Development of support system for defect detection based on human visual mechanism in visual inspection process

Yu Okabe†
Graduate School of Science and Engineering
Aoyama Gakuin University, Tokyo, Japan
Tel: (+81) 42-759-6554, Email: c5616173@aoyama.jp

Ryosuke Nakajima
Department of Systems Design Engineering
Seikei University, Tokyo, Japan
Tel: (+81) 422-37-3772, Email: nakajima@st.seikei.ac.jp

Takuya Hida
Department of Industrial & Systems Engineering
Aoyama Gakuin University, Tokyo, Japan
Tel: (+81) 42-759-6420, Email: hida@ise.aoyama.ac.jp

Toshiyuki Matsumoto
Department of Industrial and Systems Engineering
Aoyama Gakuin University, Tokyo, Japan
Tel: (+81) 42-759-6304, Email: matsumoto@ise.aoyama.ac.jp

Abstract. In manufacturing industry there are functional and visual inspections, but some defective products pass the inspection as non-defective products and deliver to the market. This study focuses on some functions of automatic and human visual inspections, and also considers the system which contains both of them. The two inspections have both the advantages and disadvantages. Automatic inspection has high-precision search and low-precision distinguish capability. On the other hand, human visual inspection has high-precision search and low-precision distinguish ability but the latter inspection sometimes has human error. Consequently, ideal visual inspection system should have both advantages of the two inspections. To develop the system, the system introduced human visual mechanism. Specifically, the mechanism is classified into four steps; search, perception, discrimination and recognition. The system introduced some functions corresponding with these steps. The system enables to show some defects for an inspector to prevent human error.

Keywords: automatic visual inspection, defect detection, human visual mechanism, support system

1. INTRODUCTION

Recently, in Japanese manufacturing industries, manufacturing systems have changed from “few kinds and big quantity manufacturing system” to “variety and variable manufacturing system” to satisfy the variable user needs. As a result, defective products have increased because of workers’ unaccustomed manufacturing. As a countermeasure to this problem, they focus on inspections for defect detection. These inspections have functional test and visual inspection. A functional test involves inspecting whether a product works well or not. A visual inspection involves detecting defects on surface of a product. A functional test becomes an automatic inspection because it is easy to determine whether a product works or not, whereas, visual inspection does not become automatic because the quantization of defects is difficult. However, some defective products have passed the inspections as non-defective products. As a way to prevent this problem, inspectors should first detect the defects with high possibility of occurrence instead of detecting all defects.

Regarding automatic and visual inspection in a visual inspection process, there is a preceding study on the development of such a system based on peripheral vision (Aoki 2013). The study focuses on peripheral vision used by an inspector in the visual inspection process and considers the ability to use "low resolution." Consequently, the system detects defects without a template matching method. On the other hand, inspectors also use "central vision;" however, the study does not consider "central vision", only focus on the human visual mechanism.

This study aims to develop a support system to prevent defective products from passing the inspection because of human error. The system has some functions corresponding with a human visual mechanism, and can enable an inspector to detect more defects.

2. Target product and making a model

2.1 Target product

To analyze automatic and human visual inspection for detecting defective products in a manufacturing industry, this study targets a vehicle's rear glass. The width and height of the glass are 130 and 55 cm, respectively; the glass also has a curved surface. In addition, the glass has 13 electrically-heated wires from the left entry side to the right entry and a 3 cm hole for a wiper. These characteristics require complex processing for detecting defects and a support system must consider them. First, a simple model is made from the glass, and then a support system is developed for the model. Finally, it is applied to the real target.

2.2 Making a model of the target product

It is necessary to calculate the RGB value of the target product for making a model. The glass has four parts: black flame, electrically-heated wires, clear glass, and a defect. The RGB value is obtained from each of four parts in a picture of the target taken by a camera. Figure 2 shows one example of the obtaining RGB value.

Figure 2 shows the intersection point of crossing white lines that show the RGB value. The RGB value in this case is (154, 153, 151). To get a more precise RGB value, pictures were taken ten times with the same condition. The average data, with the minimum and maximum values removed, were considered. The method for obtaining the RGB values of the black flame, electrically-heated wires, and clear glass is shown in Table 1. These values are rounded-off numbers from the natural number.

From Table 1, the black flame has (R, G, B) = (30, 30, 32). Electrically-heated wires have (R, G, B) = (146, 78, 40). Clear glass has (R, G, B) = (63, 66, 66). The model is thus composed of these RGB values, and the model is shown in Figure 3.

