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A Study on the Effect of Defect Shape on Defect Detection in Visual Inspection

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Abstract

In order to assure appearance quality of industrial products, inspection by human vision (visual inspection) is implemented in many manufacturing industries. In visual inspection, small visual defects such as cracks, scratches, dirt, nicks, stains, surface dents, and unevenness of the coating color are inspected. This study focuses on differences in defect shape on an inspection surface, and considers the relationship between defect shape and defect detection rate in visual inspection utilizing peripheral vision. Specifically, defect shapes, defect locations, and defect characteristics (luminance contrast between the defect and the inspection surface and size) are designed as experimental factors, and their effects on defect detection rate of twelve subjects are evaluated. As a result, it is obtained that the defect detection rate of line defect is lower than the other shapes (triangle, square, and circle) of defects regardless of luminance contrast between the defect and the inspection surface and size.

Keywords: visual inspection; defect shape; defect detection; work design;

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1. Introduction

To supply high-quality products into the market, manufacturing industries provide as much attention to product inspection as to product processing and assembly. Two types of inspections exist which are functional inspection and appearance inspection. The former inspects the effectiveness of a product, and the latter, small visual defects, such as cracks, scratches, dirt, nicks, stains, surface dents, and unevenness of the coating color. The automation of functional inspection has advanced, because it is easy to determine whether a product works or not [1]-[2]. However, it is not easy to establish standards to determine whether the appearance of a product is defective. First, many different types of defects exist. Second, the categorization of a product as defective or non-defective is affected by the characters (size, depth and/or luminance) of the defect. Third, many products have recently become smaller and more complex. Finally, the production has shifted to high-mix and low-volume production. It is thus difficult to create technologies that can capture small defects and to develop algorithms that can identify multiple types of defects with high precision. Therefore, appearance inspection still strongly depends on human visual inspection [3]-[8].

As visual inspection is performed by humans vision, inspection efficiency (inspection time) and inspection accuracy (defect detection rate) differ among different inspectors. This is a common problem in many visual inspection process of manufacturing industries. Recently, a visual inspection method utilizing peripheral vision was proposed [9]-[13], and the effectiveness of the visual inspection method has been reported by actual manufacturing factories [14]. Human vision is 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 the increase in this angle from the center of the retina [15]. The visual inspection method utilizing peripheral vision involves two steps: First, a wide spatial range is searched by peripheral vision; subsequently, the type of defect is decided by central vision which has higher spatial resolution. Thus, low-level processes such as sampling and clustering are processed using peripheral vision, whereas high-level processes such as discrimination are processed using central vision, such that the amount of information to be processed is reduced. This allows for efficient visual information processing to be realized [16]. Therefore, the visual inspection method utilizing peripheral vision is expected to lead to high inspection efficiency and inspection accuracy.

To widely adopt the inspection method in the appearance inspection process of many manufacturing industries, several studies have conducted. As one of them, in the previous study, which examined the effect of the defect characteristics, such as lightness, shading, color, and size, on the defect detection, it has been proposed that the difficulty level of the defect detection can be a value (defect surface luminance) obtained by multiplying the luminance contrast (difference between the luminance of the inspection object and luminance of the defect) by the defect size [17]. Another study examined the relationship between the defect surface luminance and the conspicuity field of the visual inspection [18]. However, in these studies, defect shapes examined are limited circles. In the actual visual inspection process, there are various defects with various shapes, such as lines, in scratches, and circles, in dents. Different defect shapes may affect the defect detection in visual inspection utilizing peripheral vision, but their relationship has not been clarified.

Therefore, this study considers the effect of defect shapes on defect detection utilizing peripheral vision. Specifically, an experiment is implemented using defect shape, defect location, and defect characteristics (luminance contrast between the inspection object and the defect, and size) as experimental factors. The effect of these factors on the defect detection is examined.

