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マハラノビスの距離を用いた米ドル紙幣の識別

INSPECTION OF US $ BILLS USING MAHALANOBIS DISTANCE

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A NEW APPROACH FOR INSPECTION OF PRINTED MATTERS AND BILLS

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ABSTRACT

Much attention has been focused on Mahalanobis distance for a method of treating multi dimensional information system, such as, pattern recognition. The use of Mahalanobis distance is proposed by Dr. G. Taguchi and some researches have been made on it. In this paper, we propose a printed matter recognition method using Mahalanobis distance. The bill money of US dollar is adopted as one of the printed matters and it is shown that good results are obtained for the recognition of US bills. Adopting the proposed method to recognition problems, the effectiveness of the method is shown.

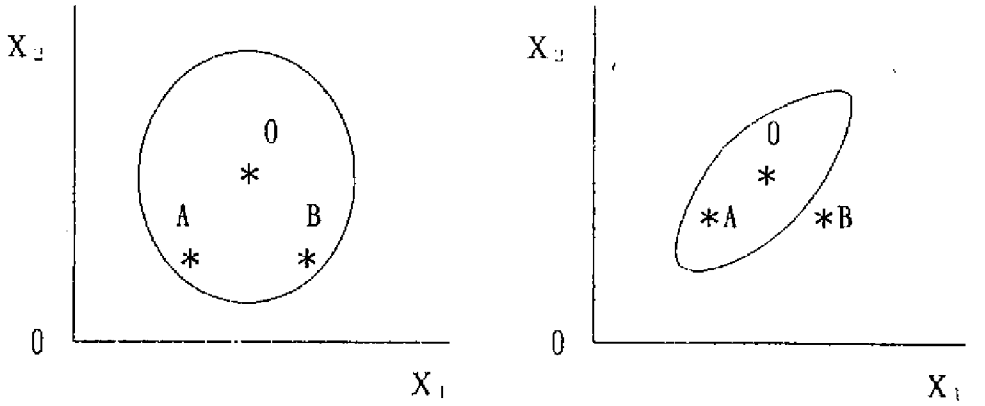
INTRODUCTION

The use of Mahalanobis distance method of treating multi-dimensional information system for health examinations was proposed by Dr. G. Taguchi. Such applications for medical forecasting and treatment have been developing in the past several years. Many researches have been made on neural networks for pattern recognition with promising results. These method use slab values and the slab values are the sum of input pixels generated as characteristics of the inputs by masks. However, mask optimization has not been elaborated sufficiently and the methods have to be improved still more. We propose the recognition method using Mahalanobis distance. The data which are collected from a normal group of the recognized objects are processed by constructing a Mahalanobis Space in the analysis. These data include various items with different dimensions and many of these items are mutually correlated. The quadratic value from the Mahalanobis Space, called Mahalanobis distance, is used for data analysis. The standard Mahalanobis Space is calculated from the inverse matrix of the correlation coefficients. In the first part of this paper, the analysis of Mahalanobis distance are explained and the application of the proposed method to the pattern recognition of the US dollar bill money is shown in the last part of this paper.

MAHALANOBIS DISTANCE

Standard Mahalanobis Space

As an example, we consider the case of two variables X_1 and X_2. If there is no correlation between X_1 and X_2, then, the Mahalanobis distance becomes a circle shown in Figure 1 (a). If there is any correlation between X_1 and X_2, the Mahalanobis distance is shown in Figure 1 (b). We can calculate the distance between 0 and A and the distance between 0 and B using the inverse matrix of the standardized correlation coefficients. This distance is called a Mahalanobis distance.



