A Study on the Effect of Mixing Rate of Defective Products on Defect Detection in Visual Inspection

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Abstract. In order to assure appearance quality of an industrial product, sensory inspection by human vision (visual inspection) is implemented in many manufacturing industries. This study focuses on the fact that the frequency of occurrence of defective products varies each time in production processes, and also considers the relationship between the mixing rate of the defective product and defect detection in visual inspection utilizing peripheral vision. Specifically, the mixing rate of defective products, defect location, and defect characteristics (luminance contrast between defect and inspection model and size) are designed as experimental factors, and their effect on inspection efficiency and inspection accuracy are evaluated with ten subjects. As a result, it is obtained that the inspection efficiency (inspection time) becomes lower and the inspection accuracy (defect detection rate) becomes higher according to the mixing rate of defective products. Consequently, it is clarified that inspection efficiency and inspection accuracy vary with the frequency of occurrence of defective products in production processes.

Keywords: visual inspection, peripheral vision, mixing rate of defective products, inspection efficiency, inspection accuracy

1. INTRODUCTION

In order to supply high-quality products to the market, manufacturing industries provide product inspection as much attention as processing and assembly. There are two types of inspection: functional inspection and appearance inspection. In functional inspection, the effectiveness of a product is inspected. In appearance inspection, small visual defects such as scratches, surface dents, and unevenness of the coating color are inspected. The automation of functional inspection has advanced because it is easy to determine whether a product works or not. However, it is not as simple to establish standards to determine whether the appearance of a product is defective. First, there are many different types of defects. Second, the categorization of a product as non-defective or defective is affected by the size and depth of the defect. Third, some products have recently become smaller and more complex. Finally, production has shifted to high-mix, low-volume production. It is thus difficult to develop technologies that can capture small defects and to create algorithms that can identify multiple types of defects with high precision. Therefore, appearance inspection still strongly depends on human visual inspection (Druty et al., 1986; Kleiner, 1993; Nickles, 2003).

As visual inspection is performed by humans, inspection efficiency and inspection accuracy are thus different by inspectors. It is a common problem in many manufacturing industries. Recently, a visual inspection method utilizing peripheral vision was proposed (Sasaki, 2005-2006), and the effectiveness of the method has been reported by manufacturing factories (Sugawara et al., 2011). Human vision can be divided into two ranges. Central vision is the 1–2° range of vision on either side of the center of the retina. The remaining range is known as peripheral vision. The spatial resolution of human vision decreases significantly with increasing angle from the center of the retina. The visual inspection method utilizing peripheral vision involves two steps: first, a wide spatial range is searched by peripheral vision; then, the type of defect is decided using the high spatial resolution of the central vision. Thus, low-level processes such as sampling and clustering are processed using peripheral vision, whereas high-level processes such as discrimination is processes using central vision, in order to reduce the amount of information to be processed. This allows for efficient visual information processing to be realized (Yoshida et al., 1992). The visual inspection method utilizing peripheral vision which can be realized high inspection efficiency and accuracy has been expected.

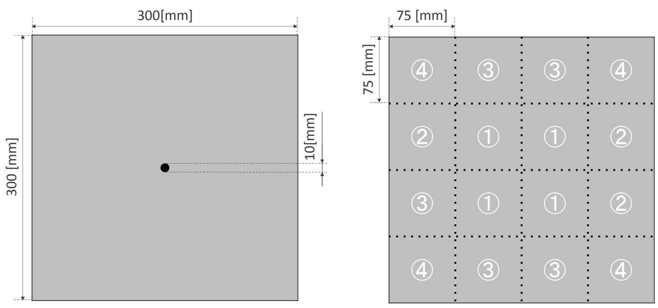
In general, the quality of products varies depends on complex factors such as the quality of low materials, the state of machines (equipment), and worker skill. Therefore, the frequency of occurrence of defective products varies each time in the production process. For example, there is a day (or time zone) which defective products does not occur, while there is a day (or time zone) which defective product continuously occurs. That is, in a situation where the mixing rate of defective products varies, inspectors are required to detect the defect. It is expected that the effect on the inspection efficiency and the inspection accuracy.

In this study, in order to consider the relationship between the mixing rate of defective products and the defect detection utilizing peripheral vision, an experiment is implemented using the mixing rate of defective products, defect location, and defect characteristics (luminance contrast between defect and inspection model and size) as experimental factors. The effect of these factors on the inspection efficiency and the inspection accuracy are examined.