2. Experimental Design

2.1. Experimental tasks

In this experimental, subjects are tasked with visually inspecting a model that is displayed on a monitor (CG277, EIZO Inc.). As shown in Fig. 1-a, a model with both height and width equal to 300 mm is used. The background color of the inspection model is set to an achromatic color (RGB values: 100, 100, 100). To lead inspection utilizing peripheral vision, the subjects are requested to focus only at the center of the inspection model during this experiment.

If no defect (non-defective model) is detected, the subject presses the SPACE KEY on the keyboard, and the next inspection model is displayed. If a defect (defective model) is detected, the subject presses the ENTER KEY. The experimental layout is shown in Fig. 2. To ensure a uniform visual distance between each subject and the inspection model, the head position of the subjects is fixed with a jaw holder placed at a distance of 400 mm from the inspection model.

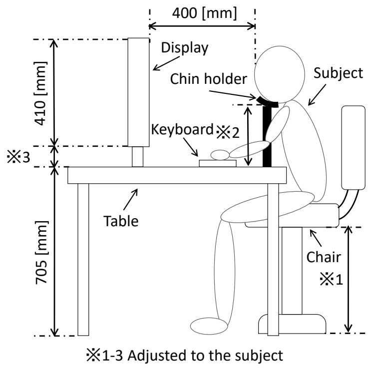

Fig. 1. Experimental layout

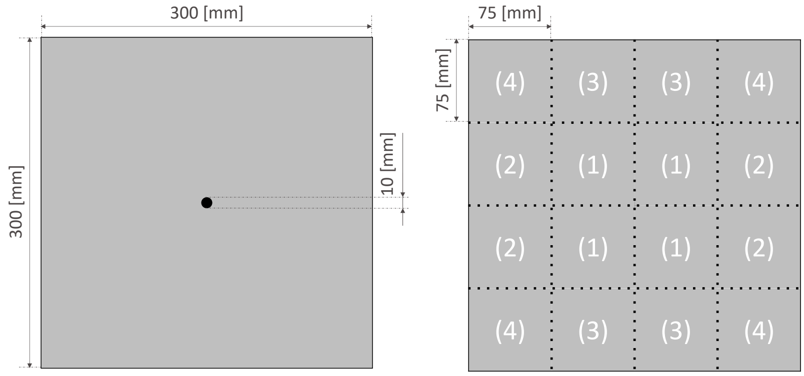

Fig. 2. (a) inspection model

Fig. 2. (b) defect location

Fig. 2. Inspection model and defect location

2.2. Experimental factor

2.2.1 Defect shape

As shown in Fig. 3, the defect shape is set to four different patterns (line, triangle, square, and circle). The line defect assumes scratches, on the other side, the triangle, square, and circle defect assume surface dents and unevenness of the coating color in the actual visual inspection process.

2.2.2 Defect location

The inspection model is divided into sixteen parts (four x four horizontally and vertically), and the defect is located at the center of either one of those parts. As shown in Fig. 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 luminance contrast of each defect is one of the three following levels: 0.08, 0.12, and 0.16. The defect size is specified by 12 pixel (0.65 mm2), 18 pixel (0.98 mm2), and 24 pixel (1.30 mm2). These defects are determined by assuming the standard of the appearance inspection. The list of defects using this experiment is shown in Fig. 3.

