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Testing of Radio Frequency Identification and Parameter Analysis Based on DOE

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ABSTRACT

The maximum read range of a Radio Frequency Identification (RFID) system depends on a number of factors. In this paper, the maximum read ranges of an RFID system with a handheld RFID reader and another RFID system with a fixed RFID reader were tested when a tag was attached to different materials. Distinguishing factors that influence the maximum read range is important. A design of experiments (DOE) method was used to understand and quantify the relative influence of three factors (the antenna number, the tagged material, and the RF interference) on the maximum read range of the RFID system with a fixed RFID reader. The influences of the three factors and their interaction effects were classified by an order of importance. The methods in this paper also apply to the study of other RFID systems and determining the relative influences of other selected factors or parameters as well as other materials.

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1. INTRODUCTION

A number of factors influence the RFID read range. They can be the frequency, the reader antenna gain, the polarization of the reader antenna and the transponder (tag) antenna, and the placement of the tag on the object to be identified. Using multiple antennae connected to the reader unit or antenna arrays can increase the gain [1]. The material to which the tag is attached such as a metal or a container with liquid, as well as the environmental factors such as ambient humidity and the RF noise also affect the read range.

If the interrogator (reader) antenna and tag antenna are both linearly polarized and when the two antennae are at right angles to each other, the tag will not be read. When the tag is parallel to the reader, the tag will be read. Therefore, read accuracy and range not only depends on the volume of the region that receives sufficient power from the reader but also depends on the relative orientations of the reader antenna and the tag antenna and their polarizations. A proposed methodology to determine optimal antenna locations along with the powering region with multiple antennas was presented [2]. Circular antennas will read tags from about any angle with respect to the interrogator antenna. When circularly polarized antennae are used, the effect of polarization mismatch can be neglected and the angle between the reader antenna and the transponder antenna has no effect on the read range [1].

Some materials such as metals and liquids (or moisture) interfere with tag performance. Tags mounted to items made from or containing these materials may not perform as expected [2]. Therefore, the tagged material has a significant effect on the read rate and the read range. Alleged 100% read rates are only attainable when attaching tags to cardboard material and are not close to the alleged 100% read rates with a metal or a liquid material [3]. Metals, liquids, and moisture interfere with radio waves; therefore, they interfere with tag performance and affect the readability of frozen food, canned goods, and liquid products

[1] [2] [4] [5]. Although the ultra high frequency (UHF) technology has a longer reading distance than the high frequency (HF) technology, its performance is greatly affected when metals or water is in the tag vicinity [6]. As the tags were brought closer to the aluminum plane, the read range was decreased [7].

A big challenge in RFID large-scale deployment is the RFID signal interference and reader collision. Reader collision is a phenomenon that the interrogation signal from a reader jams a reply of a tag to another reader [8]. RFID devices can disrupt the operation of other RFID devices operating in close proximity. Especially in a dense reader environment with UHF, there will be multiples of RFID readers and reader interference will reduce the reliability and efficiency of the RFID system. In the worst situation, the interference can paralyze the entire RFID system [9] [10].

In this paper, I tested a MC9090-G RFID Mobile Computer (with a handheld RFID reader) [11] and a BlueBean RFID Development Lab System (with an Alien RFID fixed reader ALR-9900) [12] [13], and measured the maximum read ranges (distances) between the reader and the tag when the tagged item is cardboard, a bottle with Coke Zero, or a metal, respectively. A design of experiments (DOE) method [14] was employed to understand and quantify the effects of three factors on the maximum read range of the BlueBean RFID Development Lab system. The three factors are: the antenna number of the reader ALR-9900, the tagged material, and with/without the interference from the reader of the MC9090-G RFID Mobile Computer.

2. RESEARCH METHOD

An MC9090-G RFID Mobile Computer and a BlueBean RFID Development Lab System were used to test the maximum read range under different conditions in the Automated Identification Technology lab at Mississippi Valley State University, USA. The two kinds of RFID equipment are shown in Figure 1 and Figure 2, respectively.

