CASE 73

Defect Detection Using the MTS

Abstract: In our research, selecting differential and integral characteristics calculated by a pattern as feature values, we take advantage of the Mahalanobis–Taguchi system (MTS), which creates a Mahalanobis space with normal products (base data) to study the visual inspection process. In this research, using disks judged as "normal" by inspectors, we created a base space.

1. Introduction

Since an inspector responsible for a visual inspection is considered to have many subconscious inspection standards in order to realize an automated inspection process, we need to build up a system of integrating multidimensional information. On the other hand, for the automation of an inspection process, necessary multidimensional information, or a group of characteristics, is not necessarily identical to that held by an inspector. That is, although characteristics used by an inspector are unknown in some cases, even characteristics easily handled by a computer can be utilized successfully if they lead to the same results as those determined by a visual inspection.

In our research, selecting differential and integral characteristics calculated by a pattern as feature values, we take advantage of the MTS method, which creates a Mahalanobis space with normal products (base data). In this research, using disks judged as "normal" by inspectors, we created a base space.

To obtain a highly accurate image at low cost, we adopted a method of capturing an image with a linear CCD (change-coupled device) camera while rotating a disk at constant speed (Figure 1). The captured image is input into a personal computer in real time by way of a special image input board. By doing so we can obtain extremely thin and long image data, that is, (width of a disk) × (circular length for one rotation), when the disk is turned around in one rotation. The starting point for capture in a rotational direction was set arbitrarily.

2. Differential and Integral Characteristics

An image datum was represented by color concentration. Looking at the fluctuation in concentration of a single charge-coupled device in a linear CCD camera, we can see that a waveform such as that shown in Figure 2 is obtained when a disk is turned one rotation. Its horizontal and vertical axes indicate rotational position and gradation, respectively. Now, since there are a few dozen charge-coupled devices, we can capture the same number of different waveforms as that of the devices.

The waveform shown in part (*a*), which exemplifies that of a normal disk, demonstrates that concentration peaks appear regularly around a constant concentration level. In addition, in (*b*) and (*c*) we show examples of waveforms for defective disks. More specifically, (*b*) represents the case for a disk with adhesive, and (*c*) indicates the case for a disk with frictional material peeled off. Comparing those with the normal pattern in Figure 2, we can see a significant disturbance in a waveform of (*c*), whereas a fluctuation in gradation of (*b*) due to adhesive stuck is not distinct. However, a certain type of disturbance is involved in its waveform despite its subtlety.

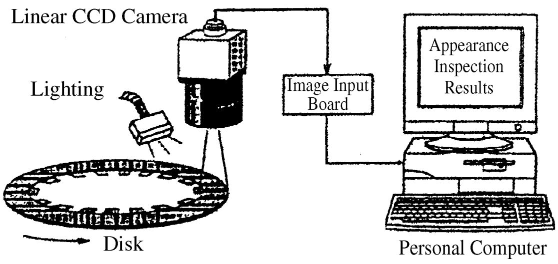

Figure 1
Appearance inspection system for disks

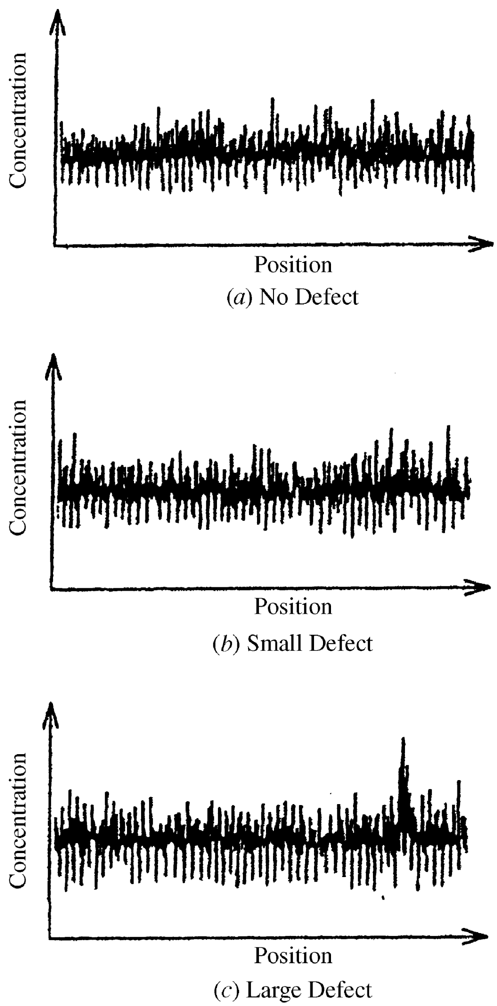

Figure 2
Waveform of disk image

A key point in our research was to deal with image data of a disk as a group of waveforms. By recognizing a disturbance in a waveform, we attempted to detect a defect. As a feature value for a waveform pattern, we calculated the following differential and integral characteristics, explained below.