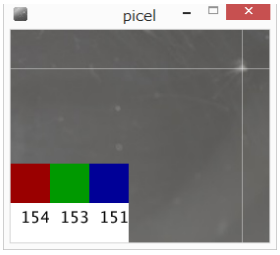


Figure 2: Defined coordinate axes

Table 1: Calculation of RGB value's average

	Red	Green	Blue
Black flame	30	30	32
Electrically-heated wires	146	78	40
Clear glass	63	66	66

Figure 3: The model

2.3 RGB value and luminance value of the target

When an inspector inspects the visual inspection process, peripheral vision facilitated by the rod cell plays a big role. That is known to respond to a contrast in luminance. In other words, peripheral vision inspects luminance. In the development of a support system, luminance value is used and not the RGB value; however, it is considered like the human visual inspection.

When luminance is converted, the red component of the RGB value means Cr, the luminance of RGB (255, 0, 0) on a display is Lr, the red component of RGB value is r, and the eigenvalue of the display is ɤ.

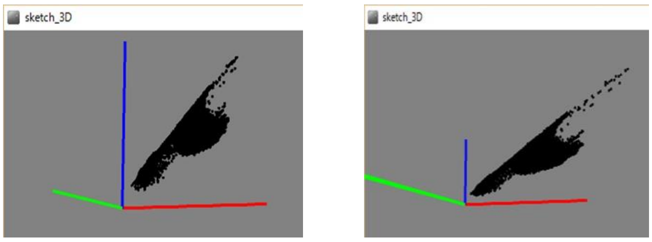
$$Cr = L_r \left(\frac{r}{255}\right)^{\gamma} \quad (1)$$

In the same way, after luminance conversion, the green component is Cg and the blue component is Cb.

$$Cg = L_g \left(\frac{g}{255}\right)^{\gamma} \tag{2}$$

$$Cb = L_b \left(\frac{b}{255}\right)^{\gamma} \tag{3}$$

By using formulas (1), (2), and (3), the support system shows the results from comparing luminance conversion and the RGB value shown in Figure 4.



(a) RGB value (b) Luminance value

Figure 4: Scatter plot

In Figures 4 (a) and (b), the red line means the red component in RGB space, the green line means the green component, and the blue line means the blue component. Also, a thin part of the scatter diagram is analyzed in Figure 4 (a) and (b). In the case of Figure 4 (b), the tip varies more widely than Figure4 (a). A group of the tips means a defect so Figure 4 (a) is easier to defect defects than (b). Consequently, when the system works, it uses not RGB value but converted luminance value.

3. Human visual mechanism and design of a support system

3.1 Human visual mechanism

In general, a human recognizes a target with the visual cortex in the brain. This study thus focuses on the human visual mechanism and classifies the process of human recognition into four steps. The human eye has cone cells and rod cells. Cone cells get information about the color and shape of a target. They are distributed around a fovea as shown in Figure 5. Using cone cells and viewing locally is called "central vision." On the other hand, rod cells are distributed all over the retina except for around a fovea in Figure 5 and determine the luminance contrast of a target. Using rod cells and viewing widely and roughly is called "peripheral vision." When a human recognizes a target, firstly, it captures the outline of a target by peripheral vision, and then it recognizes the target locally using central vision. Moreover, the two vision methods are classified in four steps, which are search, perception, discrimination, and recognition.

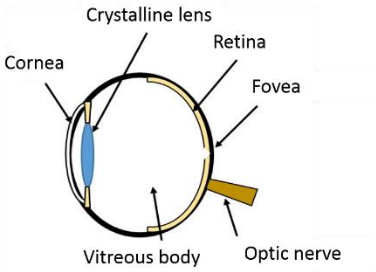


Figure 5: The mechanism of eye

As shown in Figure 6, first, in the search step, a human searches a target widely and roughly with peripheral vision. Second, rod cells capture some luminance contrasts as edges of the target. Third, cone cells discriminate the color and shape of the target around these edges. Finally, the brain of a human recognizes the target from the color and shape.

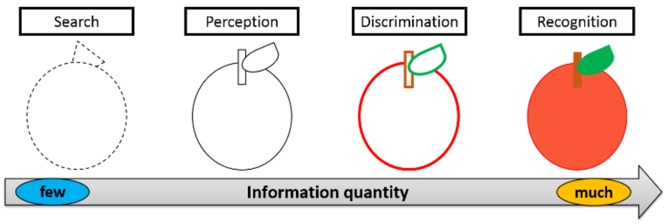


Figure 6: The steps of human recognition

3.2 Design of a support system

The human visual mechanism has four steps as mentioned above. The support system introduced three functions: increasing a low resolution, clustering, and Mahalanobis' distance for search, perception, and discrimination of the steps successively. This system does not consider recognition because the purpose of this study is to develop a support system that humans should recognize. Each of the functions in this system is described below.