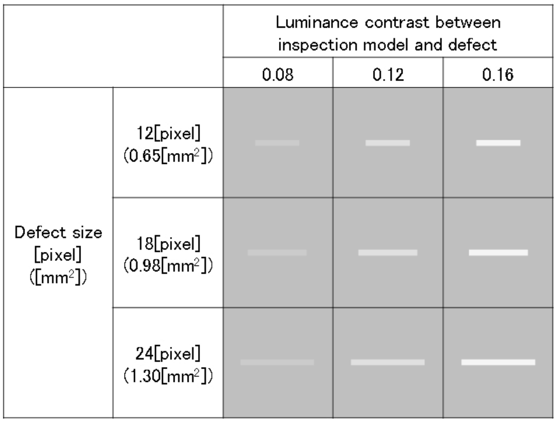

Fig. 3. (a) line defect

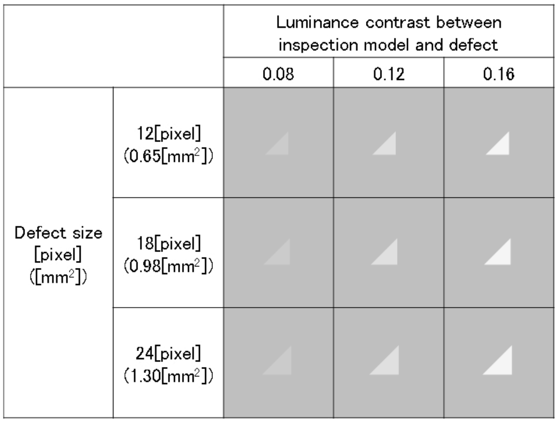

Fig. 3. (b) triangle defect

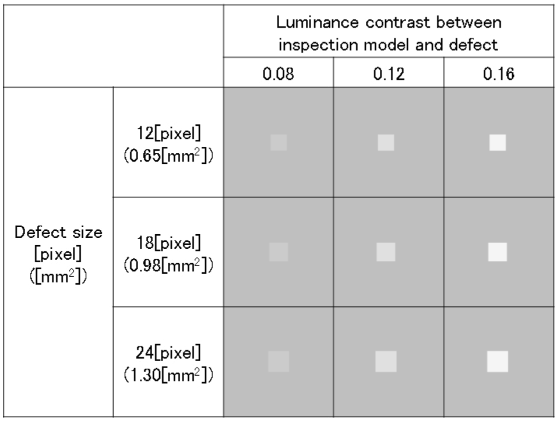

Fig. 3. (c) square defect

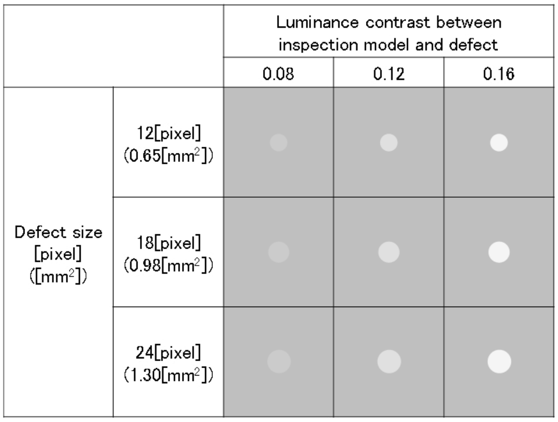

Fig. 3. (d) circle defect

Fig. 3. Defects using the experiment (schematic diagram)

2.3. Experimental procedure

Twelve subjects (six men and six women), aged between 21 and 22 years with a corrected eyesight score (decimal visual acuity) higher than 1.0, were employed in the experiment. To familiarize the subjects with the experiment, an overview was provided and the experiment procedure was explained. In addition, the subjects were requested to perform some preliminary experiments. In the experiment, the task was to inspect 1152 inspection models (576 non defective, and 576 defective).

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

Using the results of the experiment, obtained using the aforementioned procedures, the defect detection rate was calculated, which is the number of detected defects divided by the number of total defects. It is expressed by Equation (1) and is used as the evaluation index of the inspection accuracy.

$$\text{Defect detection rate [\%]} = \frac{\text{Numuber of detected defects}}{\text{Number of total defects}} \tag{1}$$

3. Experimental Results

3.1. Individual characteristics of subjects

Using the defect detection rate, the effect of the presence or absence of visual guidance is examined. Owing to the possibility that the individuality of the subjects might influence the results, the uniformity of the results for all subjects is verified.

The defect detection rate of each subject is shown in Fig. 4. As a result of the Smirnov–Grubbs test, no outlier values were observed in the defect detection rates of any of the subjects. Therefore, all the data from twelve subjects were used.