(a) no correlation (b) any correlation

Fig. 1 Mahalanobis Space and Mahalanobis distance

Caluculation of Mahalanobis distance

The data are standardized using the next equation.

$$X_{ij} = \frac{x_{ij} - m_i}{\sigma_i} \qquad (i = 1, 2 \quad j = 1, 2, \cdot \cdot n) \qquad (1)$$

where, m_i is the average of the data X_{ij} and σ_i is the standardized deviation.
The correlation coefficients are calculated from the next equation and the correlation matrix is expressed as equation (3).

$$r_{ij} = r_{ji} = \frac{1}{n} \Sigma \ (X_{ij} \times X_{ji}) \qquad (2)$$

$$R = \begin{bmatrix} 1 & r_{12} \\ r_{21} & 1 \end{bmatrix} \qquad (3)$$

The inverse matrix A is the next equation.

$$A = R^{-1} = \begin{bmatrix} a_{ij} \end{bmatrix} \qquad (4)$$

Then, the Mahalanobis distance is calculated fromthe next equation.

$$D^2 = \frac{1}{2} \Sigma a_{ij} \frac{X_i - m_i}{\sigma_i} \times \frac{X_j - m_j}{\sigma_j} \qquad (5)$$

The standard Mahalanobis Space is constructed from the data in normal condition and the Mahalanobis distances are located near 1.0. The data in abnormal condition shows the value far from 1.0. We can classify the cases of the normal condition and the abnormal condition using this standardized Mahalanobis Space and Mahalanobis distance.

Flow of caluculating

The flow of calculating the satndard Maharanobis Space is shown in Figure 2.

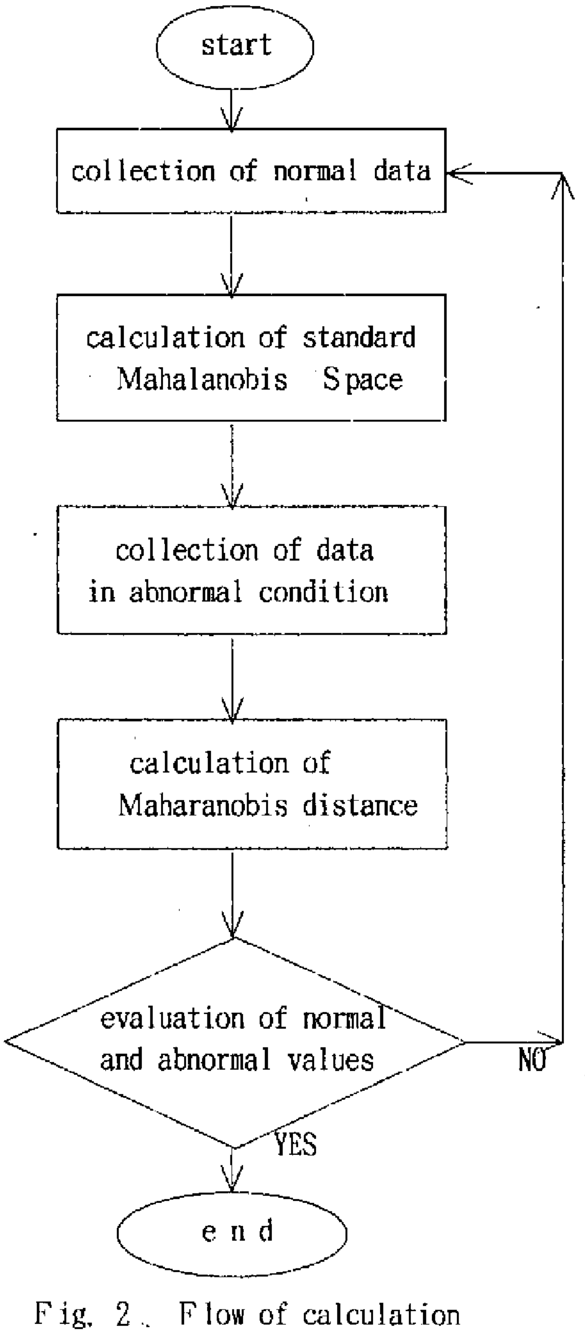


Fig. 2.. Flow of calculation

APPLICATION TO INSPECTION OF US BILLS

We apply the proposed method to the inspection of US dollar bills.

Recognition using a human picture

The human picture is drawn at the center part of US dollar bill(Figure 3). We adopt the human pictures of each dollar bills as the data and transform the dollar data into frequency domain by FFT and use amplitudes of Fourier coefficients as the input data of the caluculating standard Maharanobis Space. We get time series data using the output signals of LD and PD sensors (Figure 4).