At first, the system inspects a target roughly by increasing a low resolution. Moreover, when the standard error is at its maximum value, the system makes a picture of a target with increasing low resolution. Standard error is calculated as a variance of averages that is sampled from data of the universe. It is shown in formula (4). Maximum standard error picks the low resolution picture that has clearer defects than any other one.

Next, the picture of a target is classified into each characteristic from the color information by clustering. This is considered perception of human visual inspection.

Finally, Mahalanobis' distance is calculated from the

$$\sqrt{\frac{N-n}{N-1}}\frac{\sigma}{\sqrt{n}} \tag{4}$$

picture, and then the picture redraws the color gradation by the distance. It converts some data into just one kind of distance considering the correlations from some pluralities of information. To compare some kind of data, it must be standardized. In formula (5), u_i is standardized data, MD is Mahalanobis' distance, u_k is the kth data of standardized data, and r_{kk} is the correlation coefficient in formula (6).

$$u_i = \frac{x-m_i}{\sigma_i} \tag{5}$$

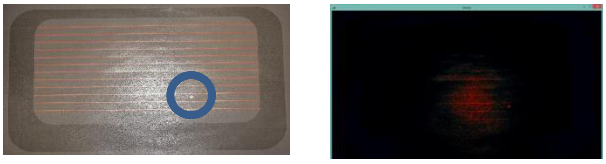
$$\mathrm{MD} = (u_1 \cdots u_j \cdots u_k)\begin{bmatrix} r_{11} & \cdots & r_{1k} \\ \vdots & \ddots & \vdots \\ r_{k1} & \cdots & r_{kk} \end{bmatrix}\begin{pmatrix} u_1 \\ \vdots \\ u_j \\ \vdots \\ u_k \end{pmatrix} \tag{6}$$

The system can convert 1-dimensional Mahalanobis' distance from a 3-dimensional RGB value, and redraws red, yellow, green, blue, and black of the large distance order.

4. Application of the support system to the target

4.1 The result by the support system

A Camera (Camera; NIKON, D610 Lens; NIKON, AF MICRO NIKON60 mm) takes pictures of the target to apply it to the support system. The result for example is shown in Figure 7 (a). A defect is indicated with a blue circle, as shown in Figure 7 (a). The result of application by the system to inspect it is shown in Figure 7 (b).



(a)The picture of target (b)The result of system

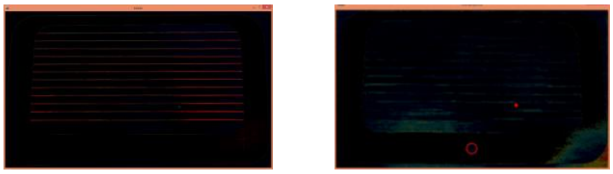
Figure 7: Target and result

In Figure 7 (b), red color, yellow, green, blue, and black represent the ordered degree of a higher possibility of defect. In Figure 7, some glares of a fluorescent lamp and reflections from the floor are detected as defective points and the painted red area by the system. The system extracts not only the defects but also any other matters indicated by the blue circle in Figure 7 (a). This false detection is caused by reduction of the feature due to background color, by detecting foreign matters, and by glares. To detect defects more precisely in the target picture, it is necessary to remove these three factors from the environment.

4.2 Setting up the environment

4.2.1 Background

The color of the background is set with a black cloth as a countermeasure to the reflection because black absorbs most of light. The part of Figure 7 (a) around a defect is shown in Figure 8 (a), and the part of Figure 7 (a) with a black cloth is shown in Figure 8 (b). Compared with Figure 8 (a) and (b), the defect shown with the blue circle is not extracted in Figure 8 (a), but it extracted in Figure 8 (b). In addition, the glass has no reflection in Figure 8 (b).

