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INVESTIGATING TYPE OF MATERIALS ON THE PRODUCTS AND RFID PASSIVE TAGS ON WIRELESS MONITORING RFID-SYSTEM USING 2-FACTOR FACTORIAL DESIGN

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Abstract *In manufacturing industries, the technology of radio frequency identification (RFID) or Auto ID is widely used due to its relatively straight-forward implementations. In production lines, there are many types of materials can be categorized based on the type of output products in manufacturing. This paper was to investigate the different types of materials such as metallic and non-metallic and types of tags that was focus on the implementation RFID system at the electronics industrial based. These two factors were investigated and study the relations between each other to study the effect on the RFID system using the conveyor. In this paper, Design of Experiments (DOE) method was used for the experimental set-up and result analysis by using two-factor factorial designs. This is to determine whether different materials on the products effecting the readability detection on the RFID system on the conveyor set. The experiment was conducted at Auto-ID Laboratory at USM by using the conveyor set. This paper presents the statistical results analysis which stated that the P-value for type of materials and type of tags were 0.00 which are significant effect on the readability of tag. The interaction between the two factors which were materials and tags given P-value of 0.00. The best tag for all materials was also determined on the result analysis part.*

Keywords: *RFID-system, DOE, Two-Factor Factorial Design, Two-way ANOVA*

1. Introduction

Radio Frequency Identification (RFID) is a wireless technology (non-contact) that consists of a tag (passive and active), reader and host computer for the identification of an object using radio waves. RFID tag consists of microchip with an antenna where it can send the unique identification (IDs) to the air when it receives electromagnetic wave which was radiated from the antenna. The reader will receive the data and process it to become a digital data in computer host.

Radio Frequency Identification (RFID) has been knowledge as a vital technology for the modern 21st century knowledge-based economy in worldwide in many sectors [1]. In manufacturing industries, the implementation of RFID technology has been identified on the traceability system in order for the improvement of efficiency in production floor, reduced cost and man power, mobility system and wireless system. According to E.W.T Ngai et al. , RFID adoption has become a new transformation in technology in manufacturing in order to the improvement of efficiency in the supply chain especially [2]. A growing numbers of organizations have been increasing to accept RFID technology which offers their benefits in long term period. The focus on this paper is to investigate the two factors which are types of materials and type of tags using DOE method in the proposed RFID system to be implemented at the production line.

The paper is organized as follows: In section 2 list out the literature review on the RFID technology and DOE study. In section 3, the detailed experimentation procedures and factors are explained. The data collection and data acquisition

procedures in terms of DOE are presented in section 4. The obtained analysis results from the DOE methods and discussion is discussed in section 5. Finally, conclusion is conferred in section 6.

2. Literature Review

In manufacturing the output products can be categorized in many types of materials such as paper, plastic, metal, glass and many more. Basically these types of product materials can be divided into two which are non-metallic and metallic materials. There are no standard in order to setting up the RFID system in production lines. Hence the experiments of DOE of statistical model need to investigate by selects all the factors at the production line. According to Amoldeep Singh Jaggi, factors that should be considered as a critical factor selection in the experiments such as package orientation, tag placement, package placement, reader location, box orientation, tag placement on box and tag placement on package [3]. Extended in Amoldeep experiment, for factor the package material the levels is set at two levels which are; metallic and non-metallic material types [3]. According on the researched by Ultan Mc Carthy et al., the factors selection on the experiments were tag detection rate were distance, sample, inlay design, conveyor speed and reader antenna polarisation to study their effects [4]. According Jesus Royo experiments, study the influence of the two factors which were the position of a tag and antenna position on the RFID system [5]. However, attenuation and scattering of the UHF electromagnetic wave in the presence of substances such as water and metal may cause suboptimal performance or even total failure to couple. Metal acts as a reflector of electromagnetic waves whereas water acts as an absorber, and these effects become more exaggerated as the frequency increases with its inherent high moisture content is prone to lower tag detection rate [4]. The main problems with RFID are including the tag collision, reader collision, false negative, false positive and the influence of certain materials such as metals and liquids [6]. From the literature reviews shows evidence of some studies on the factors that may affect to the performance RFID system to be setting-up in real environment in industries. In this paper the critical factors to investigate were types of product material and types of tag using conveyor set.