Next, we defined a waveform for one unit (a waveform consisting of pixels for one rotation) as $Y(t)$. As Figure 3 illustrates, we drew p parallel lines to the t-axis at an equal interval along the Y-axis. Counting the number of intersections between each line and the waveform, $Y(t)$, as per each line, we set this as a differential characteristic. In addition, calculating the sum of all intervals between intersections, we defined it as an integral characteristic.

The differential characteristic can be regarded to indicate a frequency of fluctuations in a waveform (i.e., information equivalent to the frequency of a waveform). Since we can obtain a frequency for each amplitude, the distribution of a frequency in the direction of an amplitude can be known. On the other hand, the integral characteristic indicates an amount of occupation for each amplitude. Both the differential and integral characteristics were considered to cover a frequency and amplitude of a waveform and useful information regarding them. In addition, since the differential and integral characteristics can be calculated more simply than the traditional characteristics such as a frequency, we can expect a faster processing speed.

Furthermore, in addition to the differential and integral characteristics, in this research we added four characteristics that are regarded to be effective for a disk appearance inspection.

3. Preparation of Base Space

From clutch disks that we confirmed had no defect we captured a total of 1000 images. One image con-

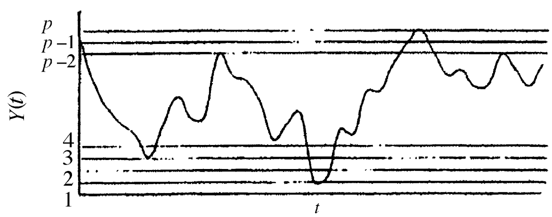

Figure 3
Differential and integral characteristics

Table 1
Feature values in the wave pattern of a disk[a]

	Characteristic					
P	Differential	Integral	*A*	*B*	*C*	*D*
1	18	5989	75	1318	54	66
2	46	5971	68	1098	82	66
3	72	5944	65	828	92	65
⋮						
37	8	4	1	1	40	1593
38	8	4	1	1	40	1593
39	4	2	1	1	1525	2552
40	2	1	1	1	2552	3447

[a] Row numbers correspond to numbers on the vertical axis of Figure 3.

sists of 36 waveforms. Then we computed 240 feature values, including the differential and integral characteristics for each waveform. However, after excluding characteristics that do not obviously contribute to image recognition, we finally obtained 160 feature values (items). Therefore, using 1000 × 160 base data, we computed 36 correlation matrices. A typical example of feature values that are not contributing to image recognition is a value with a quite large standard deviation, which can be any value.

As inspection data, we measured a certain number of data from nondefective and defective disks. Table 1 shows an example of feature values.

Figure 4 shows examples of the recognition results. In this plot the horizontal and vertical axes indicate a radial position on a disk and the

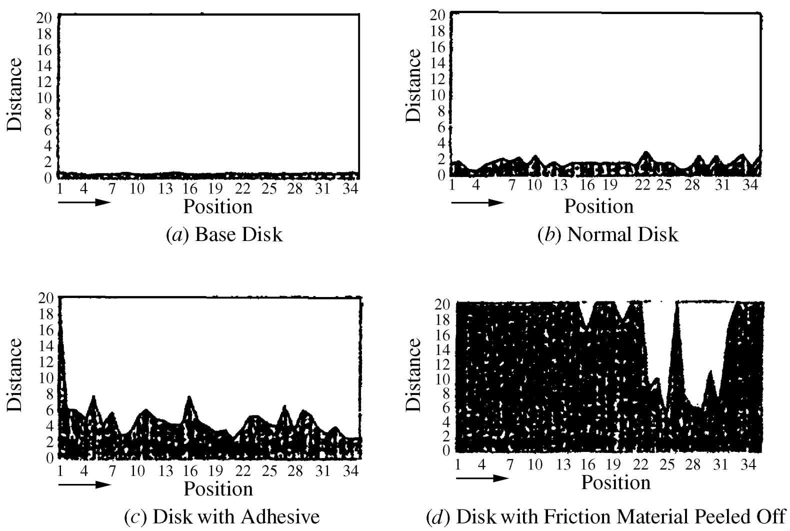

Figure 4
Distances of disk and wave patterns

Mahalanobis distance, respectively. In (*a*), representing base data, all Mahalanobis distances show a small value. Part (*b*) represents the distances of a nondefective disk; almost all lie below 2. For (*c*), for a disk with a small amount of adhesive stuck, many data exceed the value of 4. This cannot be regarded as normal. In (*d*) for a disk with friction material peeled off, many high peaks can be seen on the left side of the plot. This implies that relatively large defects exist on the corresponding positions. In addition, as a result of recognizing various types of disks, we observed that most of the recognition results were consistent with results via a human visual inspection.