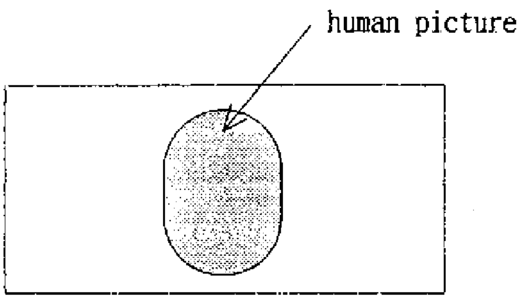


Fig. 3 Human picture of US bill

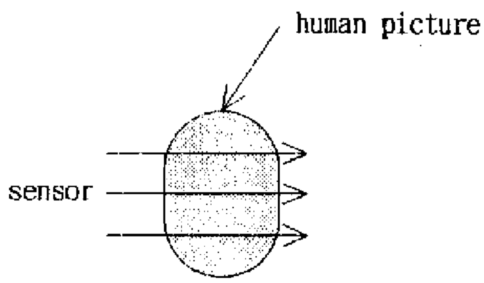


Fig. 4 Sensor output signals

Fourier transform

The time series data of $1 is obtained by the output signals of sensors and the data is shown in Figure 5. We transform this data into the amplitude of fourier coefficients with treating of fourier transform. Fourier coefficients A(n) and B(n) are calculated by the next equations.

$$A(n) = \frac{1}{N}\sum_{k=1}^{N} f(k)\cos\left\{\frac{2\pi}{N}(k-1)n\right\} \quad (6)$$

$$B(n) = \frac{1}{N}\sum_{k=1}^{N} f(k)\sin\left\{\frac{2\pi}{N}(K-1)n\right\} \quad (7)$$

The amplitude of Fourier coefficients is obtained using the next equation (Figure 6).

$$Amp(n) = \sqrt{A(n)^2 + B(n)^2} \quad \cdots (8)$$

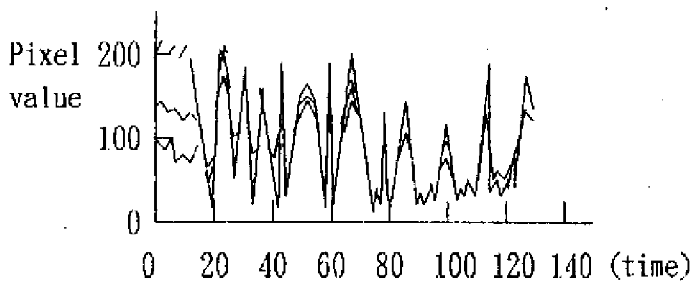


Fig. 5 Time series data of $1

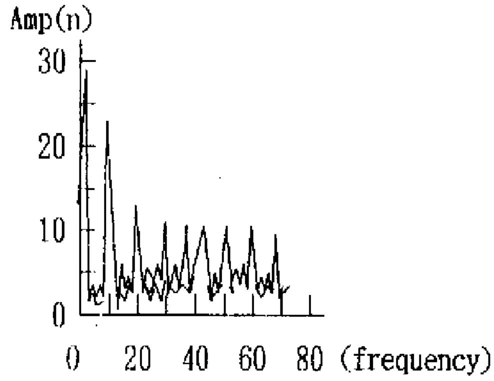


Fig. 6 Amplitude of coefficients

Construction of standard Maharanobis Space

As shown in Figure 6, amplitude of fourier coefficients of $1 has nine projections and these projections of frequency are characteristics of $1 bill. We treat the heights of these nine projections as the input data and we collectthe data of real $1 bills. The standard Mahalanobis Space is calculated using 30 sheets of $1 bill. Each bills have different heights of frequency projections because of the varieties. of their used years. Standardized data is expressed as follows:

$$X_{ij} = \frac{x_{ij} - m_i}{\sigma_i} \qquad (i = 1 \sim 9,\ j = 1 \sim 30) \tag{9}$$

where, x_{ij} is input data and m_i is average and σ_i is standardized deviation. The correlation matrix is calculated from the next equation.