To determine RFID tags readability that were attached to the product placement on the conveyor set and design of experiment (DOE) method was performed in this experiment to study the influence of these factors to the proposed RFID system. The statistical design of experiments has been choose to plan the experiment in order to get an appropriate data collection to be analysed using factorial designs in order to gets the conclusion [7]. There are several types of DOE methods can be considered runs the experiment. Randomization, replication and blocking are the three (3) basic principles of experimental design [7]. At the beginning stage, by selects the factors, levels and ranges was the main important procedure to consider which may be influenced to the proposed RFID system. In this experiment, instead to measure the primary factor on the product material (metallic and non-metallic) and the best performance on the passive tag will be investigated. Hence the two-factor factorial design has been performed in this experiment. The parameter for the response was the readability of the RFID system in the percentage form. A test runs in a real environment at the production line done at an audio company has been investigated as a part of this project.

3. Experimental Setup and Factors

The wireless RFID system was design as a new embedded system by integrating the passive and active of RFID for wireless transmission and for longer transmission distance in production line. The new traceability of an embedded system in this experiment consists of the hardware as listed below:

i) *Passive reader*; at this section the RFID reader type (EPC-Electronic Product Code Class 1 Gen 2, Read/Write, Operates at both UHF (Ultrahigh frequency) frequency band (865-868 MHz) and UHF frequency band (919-923 MHz) and Programmable Reader ID for networking). The UHF white patch antenna was connected to the passive reader.

ii) *Active tag board*; the active tag board was connected to the passive reader using the RS232 cable. The components at this section were programmable IC (PIC18F), LCD display and ZigBee functionality embedded to the passive reader for longer transmission and wirelessly sends the data to the host computer.

iii) *Active reader board and host computer (PC)*; at this section active reader will capture all the IDs wirelessly to the database system where the information will be recorded and extracted when needed.

The experiment was conducted in the Auto-ID laboratory by using some equipment that was set-up with the wireless RFID system. The entire hardware was listed below:

i. *Conveyor set*; was set-up at the Auto-ID laboratory with the dimension of 6 feet long and 1 foot wide of the conveyor belt with counter clockwise running belt. The maximum load for this conveyor set is 10 kg load. There are 10 scales of speeds controller and was set up at fix one speed (constant speed) at the medium rate of speed during this experiment.
ii. *White patch antenna UHF*; the antenna was located at the same position besides the conveyor set during runs this experiment.

All the hardware involves were set and position at the same location during this experiment.

There are many types of materials in real environment in production line. It is important to investigate the readability of RFID system on the materials and type of tags to be study and analyzed the result. The investigated factors and its levels are stated in the table 1 below:

Table 1: Potential factors for DOE experiment

Factors	Levels
1. Type of products materials	5 levels (Plastic, Glass, Wood, paper, Metal)
2.Type of passive tags	2 levels (paper tag and universal tag)

A total of 20 products for each type of materials were attached with the type of passive tags. The dimension of 20 products was the same dimension for each type of materials has been used on the conveyor set. Before run the experiment, each of the passive tags was programmed with 12 and 14-bytes of unique identification number via Passive Writer. They were set with IDs starting from AIDL01TAGPAPER to AIDL20TAGPAPER and AIDL01TAGUNI to AIDL20TAGUNI. Each passive tag was attached to each 20 products on the conveyor set as in Figure 1 is an example of the metals products that was attached with the universal tag type on the conveyor set during the experiment.

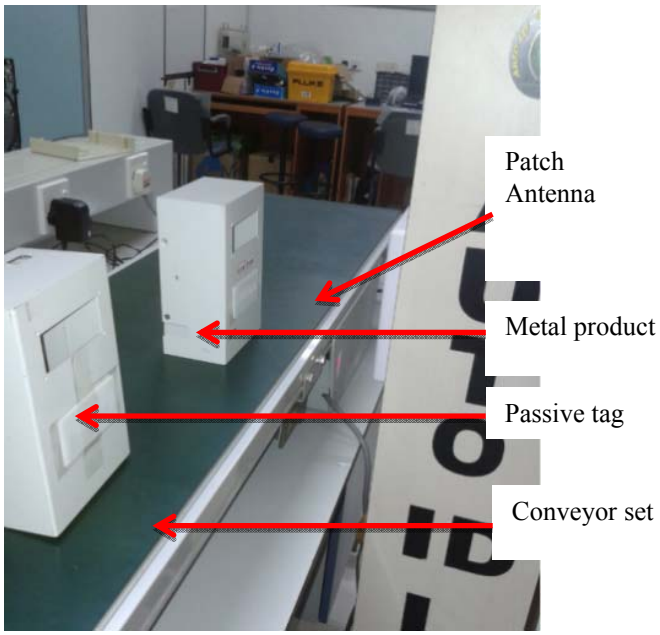


Figure 1: Type of metal product on the conveyor set

Each experiment runs with a total of 20 products that were attached with the passive tag. In this experiment, the 20 products for each material have a same dimension. The experiments was to investigated whether the materials of the products effect the readability of the RFID system in the production line as the output products in the manufacturing comes with different materials and to investigate the passive tag performance between paper tag and universal tag.

