A Method for Print Quality Evaluation of a Large Number of Data

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1. *Introduction*

It is important to evaluate quantitatively the print quality not only for the valuation of OCR (optical character reader), but also for the development of reliable OCR. Evaluation of print quality has been made manually using simple measuring device. Evaluation method described in "Printing Specifications for Optical Character Recognition" [1] which is recommended by ISO (International Organization for Standardization), seems to be too microscopic, and has little reproducibility of measured values. This paper deals with objective, mechanical, and efficient quantitative evaluation method of a large number of printed images.

2. *Definition of Normalized Pattern and Evaluation of Print Quality by the Similarity*

Consider a two-valued function $\varphi(\boldsymbol{r})$, defined on a region R in the two dimensional x-y plane, which expresses a printed pattern (cf. Fig. 1). Where the coordinates in the region R are denoted by a vector $\boldsymbol{r}$. The function $\varphi(\boldsymbol{r})$ takes unity for black portion and zero for white portion.

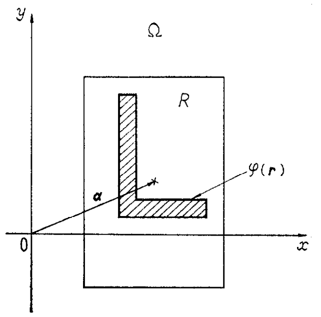

Fig. 1. Region R defined by a pattern $\varphi(\boldsymbol{r})$.

Mean darkness K, and intensity measure A of the pattern $\varphi(\boldsymbol{r})$ are respectively defined by:

$$\begin{cases} K \equiv \dfrac{1}{R}\iint_R \varphi(\boldsymbol{r})d\boldsymbol{r}, & (1) \\ A^2 \equiv \dfrac{1}{R}\iint_R [\varphi(\boldsymbol{r})-K]^2 d\boldsymbol{r} = K(1-K). & (2) \end{cases}$$

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(where the symbol R also expresses the area of the region R.)

The pattern normalized with darkness, which is named normalized pattern $\psi(\boldsymbol{r})$, is given by:

$$\psi(\boldsymbol{r})=(1/A)[\varphi(\boldsymbol{r})-K]. \tag{3}$$

The pattern $\psi(\boldsymbol{r})$ is normalized as the average and the center of gravity are zero, and the mean square is unity.

The similarity $S(f, f_0)$ between two patterns $f(\boldsymbol{r})$ and $f_0(\boldsymbol{r})$ given in the region R, is defined as:

$$S(f, f_0)\equiv(f, f_0)/(\| f \| \cdot \| f_0 \|), \tag{4}$$

where $\begin{cases} (f, f_0)=\iint_R f(\boldsymbol{r})f_0(\boldsymbol{r})d\boldsymbol{r} : \text{inner product,} \\ \| f \| =\sqrt{(f, f)} \quad : \text{norm.} \end{cases}$

The value of similarity $S(f, f_0)$ expresses the cosine of the angle formed by two pattern-vectors $f(\boldsymbol{r})$ and $f_0(\boldsymbol{r})$, considering patterns are vectors in a multi-dimensional vector space. The similarity $S(f, f_0)$ takes its maximum value unity when these two patterns coincide completely.

Let functions $f(\boldsymbol{r})$ and $f_0(\boldsymbol{r})$ be an input pattern and a standard pattern, respectively; and the mean darkness of $f(\boldsymbol{r})$ and that of $f_0(\boldsymbol{r})$ be K and K_0, respectively. If the intersection rate of the black part of two patterns is γ, when the values of mean darkness K and K_0 are equal, the similarity $S(f, f_0)$ between two-valued black and white patterns $f(\boldsymbol{r})$ and $f_0(\boldsymbol{r})$ becomes

$$S(f, f_0)=\gamma, \tag{5}$$

and the similarity $s(g, g_0)$ between normalized patterns $g(\boldsymbol{r})$ and $g_0(\boldsymbol{r})$ is

$$s(g, g_0)=(\gamma-K)/(1-K). \tag{6}$$

If the normalized input pattern $g(\boldsymbol{r})$ is decomposed into the component in the direction of normalized standard pattern vector $g_0(\boldsymbol{r})$ and the component in the direction of a function $e(\boldsymbol{r})$ intersecting perpendicularly to the direction of the normalized standard pattern vector, the projection of the normalized input pattern $g(\boldsymbol{r})$ onto the normalized standard pattern vector $g_0(\boldsymbol{r})$ is the similarity $s(g, g_0)$. The normalized input pattern $g(\boldsymbol{r})$; therefore, can be written as:

$$g(\boldsymbol{r})=s(g, g_0)g_0(\boldsymbol{r})+e(\boldsymbol{r}). \tag{7}$$

Consequently, the similarity $s(g, g_0)$ represents the component in the direction of the standard pattern $g_0(\boldsymbol{r})$ comprised in the input pattern $g(\boldsymbol{r})$, and $e(\boldsymbol{r})$ represents noise component except $g_0(\boldsymbol{r})$.

Noise factor ε^2 is defined by:

$$\varepsilon^2\equiv \| e \|^2/R=1-s^2(g, g_0). \tag{8}$$

Positioning and coincidence of stroke-widths between an input pattern and the standard pattern are necessary, to evaluate print quality of character patterns using the similarity.