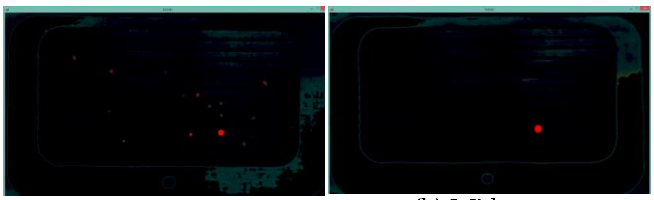


(a) White background (b)Black background

Figure 8: Set background

4.2.2 Removal of foreign matters on the target

The foreign matters on the glass are analyzed to measure false detection by the system. The difference of the result from Figure 8 (b), with and without false detections, is shown in Figure 9. The system does not detect the defect on the same point in Figure 8 (b) but some foreign matters in Figure 9(a). The system detects the defect around the center of the picture by removing foreign matters from the surface of the target.

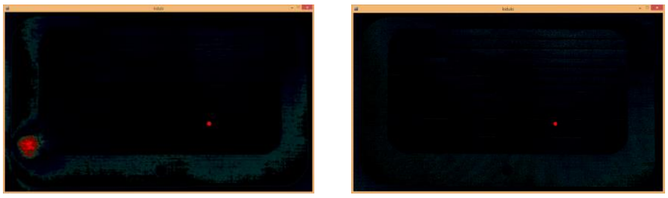


(a) With ones (b) Without ones

Figure 9: The effect from foreign matters

4.2.3 A Countermeasure to glare

To prevent glare on the target, pictures are taken in a dark room. Specifically, the black-out curtain shuts off the light from the outside and a light lightens the target without glare. The two cases with glare and no glare are shown in Figure 10.



(a) Glare (b) No glare

Figure 10: The effect from glare to the result

In Figure 10 (a), the red zone means that the system detects glare from a fluorescent light as defect. On the other hand, the defect that was detected by the system in Figure 10(b) does not have glare like that in Figure 10 (a). Results when the target picture considered background, foreign matters, and glare, are shown in Figure 11.

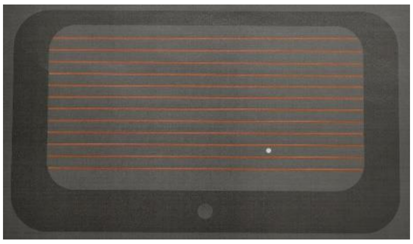


Figure 11 Setting up the environment

In Figure 11, there are no reflections from the floor, no foreign matters, and no glare on the surface of the glass. The result of detecting Figure 11 by the system are shown in Figure 12.

Figure 12 The result of system

The system can extract defect candidates and paint them red in Figure 12. In this case, when an inspector uses this system in the visual inspection process, he/she just inspects red points around the center and the lower part of Figure 12. Therefore, the system can indicate some candidates of defect that the inspector should detect after a suitable environment has been constructed for defect detection.

5. Conclusion

There are automatic and human visual inspections used in the manufacturing industry, but some defective products have passed these inspections as non-defective products. This study developed a support system for defect detection. Specifically, the mechanism was classified into four steps: search, perception, discrimination, and recognition. The system introduced some functions corresponding with these steps. In the search and perception steps of the mechanism, visual inspectors use their ability to inspect with wide vision and low precision. They represented functions as "clustering" and "increasing a low resolution" in the system. In the discrimination and recognition steps, visual inspectors use their ability to inspect by shortsighted vision and high precision. They represented functions as "Mahalanobis' distance" in it. As a result of applying the system to inspect the picture of a target, the system can indicate some possible defects for an inspector to review.

In future studies, we will add defect characteristics and product shape to evaluate the effectiveness of the system.

REFERENCES

Ikeda, M., (2004) Meha Naniwo Miteiruka, Heibonsha, 1-289

Aoki, K., (2013) "KIZUKI" Algorithm inspired by Peripheral Vision and Involuntary Eye Movement, Japanese Journal of Precision Engineering, **79**(4), 1045-1049

Aoki, K., (2014) "KIZU NO KIZUKI" algorithm, Japanese Journal of Precision Engineering, **79**(4), 1045-1049

Sasaki, A., (2005) Syuhenshi Mokushikensahou[1], Japan Institute of Industrial Engineering Review, 46(4), 65-75

Sasaki, A., (2005) Syuhenshi Mokushikensahou[2], Japan Institute of Industrial Engineering Review, 46(5), 61-68

Sasaki, A., (2005) Syuhenshi Mokushikensahou[3], Japan Institute of Industrial Engineering Review, 47(1), 55-60

Sasaki, A., (2005) Syuhenshi Mokushikensahou[4], Japan Institute of Industrial Engineering Review, 47(2), 53-58

Sasaki, A., (2005) Syuhenshi Mokushikensahou[5], Japan Institute of Industrial Engineering Review, 47(3), 67-72