4. Statistical Model for Two-Factor Factorial Design

The main objective to run this experiment was to measure the two factors which were the products materials and type of tags effects on the proposed RFID system. Thus, the factorial design method was considered in this experiment which involves the study effect of two effects factor. Factorial design involves the replication of the experiment for all possible combinations of the level factors to be investigated [7]. The explanations in a factorial experiment can be derived by a model in equation (1-4) below [7]:

$$y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \epsilon_{ijk} \begin{cases} i = 1,2,\dots,a \\ j = 1,2,\dots,b \\ k = 1,2,\dots,n \end{cases} \quad (1)$$

Where, μ is the overall mean effect, τ_i is the effect of the *i*th level of row factor (product material), β_j is the effect of the *j*th level of column factor (type of tags), $(\tau\beta)_{ij}$ is the effect of the interaction between τ_i and $\beta_j$and $\epsilon_{ijk}$are random error component.

Factorial design is considered for this DOE experiment to investigate the primary factor which is the product materials (row factor) and the nuisance factor which is the type of tags (column factor). Where row factor was the product material and column factor was the type of tags.

In this DOE setup, 4 times replication was designed for the same totals number of the boxes. Hence the value a, is equals to five (5) with 5 levels of products material, b value is equals to 2 which two types of passive tags and n value is 4 with 4 replicates data. Consequently, the treatment and block affects as deviations from the overall mean so that. Thus the testing hypotheses of interest about the effects of equality of row treatment are:

$$H_o: \tau_1 = \tau_2 = \dots = \tau_a \quad (2)$$

$$H_1: at\ least\ one\ \tau_i \neq 0$$

The equality of column treatment effect is:

$$H_o: \beta_1 = \beta_2 = \dots = \beta_a = 0 \quad (3)$$

$$H_1: at\ least\ one\ \beta_j \neq 0$$

The equation for determining whether the row and column treatments interact is:

$$H_o: \tau\beta_{ij} = 0 \quad (4)$$

$$H_1: at\ least\ one\ (\tau\beta_j) \neq 0$$

Therefore equation (2), (3) and (4) derived to test the hypotheses of each factor:

Null Hypothesis, H0M: Product materials is not a significant factor, μ1= μ2 =μ3= μ4= μ5

Alternative Hypothesis, H1M: Product materialsis a significant factor, μ1≠ μ2, at least for one pair

Null Hypothesis, H0T: Type of tags is not a significant factor, μ1= μ2

Alternative Hypothesis, H1T: Type of tag is a significant factor, μ1≠ μ2, at least for one pair

An interaction is the failure of one factor to produce the same effect on the response at different levels of another factor [7]. Hence, the interaction between the factors is considered.

(1) Factors for materials

The objective of this experiment is to investigate the readability of RFID-system with different material on the products by using the conveyor set at the lab. Basically the material of products in manufacturing can be categorized as a metallic and non-metallic product. In this experiment, the materials type of plastic, glass, wood, paper and metal type has been selected as listed as in Table 2 below. Material was select as a primary factor in this experiment. A total of 20 products for each material with the same dimension have to be attached with the passive tag to run the experiment.

Table 2: Factors for materials for products

Type of materials	Factors on materials
Non-metallic	Plastic
Non-metallic	Glass
Non-metallic	Wood
Non-metallic	Paper
Metallic	Metal

All the 20 products were placed on the conveyor set with remains at the same speed of conveyor set for this experiment. All the products at the conveyor set with passive tag facing front and direct to the white patch antenna during the experiment. The objective of this experiment is to investigate the readability with the different materials by using the RFID system in line production. Figure 2 shows the products of box with wood material in this experiment.