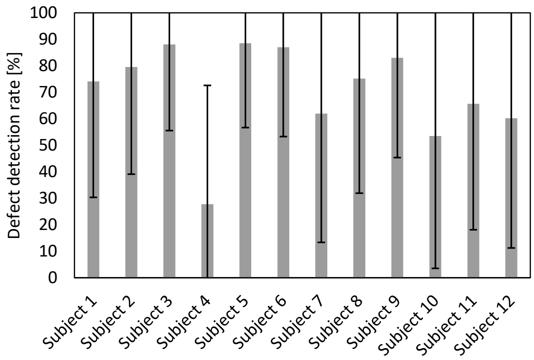

Fig. 4. Defect detection rate for each subject

Table. 1. ANOVA for defect detection rate

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

Factor	Sum of squares	Degrees of freedom	Mean square	F-value	Significant difference
Subject(S)	502954.28	11	45723.12		
Defect shape(A)	133764.47	3	44588.16	55.70	**
S×A	26417.82	33	800.54		
Defect location(B)	213556.13	3	71185.38	23.49	**
S×B	99994.21	33	3030.13		
Defect characteristics(C)	346758.54	8	43344.82	59.28	**
S×C	64343.89	88	731.18		
A×B	6545.14	9	727.24	2.33	*
S×A×B	30842.01	99	311.54		
A×C	17960.79	24	748.37	2.25	**
S×A×C	87950.67	264	333.15		
B×C	41450.38	24	1727.10	4.48	**
S×B×C	101718.03	264	385.30		
A×B×C	27823.35	72	386.44	1.15	
S×A×B×C	267133.25	792	337.29		
Total	1969212.96	1727			

3.2. Effect of defect shape on defect detection

To analyze the effect of defect shapes on defect detection, three-way analysis of variance (ANOVA) was executed with the defect shape (4), defect location (4), and defect characteristics (9) as factors. The ANOVA table is shown in Table 1. As a result, a significant difference of 1% was observed for the main effect of the defect shapes, the defect locations, and the defect characteristics, and the mutual interactions between the defect shapes and the defect characteristics, the defect locations and the defect characteristics. Furthermore, a significant difference of 5% is observed for the mutual interactions between the defect shapes and the defect locations. The effect of these experimental factors on defect detection are shown in Fig. 5, the relationship between each experimental factors are shown in Fig. 6.