$$R = \begin{bmatrix} 1 & r_{12} & r_{13} & \cdots & r_{18} & r_{19} \\ r_{21} & 1 & r_{23} & \cdots & r_{28} & r_{29} \\ r_{31} & r_{32} & 1 & \cdots & r_{38} & r_{39} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ r_{91} & r_{92} & r_{93} & \cdots & r_{98} & 1 \end{bmatrix} \tag{10}$$

Each r_{ij} is calculated from the next equations.

$$r_{12} = r_{21} = \frac{1}{30} (X_{11} X_{21} + X_{12} X_{22} + \cdots\cdots + X_{129} X_{229} + X_{130} X_{230})$$

$$r_{13} = r_{31} = \frac{1}{30} (X_{11} X_{31} + X_{12} X_{32} + \cdots\cdots + X_{129} X_{329} + X_{130} X_{330})$$

$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$

$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \tag{11}$$

The inverse matrix of the correlation matrix is calculated using eq(4) and Mahalanobis distance D_k^2 is expressed as the next equation.

$$D_k^2 = \frac{1}{9} \Sigma \Sigma a_{ij} \times X_{ik} \times X_{jk} \tag{12}$$

For example, X_{11}=0. 0, X_{21}=-0. 62, X_{31}=0. 78, X_{41}=1. 32, X_{51}=-0. 48, X_{61}=-0. 51, X_{71}=-0. 56, X_{81}=0. 0, X_{91}=0. 30, then D_1^2 = 0. 44.

The data base of Mahalanobis Space is constructed from the Mahalanobis dintances of 30 sheets of $1. When the Mahalanobis distances of some remodeled $1 bills are calculated, their numbers are far from 1. 0.

Inspction experiments

The standard Mahalanobis Space is constructed of calculating the Mahalanobis distance of real $1 bills and using the 30 sheets of the remodeled $1 bills the inspection experiments are practised. The result of the experiments are shown in next Figure.

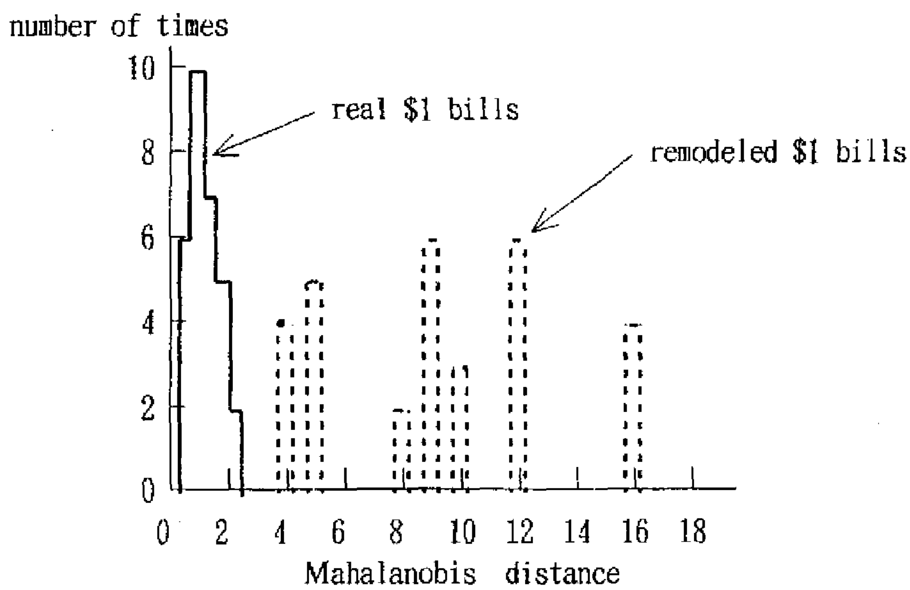


Fig. 3 Result of inspection experiments

As shown in the above experiments result, we can discern between the real good bills and the remodeled bad bills using the proposed Mahalanobis Space and Mahalanobis distance.