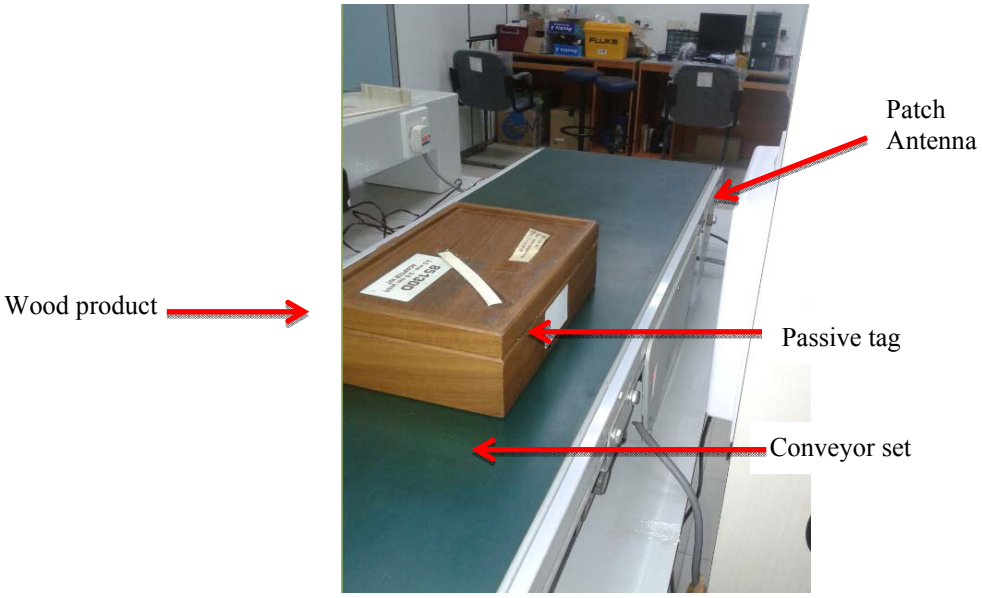


Figure 2: Wood type of products on the conveyor set

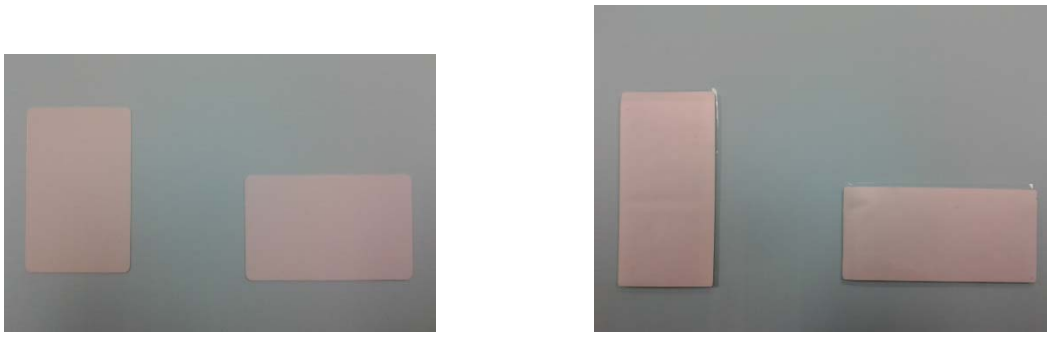
(2) Factors for type of passive tags

There are two type of passive tag has been choose on this experiment. The first type of passive tag was a paper type the dimension of 5.5 cm X 3.5 cm with a paper type of material. The second type of passive tag was namely as universal tag with the dimension of 7 cm X 3.5 cm. All the passive tags were programmed with their own IDs easily to be traced and installed in the database system. All the passive tags will be attached to each product before start the experiment. Table 3 listed the types and specifications for each type of passive tag.

Table 3: Factors for type of passive tags

Type of passive tag	Specifications
Paper tag	For non- metallic type
Universal tag	For all types of materials

Both passive tags easily can be stick on the product. Figure 3 below shows the types of passive tags with the vertical and horizontal positions.



(a) Paper tag of passive tag (b) Universal tag of passive tag

Figure 3: Type of passive tag (a) paper tag (b) universal tag

A detailed representation of the experiment set up is clarified in Figure 4. The flow of the data collection process is briefly described in Figure 5.