2. EXPERIMENTAL DESIGN

2.1 Experimental Task

Experimental subjects are tasked with visually inspecting a model that is displayed on a monitor (CG276, EIZO Inc.). A model with height and width both equal to 300 mm and a black 10 mm diameter circle (used as a fixation point) on the center is used. This model is shown in Figure 1-a. The background color of the inspection model is set to an achromatic color.



a. Inspection model　　　b. Defect location

Figure 1: Inspection model and defect location

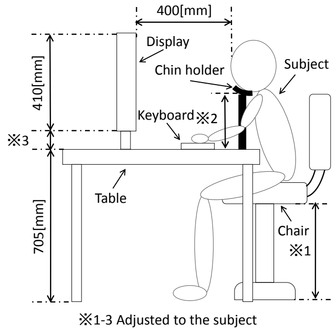


Figure 2: Experimental layout

In order to lead inspection utilizing peripheral vision, the subjects are requested to focus only at the fixation point during the experiment. If no defect is detected, the subject presses the SPACE KEY on the keyboard, and the next inspection model will be displayed. If a defect is detected, the subject presses the ENTER KEY.

The experimental layout is shown in Figure 2. In order to ensure a uniform visual distance between each subject and the inspection model, the chin holder is placed at a distance of 400 mm from the inspection model in order to fix the head of a subject.

2.2 Experimental Factors

2.2.1 Mixing Rate of Defective Products

The mixing rate of defective products is set to five different percentages, 10%, 30%, 50%, 70%, and 90%. As a result of a field survey of the visual inspection process, it is found that when low frequency of occurrence of defective products was detected, the mixing rate was approximately equal to a few percent, whereas when high frequency of occurrence of defective products was detected, the mixing rate was approximately 90%. The mixing rate of defective products is thus determined by considering the result of the field survey.

2.2.2 Defect location

The inspection model is divided into sixteen parts (4 × 4 horizontally and vertically), and the defect is located at the center of either one of these parts. As shown in Figure 1-b, the parts are divided into four areas, from area ① to area ④ according to the distance from the fixation point.

2.2.3 Defect characteristics

The defect characteristics are defined by the luminance contrast between the inspection model and the defect and by the size. The shape of all defects is circular. The luminance contrast of each defect is one of the three following levels: 0.10, 0.15, and 0.20. The size of the defect is specified by a diameter of 0.7 mm, 1.0 mm, and 1.3 mm. These defects are determined by assuming the standard of the appearance inspection.

2.3 Experimental procedure

Ten subjects, between aged of 21 and 24 years, are employed in this experiment. Only subjects with a corrected eyesight score (decimal visual acuity) higher than 1.0 are employed. In order to familiarize the subjects with the experiment, an overview is provided and the experiment procedure is explained. In addition, the subjects are requested to perform some preliminary experiments. In the experiment, the task is to inspect 1440 inspection models for each mixing rate of defective products.

The experimental room temperature is set between 18 and 24°C, and the humidity is set between 40 and 60%. Since the luminance of the inspection model and the defect are affected by external and internal light (such as fluorescent lighting), the experiment is implemented in a dark room. A written statement of the purpose and contents of the experiment is provided to the subjects, and informed consent is obtained from all subjects.

Using the results of the experiment, obtained using the aforementioned procedures, the inspection time per inspection model is calculated, which is the total inspection time divided by the total number of inspection models. It is expressed by Equation (1) and is used as an evaluation index of the inspection efficiency. In addition, the defect detection rate is calculated, which is the number of detected defects divided by the number of total defects. It is expressed by Equation (2) and is used as the evaluation index of the inspection accuracy.

$$\text{Inspection time [s]} = \frac{\text{Total inspection time}}{\text{Number of total inspection model}} \quad (1)$$

$$\text{Defect detection rate [\%]} = \frac{\text{Number of detected defects}}{\text{Number of total defects}} \quad (2)$$

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Individual Characteristics of Subjects

Using the inspection time and the defect detection rate, the effect of the mixing rate on defective products is examined. Owing to the possibility that the individuality of the subject might have affected the results, the uniformity of the results for all subjects is verified.

The inspection time of the subjects for each mixing rate of defective products is shown in Figure 3. The defect detection rate of the subjects for each mixing rate of defective products is shown in Figure 4. As a result of the Smirnov–Grubbs test shows that there are no outlier values in the inspection time and the defect detection rates of any of the subjects. Therefore, the data from ten subjects are used.