Figure 1. Symbol (Motorola) MC9090-G RFID Mobile Computer

Figure 2. BlueBean RFID Development Lab System

The MC9090-G RFID Mobile Computer was developed by Symbol (Motorola), the Enterprise Mobility Company. It has a dual function: reading RFID tags and capturing one- dimensional (1D) and two-dimensional (2D) bar codes. Several main parameters and features of the RFID Mobile Computer [11] are listed in Table 1:

Table 1. Several main parameters and features of the MC9090-G RFID Mobile Computer

Item	MC9090-G RFID
CPU	Intel® XScale™ Bulverde PXA270 processor at 624 MHz
Operating system	Microsoft Windows Mobile 5.0 with the Messaging and Security Feature Park
Memory (RAM/ROM)	55.90 MB
RFID standards supported	EPC Generation 2 UHF
Antenna	Integrated, circularly polarized
RFID frequency range	US: 902-928 MHz; Europe: 865.7-867.5MHz
Output power	US: 1W (2W EIRP) Europe: 0.5w

The BlueBean RFID Development Lab System mainly includes a BlueBean RFID Development Lab Kit, the Alien RFID Gateway demonstration software [13], and a computer. The BlueBean RFID Development Lab Kit was developed by BlueBean, LLC that is a RFID consulting and systems integration company. The kit mainly includes a portal and an ALR-9900 RFID reader with a pair of antennae. The RFID portal is on wheels for easy transport. Antennae are fixed at the same horizontal line on each side of portal. Several main parameters and features of the ALR-9900 RFID reader [12] are provided in Table 2. Before using the ALR-9900 RFID reader, open the 'Alien RFID Gateway' software from the shortcut on the desktop.

Table 2. Several main parameters and features of the ALR-9900 RFID reader

Item	ALR-9900 RFID reader
Architecture	Point-to-multipoint reader network, mono-static antenna
Supported RFID tag protocols	EPC Gen 2; ISO 18000-6c
Antenna	4 ports, monostatic topology, circular polarization
Frequency range	902.75 MHz – 927.25 MHz
RF power	Max 4 watts EIRP with Alien Antenna

An RFID tag with a UPM Belt Antenna and an Impinj Monza 5 chip was used for the reading operation of the MC9090-G RFID Mobile Computer and the BlueBean RFID Development Lab System. The protocol support of the tag complies with EPC Class 1 Gen 2 and ISO 18000-6C.

Move the MC9090-G RFID Mobile Computer (with a handheld reader) slowly away from the tag until the reader cannot read the tag, and measure the maximum read range (distance). For the BlueBean RFID Development Lab system (with an Alien RFID fixed reader ALR-9900), move the tag slowly away from the fixed reader until the reader cannot read the tag, and measure the maximum read range. The tagged materials in this research are a slice of cardboard, a bottle with Coke Zero, and metallic materials.

A design of experiments (DOE) method was used to analyze various factors' impacts on the maximum read range of the BlueBean RFID Development Lab system. The DOE method helps eliminate unnecessary or undesirable experimentation and provide accurate information. Three independent factors and one dependent variable were used. The dependent variable is the maximum read range. The three independent factors include: the antenna number of the reader ALR-9900 (using one antenna or two antennae of the pair of antennae), the tagged material, and with/without the interference from the MC9090-G reader (integrated in the MC9090-G RFID Mobile Computer). The three factors are each tested at two different levels. The levels generally are the minimum and maximum (or lowest and highest) target values for a factor. The factors and the level description are listed below:

The antenna number of the reader: one (-1) and two (+1)

The tagged material: stapler with steel (-1) and cardboard (+1)

Interference: with the MC9090-G reader (-1) and without the MC9090-G reader (+1)

3. RESULTS AND ANALYSIS

3.1. Testing Results Using the MC9090-G RFID Mobile Computer

Position the tag in front of the MC9090-G RFID Mobile Computer, change the orientation of the tag. It was found that the orientation change almost did not have any effect on readability and the maximum read range for the same tagged material. The reason is that the handheld RFID reader has a circularly polarized antenna. It was also found that the reader was not able to read the tag at every attempt and there were multiple missed cases when the read range was or close to the maximum read range. The tag was attached to various materials (paper, liquid, and metals) to test and demonstrate the readability of the MC9090-G RFID handheld reader and the effects of materials on the maximum read range. The tagged items are: a cardboard, a bottle with Coke Zero, a clip (with less steel), a stapler (with more steel), and the side part of a computer case (with aluminum). Table 3 shows the maximum read ranges when the materials were tagged. It indicates that the maximum read range decreases due to the interference created by the metals and the liquid. The stapler made the maximum read range decrease more than the clip because of more steel. The operating frequency range is 902-928 MHz (UHF). UHF's short wavelengths tend to get absorbed by liquids and reflected by metals, which reduces the read range.