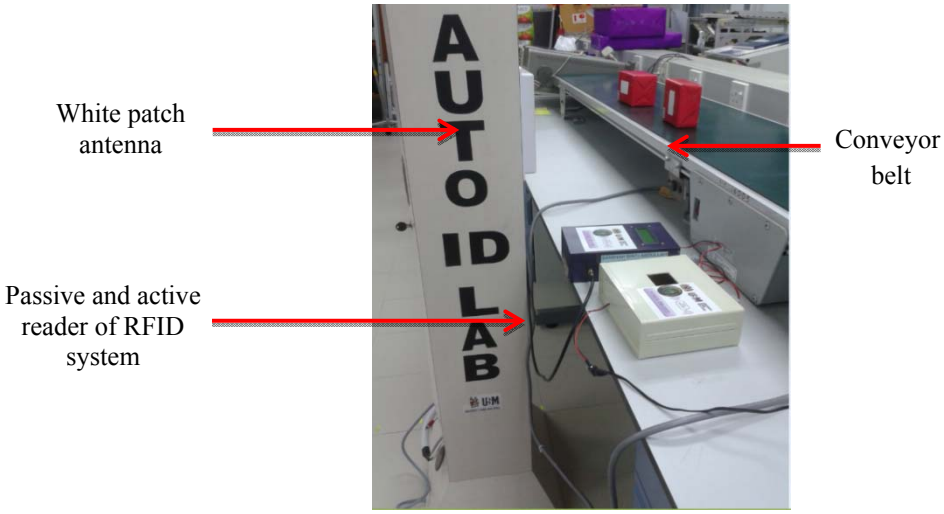


Figure 4: Experimental set-up in Auto-ID Laboratory

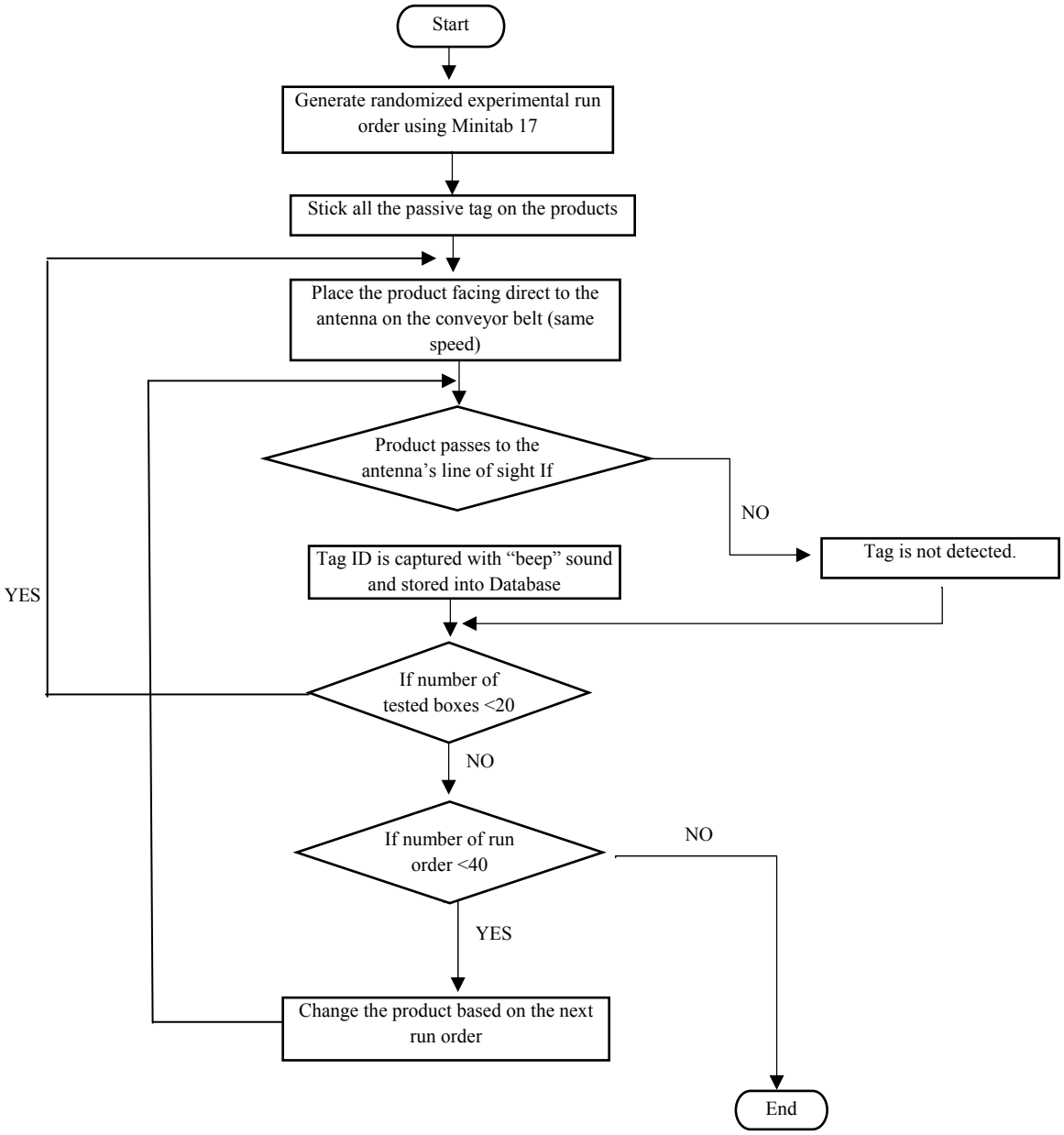


Figure 5: Experimental flow for data collection

5. Data Collection

Minitab 17 was used to generate the data as shown in Table 4 followed the run order sequence. As the tagged product was within the antenna's reading range, the detected IDs with respect to that were stored into a specific designed database with wireless transmission to the PC at frequency 2.4GHz. Then the IDs were then extracted and manually filled to complete as in the Table 4 and later convert in percentage form.

Table 4: Factorial design table for the DOE experiment

Run Order	Material product	Type of tag	Detection	Detection in Percentage
1	2	2	19	95
2	2	1	0	0
3	4	1	20	100
4	3	1	19	95
5	1	1	20	100
6	2	2	20	100
7	1	2	19	95
8	4	2	18	90
9	5	1	0	0
10	1	1	19	95
11	5	2	20	100
12	5	2	19	95
13	3	2	20	100
14	3	2	20	100
15	3	1	18	90
16	4	1	20	100
17	2	1	0	0
18	1	1	19	95
19	4	2	19	95
20	5	2	18	90
21	5	2	19	95
22	1	1	20	100
23	5	1	0	0
24	5	1	0	0
25	5	1	0	0
26	4	2	20	100
27	1	2	20	100
28	3	2	19	95
29	3	1	18	90
30	2	2	18	90
31	3	2	19	95
32	2	1	0	0
33	2	2	20	100
34	4	1	19	95
35	1	2	18	90
36	3	1	17	85
37	4	1	20	100
38	2	1	0	0
39	4	2	20	100
40	1	2	19	95

6. Statistical Result Analysis and Discussion

1- Two-way ANOVA

The detection in percentage was analysed by using Minitab 17 software using the Two-way ANOVA method. Table 5 presented the Two-way ANOVA analysis.

Table 5: Two-way ANOVA table detection in percentage versus material of products and type of tag

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	P-value
Type of material	4	22197.5	5549.4	0.000
Type of tag	1	15015.6	15015.6	0.000
Interaction	4	21700.0	5425.0	0.000
Error	30	356.3	11.9	
Total	39	59269.4		

(A) Analysis on the type of material