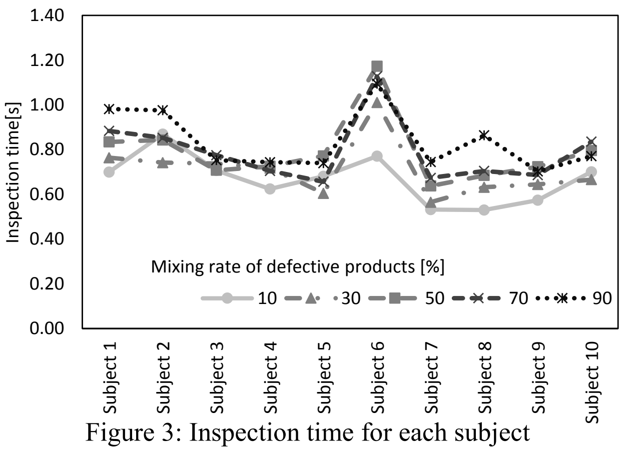


Figure 3: Inspection time for each subject according to mixing rate of defective products

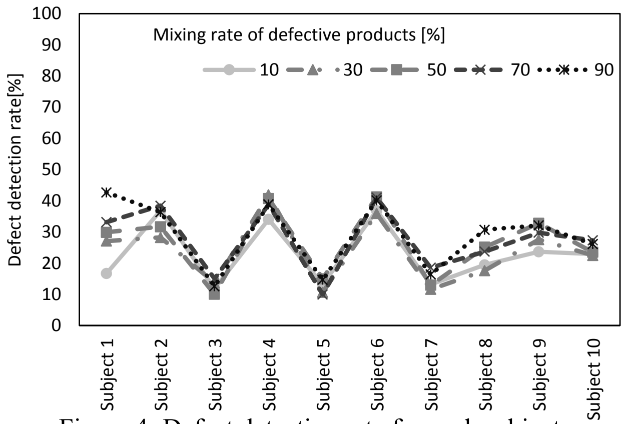


Figure 4: Defect detection rate for each subject according to mixing rate of defective products

3.2 Effect of Mixing Rate of Defective Products on Inspection Efficiency

In order to analyze the effect of the mixing rate of defective products on inspection efficiency, one-way ANOVA is executed with the mixing rate of defective products (5) as a factor. ANOVA table is shown in Table 1, and the effect of the mixing rate of defective products on the inspection time is shown in Figure 5. As a result, a significant difference of 1% is observed for the main effect. In addition, as sub-effect tests (Bonferroni method) of the main effect, an analysis of multiple comparisons is executed. As a result, a significant difference of 1% is observed between 10% and 50%, 10% and 50%, 10% and 90%, 30% and 90%. Based on the above results, it is found that the inspection time becomes significantly longer as the mixing rate of defective products increases.

Table 1: ANOVA for inspection time

p <0.05: *, P <0.01: **

Foctor	Sum of squares	Degrees of freedom	Mean square	F-value	Significant difference
Subject(S)	0.65	9	0.07		
Mixing rate of defective products(A)	0.19	4	0.05	11.94	**
S×A	0.14	36	0.00		
Total	0.98	49			

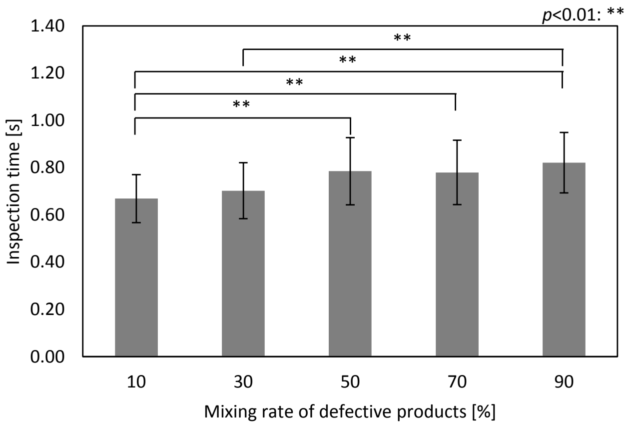


Figure 5: Inspection time for each mixing rate of defective products

3.3 Effect of Mixing Rate of Defective Products on Inspection Accuracy

In order to analyze the effect of mixing rate of defective products on inspection accuracy, three-way ANOVA is executed with the mixing rate of defective products (5), defect location (4), and defect characteristics (9) as factors. The ANOVA table is shown in Table 2, and the effect of the mixing rate of defective products on the defect detection rate is shown in Figure 6. As a result, a significant difference of 1% is observed for the main effect of the three factors. In addition, a significant difference of 1% is observed for the mutual interaction of the mixing rate of defective products and the defect characteristics and of the defect location and the defect characteristics. Moreover, an analysis of multiple comparisons is executed as sub-effect tests (Bonferroni method) of the main effect. As a result, a significant difference of 1% is observed between 10% and 70%, 30% and 70%, 30% and 90%. Based on the above results, it is found that the defect detection rate becomes significantly higher as the mixing rate of defective products increases.