4. Item Selection Using Orthogonal Array L_{64}

One hundred sixty items were used for recognition thus far. Now, to improve processing time and reduce measurement cost, we picked up items that were effective for recognition. To this end, using an L_{64} orthogonal array, we attempted to select items.

Primarily, from all of the 160 items used in the prior experiment, we selected 40 items that are considered essential for recognition without being selected. Secondarily, after dividing the remaining 120 items into three groups of 40 items by each attribute, according to the following procedure, we performed three experiments based on an L_{64} orthogonal array to verbatim narrow down the items.

For selection 1:

- ❑ We allocate the 40 characteristics belonging to group 1 to an L_{64} orthogonal array, setting "no use of an item" to level 1 and "use the item" to level 2.
- ❑ For recognition, we used the 80 characteristics included in groups 2 and 3, 40 in each group.
- ❑ Using the base data, we calculated a correlation matrix under each experimental condition. Then, in each experiment we compute a Mahalanobis distance for each of 10 defective disks with adhesive or friction material peeled off. Since its larger value is regarded as better, we calculated a larger-the-better SN ratio with the following equation:

$$\eta = -10 \log \frac{1/D_1^2 + 1/D_2^2 + \cdots + 1/D_m^2}{m} \quad \text{dB} \tag{1}$$

where m indicates the total number of data.

- ❑ A response graph was created. Figure 5 represents the difference between the sum of SN ratios for level 2 and that of SN ratios for level 1. Because level 2 corresponds to the case of "use the item (characteristic)," a factor with a larger difference is regarded to have a greater effect on defect recognition.
- ❑ Twenty items among 40 with a larger factor effect were selected.

For selections 2 and 3:

- ❑ After assigning each of the 40 characteristics belonging to groups 2 or 3, respectively, to an L_{64} orthogonal array, we performed a similar experiment.
- ❑ Similar to group 1, for each group we selected 20 larger items that were effective for recognition.

Because we split up the 120 items into three groups of 40 items each, any interactions among groups were ignored. However, since all groups had initially been classified according to their nature, we considered that there were no significant interactions.

Narrowing down the number of items on a step-by-step basis in accordance with the foregoing procedure, we finally reduced the number of the items from 160 to 100: 40 essential items without being selected and 20 each from three groups. As a next

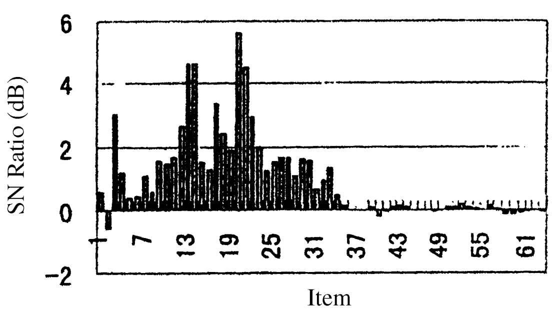

Figure 5
Response graphs for item selection

step, we conducted a confirmatory experiment using the surviving 100 items. Figure 6, which shows the recognition result for a disk with adhesive, highlights the difference in the SN ratio between the two cases of using the 160 and 100 feature values. The shaded part above a fluctuating line represents an increment in the Mahalanobis distance caused by the items selected. Basically, a Mahalanobis distance for a defect is expected to emerge as a larger value.

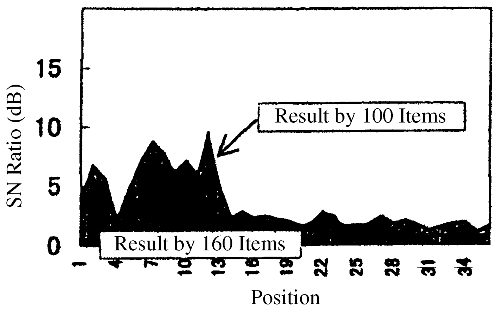

Figure 6
Recognition result by selected items

Since the Mahalanobis distances for defective areas in this case were increased by the items selected, we can conclude that the detectability of defects is enhanced. This is supposedly because we have picked up only items that were effective for defect recognition, thereby mitigating noises in recognition. On the other hand, no increase in Mahalanobis distance can be seen in the normal areas. Since the base space is created from the data for a normal disk, its Mahalanobis distance lies around 1.

Our research demonstrates that by narrowing down the original items, we can enhance the capability of recognition with less calculation.

Reference

Shoichi Teshima, Tomonori Bando, and Dan Jin, 1997. A research of defect detection using the Mahalanobis–Taguchi system. *Quality Engineering*, Vol. 5, No. 5, pp. 38–45.

This case study is contributed by Shoichi Teshima, Tomonori Bando, and Dan Jin.