Null Hypothesis, H0M: Material is not a significant factor, $\mu1 = \mu2 = \mu3$

Alternative Hypothesis, H1M: Material is a significant factor, $\mu1 \neq \mu2$, at least for one pair

Based on the analysed results in Table (4), the p-value = 0.00, which is less than $\alpha = 0.05$. The null hypothesis is rejected showing that the materials of product play a prominent role in the readability of the RFID system. Materials do affect the readability of the RFID system.

(B) Analysis on the type of passive tag

Null Hypothesis, H0T: Tag is not a significant factor, $\mu1 = \mu2 = \mu3 = \mu4 = \mu5 = \mu6$

Alternative Hypothesis, H1T: Tag is a significant factor, $\mu1 \neq \mu2$, at least for one pair

Based on the analysed results in Table (4), the p-value = 0.00, which is less than $\alpha = 0.05$. The null hypothesis is rejected showing that the type of passive tag do effect the readability of the RFID system. Table 6 listed the value of mean for all the materials tested in this experiment which were plastic, glass, wood, paper, metal type.

Table 6: Mean for type of materials products in percentage

Type of materials of the products	Mean (Percentage)
Plastic	96.25
Glass	48.13
Wood	93.75
Paper	97.5
Metal	47.5

As in Table 6, the highest mean in percentage was a paper type followed by the plastic and wood with the mean value of 97.9, 96.25 and 93.75 respectively. These types of materials can be classified as non-metallic type. Whereas the type of glass of product with the mean value was 48.13 and the lowest value of mean was the metal type which determined at value 47.5. The highest mean indicates that the material from non-metallic type have high readability of RFID system. Table 7 indicates the mean value for passive tag that has been used in this experiment.