The relationship between the mixing rate of defective products and the defect location is shown in Figure 7-a. In all defect locations, the defect detection rare becomes higher as the mixing rate of defective products. That is, it is found that the defect detection rate becomes higher as the mixing rate of defective products regardless of the defect location.

Table 2: ANOVA for defect detection rate

p <0.05: *, P <0.01: **

Foctor	Sum of squares	Degrees of freedom	Mean square	F-value	Significant difference
Subject(S)	152443.11	9	16938.12		
Mixing rate of defective products(A)	13902.34	4	3475.59	8.91	**
S×A	14048.55	36	390.24		
Defect location(B)	626308.99	3	208769.66	124.05	**
S×B	45441.21	27	1683.01		
Defect characteristics(C)	712363.45	8	89045.43	19.06	**
S×C	58788.91	72	816.51		
A×B	1700.81	12	141.73	1.19	
S×A×B	12907.49	108	119.51		
A×C	5890.86	32	184.09	2.55	**
S×A×C	20780.79	288	72.16		
B×C	200158.92	24	8339.95	17.46	**
S×B×C	103179.88	216	477.68		
A×B×C	16326.12	96	170.06	2.48	**
S×A×B×C	59159.61	864	68.47		
Total	2043401.05	1799	1135.85		

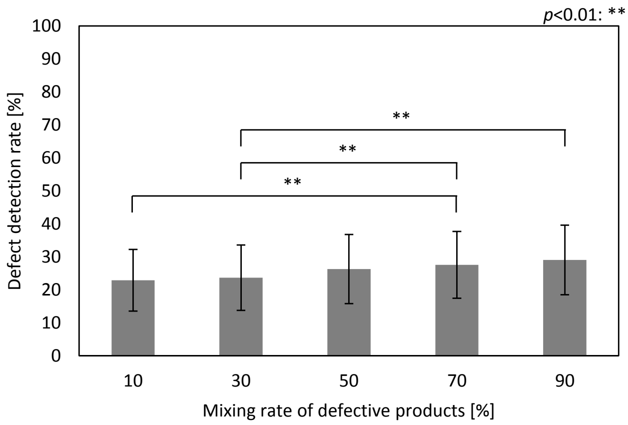
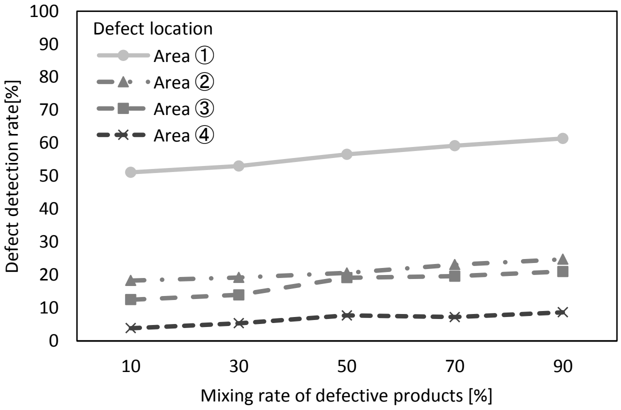


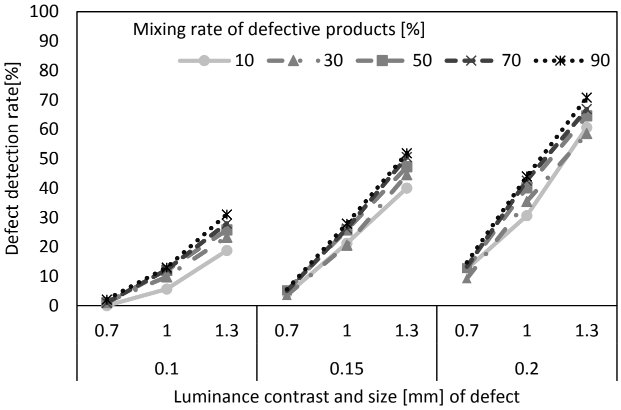
Figure 6: Defect detection rate for each mixing rate of defective products

Secondly, the relationship between the mixing rate of defective products and the defect characteristics is shown in Figure 7-b. In All mixing rate of defective products, the defect detection rate becomes higher as the defect characteristics (the luminance contrast and/or size of the defect) increases. However, as the mixing rate of defective products increases, the tendency is remarkable. That is, it is found that the degree of the effect on defect detection varies according to the defect characteristics.

