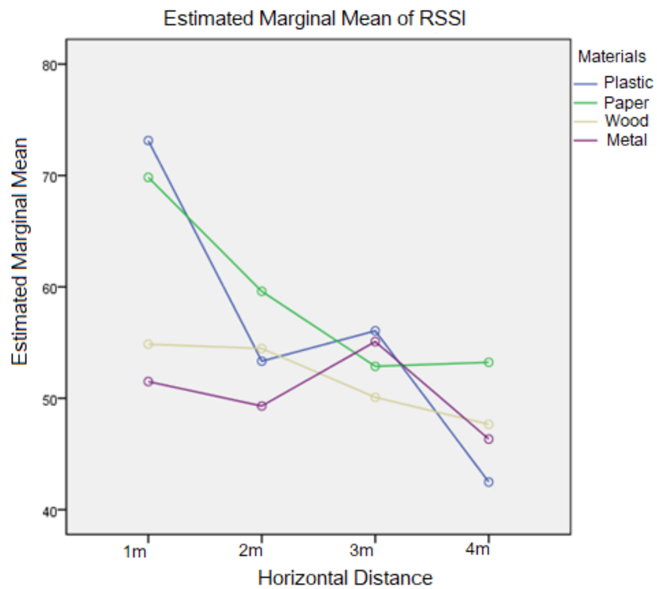


Figure 4: Interaction effect of horizontal distance and material

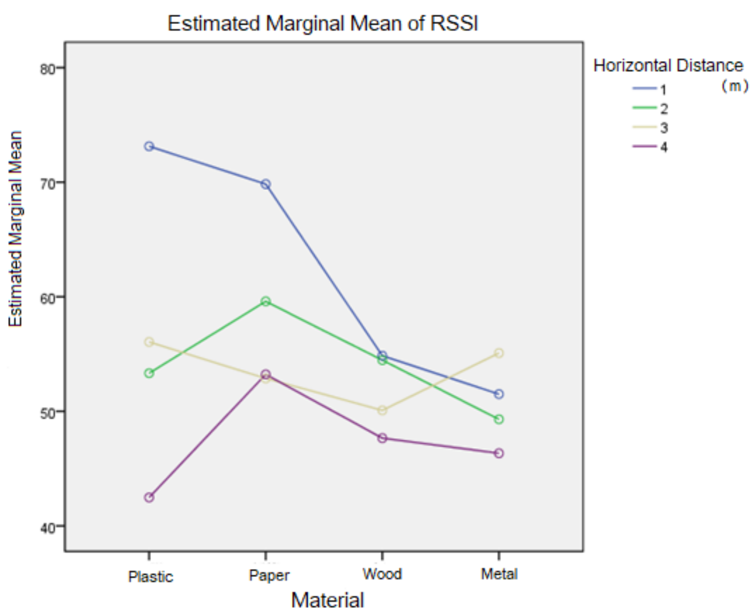


Figure 5: Interaction effect of material and horizontal distance

5. Conclusion

The research set out to investigate the factors for influencing the readability of RFID tags in the setting of parts distribution centers in the utility sector. Horizontal distances and materials were determined to be influential factors for impacting RFID readability. The response variable assigned in the research was received signal strength indicator (RSSI). One factor and two factor experiments were conducted to collect the data. Those collected data were analyzed through one-factor, two-factor ANOVA and follow-up tests. The analyzed results indicated that for the one-factor experiment (horizontal distance), we obtained the strongest RSSI value at distance of 1m while the weakest at 4m. All levels were significantly different with *p* value much lower than significant level of 0.05. For the two-factor experiment (horizontal distance and material), the interaction effect of distance and material existed with *p* value much lower than the significant level of 0.05. Additionally, the strongest RSSI values were recorded for the plastic box at distances of 1m and 3m. Both strongest and weakest RSSI values were recorded at 1m and 4m, respectively, for the plastic box in comparison with other materials. RFID readability was most peculiar for the metal box with the strongest RSSI value at 3m and weakest at 4m.

From the results, we may reach the conclusion that the RFID tag worked the best with the plastic material. Moreover, the RFID readability performance weakened as the distance got longer if no other factor was involved. With two factors of distance and material, the interaction effect impacted the readability and the strength of RSSI did not get weaker in a linear fashion.

The research is unique in addressing the practical aspects of RFID environment in terms of readability. The results may provide useful information to both academia and industry for better understanding the characteristics of RFID.

The contributions of this research are not only limited to the warehouse setting, however. By having a better understanding the characteristics of RFID tags, the results from the research can be easily applied to somewhere where RFID technologies are concerned.

Since the experiments mainly took place in an academic setting, it would be more realistic if further experiments can be performed at the industrial setting. Additionally, some more factors can be performed such as multi- RFID tag and water immersion experiments.

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