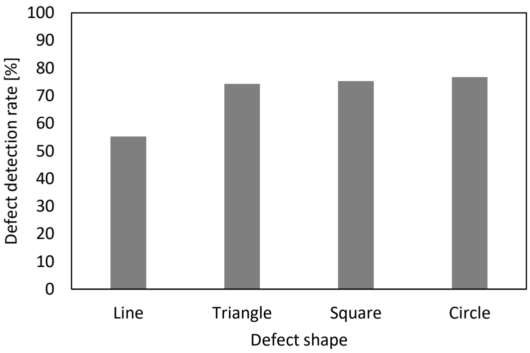

Fig. 5. (a) defect shape

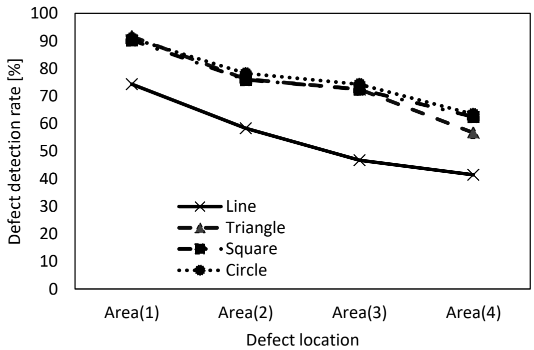

Fig. 6. (a) relationship between defect shape and defect location

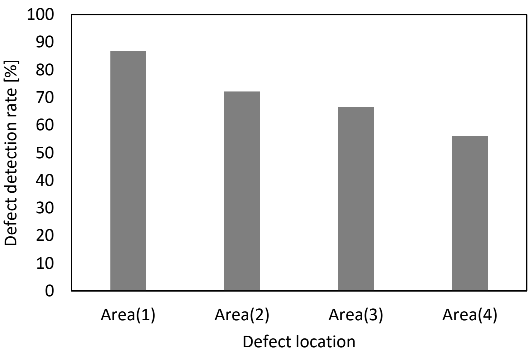

Fig. 5. (b) defect location

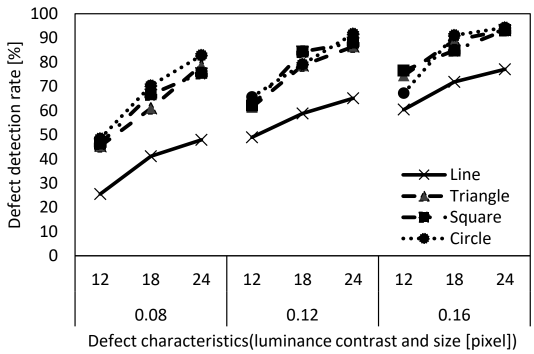

Fig. 6. (b) relationship between defect shape and defect characteristics

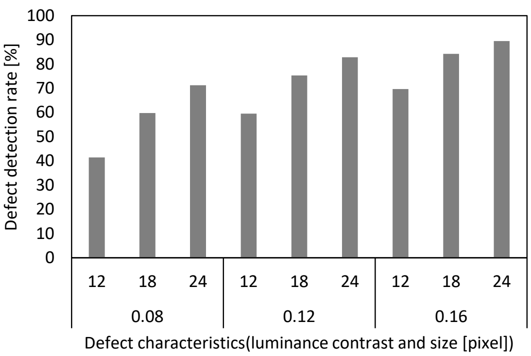

Fig. 5. (c) defect characteristics

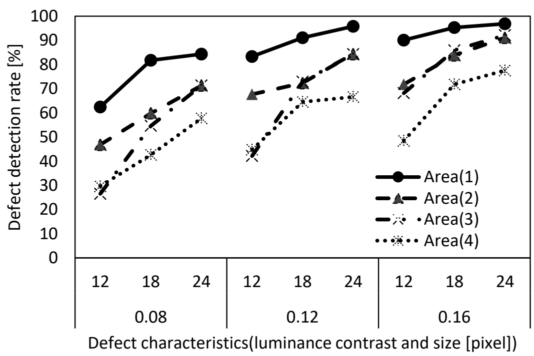

Fig. 6. (c) relationship between defect location and defect characteristics

Fig. 5. Average value of experimental factors

Fig. 6. Interaction between experimental factors

From this results, it is clarified that the defect detection rate of line defects is lower than the other defect shapes (triangles, squares, and circles) regardless of luminance contrast between defect and inspection surface and size. Furthermore, this trend is common in all defect locations and it is shown to be particularly conspicuous in peripheral vision. That is, in the visual inspection method utilizing the peripheral vision, it is more difficult to detect linear defects than defects with other shapes. Therefore, for detection of linear defects, it is necessary to increase the inspection time and fixation points. Moreover, the evaluation index of defect detection difficulty should consider both the defect surface luminance, i.e., the value obtained by multiplying the defect luminance contrast by its size, and the defect shape.

4. Conclusion

In this study, the effect of the defect shape on the defect detection in visual inspection utilizing peripheral vision was considered experimentally. As a result, it is clarified that the defect detection rate of line defects is lower than the other shapes (triangles, squares, and circles), regardless of luminance contrast between defect and inspection surface and size. That is, in the visual inspection method utilizing the peripheral vision, it is more difficult to detect line defects than defects with other shapes. For detection of nonlinear defects, it is necessary to increase the inspection time and fixation points. Moreover, the evaluation index of defect detection difficulty should consider both the defect surface luminance, i.e., the value obtained by multiplying the defect luminance contrast by its size, and the defect shape.

In the future, we will consider new evaluation index of the defect detection difficulty level in the visual inspection utilizing the peripheral vision including the findings of this research. Further, we will also consider the work design and the standardization of the visual inspection method utilizing peripheral vision.

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