Table 3. The maximum read range of the MC9090-G RFID Mobile Computer

Tagged material	Cardboard	Coke Zero	Clip (with less steel)	Computer case (with aluminum)	Stapler (with more steel)
Maximum range (cm)	306.3	176.5	161.1	54.0	13.4

3.2. Testing Results Using the BlueBean RFID Development Lab System

Similar to the MC9090-G RFID Mobile Computer, the tag orientation change almost did not have any effect on readability and the maximum read range of the BlueBean RFID reader ALR-9900 for the same tagged material because the reader has a pair of antennae with a circular polarization. The antennae were placed at 112.3 cm above ground. The distance between the two antennae were 186.5 cm. Move the tag slowly away from the fixed reader until the reader cannot read the tag, and at this time the distance between the read and the tag is regarded as the maximum read range. The reader was not able to read the tag at every attempt when the read range was or close to the maximum read range. The tag was attached to the same materials that were used in testing the MC9090-G RFID Mobile Computer. They are: the cardboard, the bottle with Coke Zero, the clip, the stapler, and the side part of a computer case. The experiment was to test and demonstrate the readability of the BlueBean RFID reader ALR-9900 and the effects of materials on the maximum read range. Table 4 shows the maximum read ranges when these materials were tagged. It was found that the maximum read range decreased due to the interference created by the metals and the liquid. The reader ALR-9900 has a greater maximum read range than the MC9090-G RFID Mobile Computer because of a greater RF power. The level of available power is an important determinant of range performance.

Table 4. The maximum read ranges of the BlueBean RFID Development Lab System

Tagged material	Cardboard	Coke Zero	Clip (with less steel)	Computer case (with aluminum)	Stapler (with more steel)
Maximum range (cm)	528.5	256.0	225.2	174.1	104.7

3.3. DOE Analysis and Results

A two-level factorial DOE methodology was used to study the effects of various factors on the maximum read range of the BlueBean RFID Development Lab System. The selected factors are: the antenna number, the tagged material, and the interference from the MC9090-G RFID Mobile Computer. They are denoted by A, M, and I, respectively. The maximum read range is denoted by R. Each of the three factors has two levels. The DOE approach using a fractional factorial design based on the orthogonality principle requires 2^3= 8 tests. Table 5 shows the three factors, the orthogonal table, and experiment arrangement for testing the maximum read range of the BlueBean reader ALR-9900 based on the orthogonality principle. R_1, R_2 …, and R_8 represent the maximum read ranges in eight tests, respectively. During testing interference, the distance between the MC9090-G mobile reader and either antenna of the reader ALR-9900 was 198.4 cm.

Table 5. Three factors, orthogonal table, and experiment arrangement

Antenna number: *A*	Tagged material: *M*	Interference: *I*	Antenna number: *A*	Tagged material: *M*	Interference: *I*	Maximum range: *R* (cm)
-1	-1	-1	1	stapler (steel)	with MC9090-G	R_1
1	-1	-1	2	stapler (steel)	with MC9090-G	R_2
-1	1	-1	1	cardboard	with MC9090-G	R_3
1	1	-1	2	cardboard	with MC9090-G	R_4
-1	-1	1	1	stapler (steel)	without MC9090-G	R_5
1	-1	1	2	stapler (steel)	without MC9090-G	R_6
-1	1	1	1	cardboard	without MC9090-G	R_7
1	1	1	2	cardboard	without MC9090-G	R_8

The effects (main effects and interaction effects) [14] [15] of the three factors (*A*, *M*, and *I*) on the maximum read range R can be calculated according to the formulas (1) - (7) [14]. A_{eff}, M_{eff}, and I_{eff} are main effects representing the effect of the antenna number, the tagged material, and interference on the maximum read range, respectively. AM_{eff}, AI_{eff}, MI_{eff}, and AMI_{eff} are interaction effects representing the effect of two factors (*A* and *M*, *A* and *I*, and *M* and *I*) and three factors (*A*, *M*, and *I*), respectively.