SELECTION OF PARAMETER ITEMS

Experiment using orthogonal array

As the sbove mentioned, we use the nine projections of frequency amplitude as the input data and we get the adequate result of the inspection experiments. But if we select the input data, we will be able to inspect the bills more easily. We practise the experiment of parameters selection. The experiment is practised using L_{12} orthogonal array. The case of taking use of the parameters item corresponds to the first level in the experiment and the case of taking no use of the item corresponds to the second level The effect of the experiment is shown in the next SN ratio.

$$\eta = -\log\{ \frac{1}{m} (\frac{1}{D_1{}^2} + \frac{1}{D_2{}^2} + \cdots + \frac{1}{D_m{}^2})\} \qquad (12)$$

The layout of parameters and the SN ratio are shown in Table 1. SN ratio is calculated using the experiment data. Table 2 shows the effect of the parameter items. As shown in Table 2, item 1 and item 2 become the main items for the input data. Each items correspond to the first projection and the second projection of the frequency. The amplitudes of low frequency influence the inspection of bills.

Table. 1 Layout and SN ratio

NO	1 2 3 4 5 6 7 8 9	SN ratio(db)
1	1 1 1 1 1 1 1 1 1	15.1176
2	1 1 1 1 1 2 2 2 2	16.8399
3	1 1 2 2 2 1 1 1 2	17.3672
4	1 2 1 2 2 1 2 2 1	17.0434
5	1 2 2 1 2 2 1 2 1	16.7796
6	1 2 2 2 1 2 2 1 2	18.3582
7	2 1 2 2 1 1 2 2 1	11.6617
8	2 1 2 1 2 2 2 1 1	11.8464
9	2 1 1 2 2 2 1 2 2	12.4911
10	2 2 2 1 1 1 1 2 2	3.4840
11	2 2 1 2 1 2 1 1 1	3.2606
12	2 2 1 1 2 1 2 1 2	2.2671

Table. 2 Effect of items

NO	level 1	level 2	1 - 2
1	16.9177	7.5018	9.4159
2	14.2207	10.1988	4.0219
3	11.1700	13.2495	-2.0795
4	11.0558	13.3637	-2.3079
5	11.4537	12.9658	-1.5121
6	11.1568	13.2626	-2.1058
7	11.4167	13.0028	-1.5861
8	11.3695	13.0500	-1.6805
9	12.6128	11.8013	0.8170

The result of the experiment using the above two items shows in Figure 4. We can construct the bills inspection system using the low frequency items of time series data of US dollar bills.

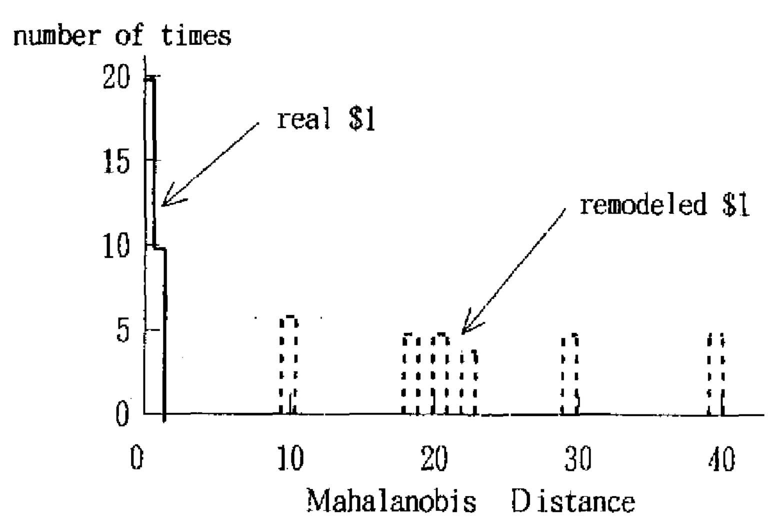


Fig. 4 Experiment result after selecting parameter items

CONCLUSION

The use of Mahalanobis distance method of treating multi-dimensional information system for US bills inspection was proposed. The standard Mahalanobis Space was used for the recognition of pictures. The Mhalanobis distance was calculated from the inverse matrix of the correlation coefficients. The proposed method can be applied not only to bills inspection but also to parinted matters recognition.

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