Table 7: Mean for type of passive tag in percentage

Type of passive tag	Mean (Percentage)
Paper tag	57.25
Universal tag	96.00

Table 7 shows the mean value in percentage form for the type of passive tag which are paper tag and universal tag. For mean analysis for type of passive tag the paper tags indicates the mean value 57.25 whereas the universal tag indicates the mean value 96. For paper tag its only suit for non-metallic (accept for glass) type of material only. The highest mean which was namely as a universal tag indicate the best performance in this experiment. Universal tag can detect the IDs using this RFID system for all the materials of non-metallic and metal type.

2- Main Effect Plot , Interaction Plot and Residual Plot

One of the advantages of factorial design is the ability to the main effect plot and inetraction plot represented blow as Figure 6 and Figure 7 below. Both graphes plotted for the factors and levels combinatios as of type of product materials with 5 levels and type of passive tags with 2 levels in percentage data.

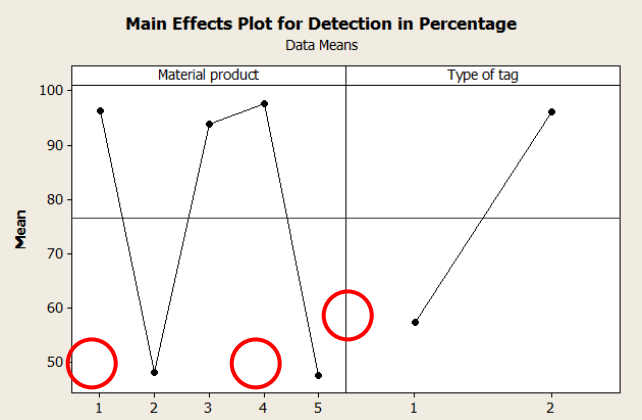


Figure 6: Main Effect Plot for data means for (i) Type of product materials (ii) Type of passive tag

As in Figure 6, the main effect plot indicates that the above the horizontal line for mean for type of product materials which were plastic, paper and wood types. The main effect plot indicates at below the horizontal line for mean for type of product materials which were glass and metal. For type of passive tags above the horizontal line was the universal tag whereas the below was the paper type. Figure 7 shows the interaction plots for data mean between two factors of type of product materials and type of passive tags.

As depicted in Figure 7, the interaction plots in percentage form for factors and levels combination. From the Figure 7 shows the interaction plot of materials and type of passive tags response to the percentage of detection of readability of RFID system. From the plotted graph, it shows that for the materials 2 and 5 has a lower readability detection which were glass and metal to the type of paper type of passive tags. While for the type of passive tags 1 which was paper type has a lower readability of tags for all the types of materials. For this DOE experiment the passive tag 1 (paper type) is choose because of small size which was dimension of 54 X 34 mm and paper type compare to the universal tags the size of tags was bigger. From the analysis results it shows that the paper tags types have highly performance on the non-metallic type which were plastic, wood and paper and hence has a lower detection on the glass and metal as in Figure 7. From the analysis results shown that the universal tags type robust to all types of materials including glass and metal types. These results reveal that the passive tag 1 which was the universal tag has given the best performance of readability of the proposed RFID system. The residual plot for the detection in percentage form is shown as in Figure 8.

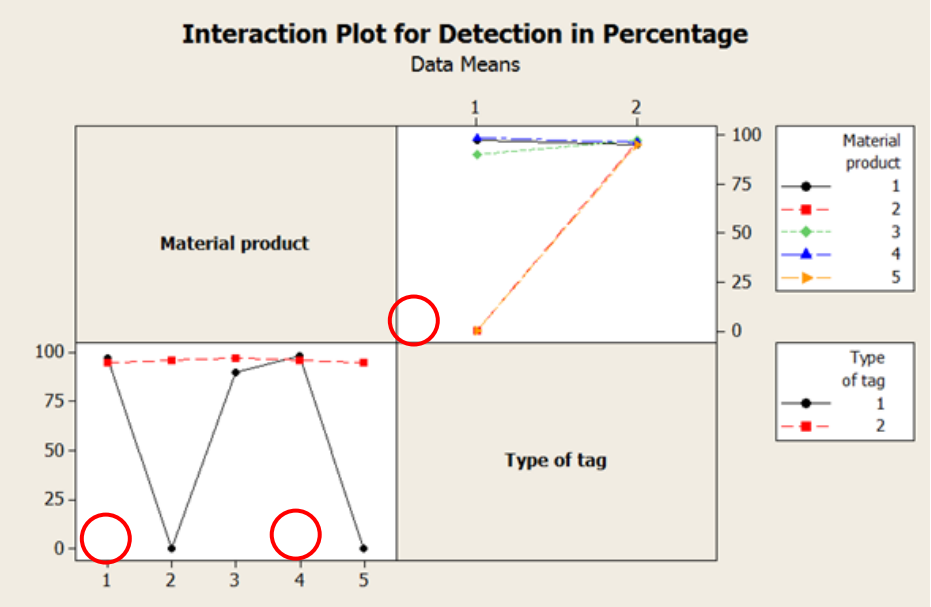


Figure 7: Interaction Plot for data means for (i) Type of product materials (ii) Type of passive tag