$$A_{eff} = (-R_1 + R_2 - R_3 + R_4 - R_5 + R_6 - R_7 + R_8)/4 \quad (1)$$

$$M_{eff} = (-R_1 - R_2 + R_3 + R_4 - R_5 - R_6 + R_7 + R_8)/4 \quad (2)$$

$$I_{eff} = (-R_1 - R_2 - R_3 - R_4 + R_5 + R_6 + R_7 + R_8)/4 \quad (3)$$

$$AM_{eff} = (R_1 - R_2 - R_3 + R_4 + R_5 - R_6 - R_7 + R_8)/4 \quad (4)$$

$$AI_{eff} = (R_1 - R_2 + R_3 - R_4 - R_5 + R_6 + R_7 + R_8)/4 \quad (5)$$

$$MI_{eff} = (R_1 + R_2 - R_3 - R_4 - R_5 - R_6 + R_7 + R_8)/4 \quad (6)$$

$$AMI_{eff} = (-R_1 + R_2 + R_3 - R_4 + R_5 - R_6 - R_7 + R_8)/4 \quad (7)$$

The maximum read ranges in the eight tests and the calculated main effects and interaction effects are shown in Table 6 with the orthogonal table. Table 7 summarizes the normalized results from the DOE study and demonstrates the main effects as well as the interaction effects on the maximum read range. The results indicate that the metal steel is the most influential factor on the maximum read range of the BlueBean RFID reader ALR-9900. The next most influential factors are the interference from the MC9090-G RFID Mobile Computer and the antenna number, which are much less than the material effect. The RF power of the MC9090-G RFID Mobile Computer is much less than that of the BlueBean RFID reader ALR-9900; therefore, its interference is weak. The interaction of the two or three factors shows less influence on the maximum read range; and the interaction of the antenna number and interference has the least influence.

Table 6. Orthogonal table, the maximum read ranges, and calculated effects

Standard	*A*	*M*	*I*	*AM*	*AI*	*MI*	*AMI*	*R*
1	-1	-1	-1	+1	+1	+1	-1	50.4
2	+1	-1	-1	-1	-1	+1	+1	73.5
3	-1	+1	-1	-1	+1	-1	+1	407.2
4	+1	+1	-1	+1	-1	-1	-1	448.9
5	-1	-1	+1	+1	-1	-1	+1	91.6
6	+1	-1	+1	-1	+1	-1	-1	104.7
7	-1	+1	+1	-1	-1	+1	-1	469.8
8	+1	+1	+1	+1	+1	+1	+1	528.5
Estimated effect	34.15	383.55	53.65	16.05	1.75	17.45	6.75	

Table 7. Normalized effects on the maximum read range

Rank	Effect	Value of effect	Normalized effect
1	*M*	383.55	1.000
2	*I*	53.65	0.140
3	*A*	34.15	0.089
4	*MI*	17.45	0.046
5	*AM*	16.05	0.042
6	*AMI*	6.75	0.018
7	*AI*	1.75	0.005

4. CONCLUSION

The interference created by steel, aluminum, or Coke Zero decreases the maximum read ranges of the MC9090-G RFID Mobile Computer and the BlueBean RFID Development Lab System with the reader ALR-9900. The greatest maximum read range was achieved when the tagged material is cardboard. The BlueBean RFID Development Lab System has a greater maximum read range than the MC9090-G RFID Mobile Computer because of a greater RF power.

The DOE study of the main effects and the interaction effects of three factors (the antenna number, the tagged material, and interference) revealed that the metal steel was by far the most influential factor on the maximum read range of the BlueBean RFID reader ALR-9900. The next most influential factors were the interference from the MC9090-G RFID Mobile Computer and the antenna number, which were much less than the material effect. The interaction of the two or three factors showed less influence on the maximum read range, and the interaction of the antenna number and the interference exhibited the least importance.

Although this paper focused on the study of MC9090-G RFID Mobile Computer and the BlueBean RFID Development Lab System, and testing four tagged materials (Cardboard, Coke Zero, steel, and aluminum), the methodology of DOE also can be used to study other RFID systems and determine the relative importance for other factors or parameters as well as other materials.

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