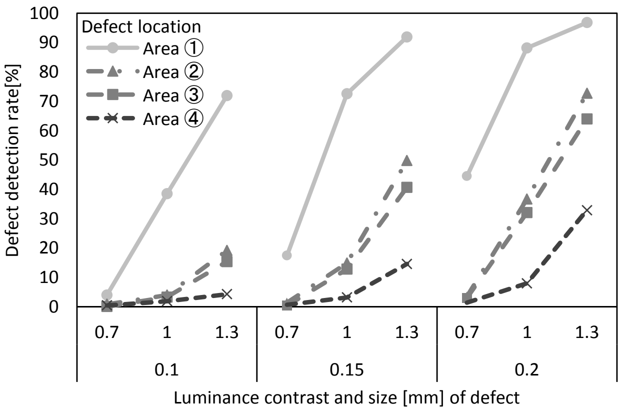
Finally, the relationship between the defect location and the defect characteristics is shown in Figure 7-c. In all defect locations, the defect detection rare becomes higher as the defect characteristics (the luminance contrast and/or size of the defect) increases. However, as the distance between the fixation point and defect location decreases, the tendency is remarkable. That is, it is found that the degree of the effect on defect detection varies according to the defect characteristics.



a. Relationship between mixing rate of defective products and defect location



b. Relationship between mixing rate of defective products and defect characteristics



c. Relationship between defect location and defect characteristics

Figure 7: Interaction between experimental factors

3.4 Discussion

From section 3.2 and 3.3, it is found that the inspection efficiency (the inspection time) and the inspection accuracy (the defect detection rate) varied in accordance with the mixing rate of defective products. Then, in order to analyze the effect of the mixing rate of defective products on the inspection efficiency and the inspection accuracy in an integrated manner, the result which plots the inspection time and the defect detection rate for each mixing rate of defective products of all subjects is shown in Figure 8. The correlation coefficient of inspection time and defect detection rate is 0.56. There is a certain degree of correlation between the inspection time and the defect detection rate. It is assumed that the subjects pay more attention to inspect than usual since "The next inspection model might also be a defective product" as the mixing rate of defective products increases with the inspection time and the defect detection rate. From the above results, it is clarified that the inspection efficiency and the inspection accuracy vary according to the frequency of occurrence of defective products in production processes.

On the other hand, applying the plotted date to the approximate curve ($y = 33.22\ln(x) + 35.01$) the coefficient of determination is 0.32, it is confirmed that the inspection time is not the only factor that impacts the defect detection rate. In the future, it is necessary to examine and focus on the psychology and the consciousness of inspectors due to the change of the mixing rate of defective products.

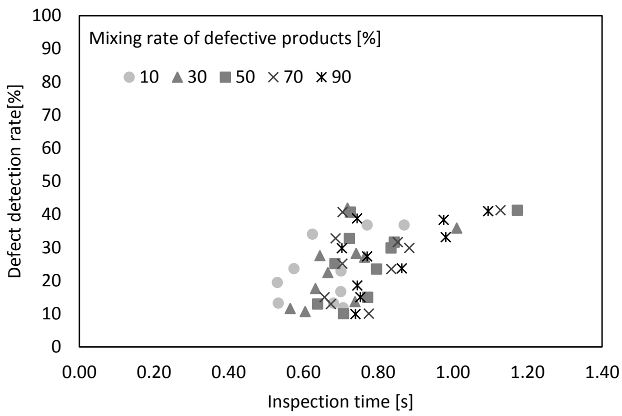


Figure 8: Relationship between inspection time and defect detection rate

4. CONCLUSION

In order to consider the effect of the mixing rate of defective product on the inspection efficiency and the inspection accuracy in visual inspection utilizing peripheral vision, the experiment was designed using the mixing rate of defective products, defect location, and defect characteristics (luminance contrast between defect and inspection model and size) as experimental factors in this study. The effect of these factors on the inspection efficiency and the inspection accuracy are examined with ten subjects. As a result, it is obtained that the inspection efficiency (the inspection time) becomes lower and the inspection accuracy (the defect detection rate) becomes higher according to the mixing rate of the defective products. That is, it is clarified that the inspection efficiency and the inspection accuracy are different according to the frequency of occurrence of defective products in the production processes.

In a future, we will consider in more detail the relationship between the mixing rate of defective products and defect detection for each location area and for each defect characteristics. We will also consider the psychology and consciousness of inspectors due to change of the mixing rate of defective products.

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