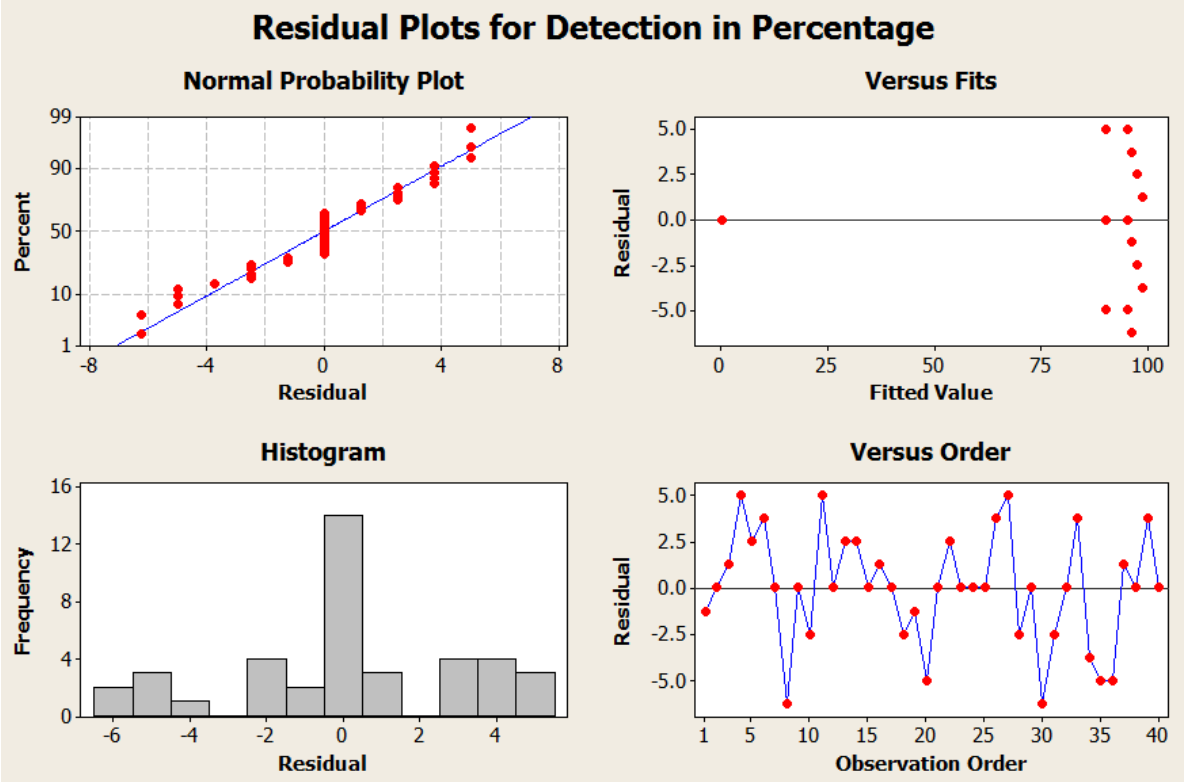


Figure 8: Residual plot

As depicted in Figure 8 the points in the normal distribution plot form a nearly linear pattern which indicates that the normal distribution is appropriate for this data set with no signs of departure from normality. For the fitted value is shows the data has normal plot with two conditions system of detection. The residual plot also shows the normal distribution of data to the RFID system.

7. Conclusion

From the analysed result, the data of percentage proved that the types of material and type of passive RFID tags does effect to the proposed RFID system. From the analysis for the Two-Way ANOVA using the two-factor factorial method the P-value for types of material for products and types of RFID passive tag is 0.000. The interaction also resulted the P-value is 0.000. From the materials product type of plastic, glass, wood, paper and metal the results shown that the glass and metal has a low result of mean value. Plastic, wood and paper has a high value of mean that has been tested with 2 types of passive RFID tags. For the type of passive RFID tag shown that the universal tag type has a high value of mean whereas the paper tag resulted very low. In conclusion, the type of universal tags is suitable to be used in this proposed RFID system in production line in industries for all types of materials of product.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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