3. *Estimation of the Similarity at Equal Mean Darkness*

A method for estimation of the similarity at equal mean darkness has been studied.

A variable ξ and its function $H(\xi)$, using mean darkness K and K_0, and the similarity $s(f, f_0)$, are defined as follows:

$$\xi \equiv K_0/K, \tag{9}$$

$$H(\xi) = S(f, f_0). \tag{10}$$

The function $H(\xi)$ takes following values:

$$\begin{cases} H(\xi)=\xi, \text{ if } T_0 \subset T; & (11) \\ H(\xi)=1, \text{ if } T_0 \supset T; & (12) \\ 0 < H(\xi) < \min(1, \xi), \text{ otherwise,} & (13) \end{cases}$$

where the areas occupied by the black parts of the input pattern and the standard pattern in the region R are denoted by T and T_0, respectively. The outline drawing of $H(\xi)$ is shown in Fig. 2.

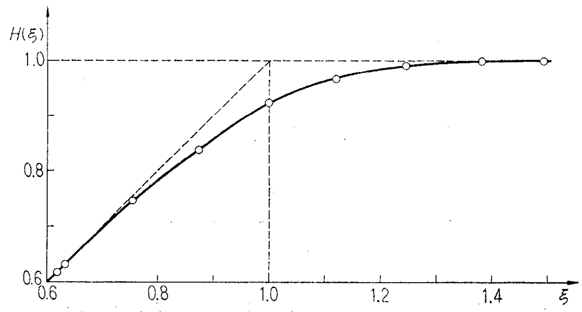

Fig. 2. An example of $H(\xi)$.

The function $H(\xi)$ is approximated with the function $\eta(\xi)$ defined by:

$$\eta(\xi) = [1 + \xi - \sqrt{\xi^2 - 2k\xi + 1}]/(1+k), \tag{14}$$

where $-\infty < k \leqq 1$. (15)

If the value of $\eta(\xi)$ (denoted by η') for a certain value of ξ (denoted by ξ') is known, the parameter k in Eq. (14) is determined, and the approximation function which estimates the value of $H(\xi)$ for $\xi=1$ (namely, $K=K_0$) is fixed. An estimate $H'[\equiv \eta(1)]$ for the value $H(1)$ is given by:

$$H' \equiv \eta(1) = \eta'/[\eta' + \sqrt{(\xi' - \eta')(1 - \eta')}]. \tag{16}$$

If a value of the variable ξ is ξ_1 and estimate for $H(1)$ is H_1' in the case of mean darkness K of the input pattern is smaller than that K_0 of the standard pattern ($K < K_0$), and a variable ξ and an estimate for $H(1)$ are respectively ξ_2 and H_2' in the case of K is larger than K_0; the formula obtaining a new estimate H_0' for $H(1)$ from these two estimates H_1' and H_2' in proportion to the distance between unity and ξ_1, or ξ_2, is given by:

$$H_0' = [(\xi_2 - 1)H_1' + (1 - \xi_1)H_2']/(\xi_2 - \xi_1). \tag{17}$$

The similarity $S(f, f_0)$ between two-valued black and white pattern at equal mean darkness is

$$S(f, f_0)=H_0', \tag{18}$$

and the similarity $s(g, g_0)$ between normalized patterns is

$$s(g, g_0)=(H_0'-K)/(1-K). \tag{19}$$

4. *Estimation of True Maximum Similarity and the Relative Position in This Case*

A rectangular network of equi-spaced points is superimposed over the region R. Let l be mesh spacing in horizontal and vertical directions, and assume one of mesh points coincides with the centroid $\boldsymbol{a}_0$ of the standard pattern. Mesh points are named $P_{i,j}$ $(i, j=0, \pm1, \pm2, \cdots)$ (cf. Fig. 3).

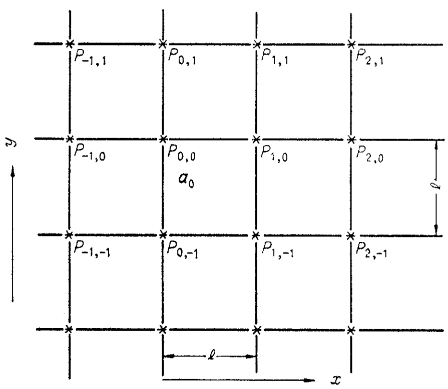

Fig. 3. Rectangular network of points for estimating true maximum similarity.

Consider the similarity $S_{i,j}$ between translated input pattern $f_{i,j}(\boldsymbol{r})$, which is translated so as to its centroid is coincides with the point $P_{i,j}$, and the standard pattern $f_0(\boldsymbol{r})$; namely,

$$S_{i,j}\equiv S(f_{i,j}, f_0). \tag{20}$$

If parameters i and j are changed one by one, the similarity takes a maximum for a certain values of i and j (These values are denoted by I and J, respectively.) The values of similarity at the relative position $P_{I,J}$ and the four cardinal points centering around the point $P_{I,J}$ (plus-shaped five relative positions) are denoted as follows:

$$Z_0\equiv S_{I,J},\ Z_1\equiv S_{I+1,J},\ Z_2\equiv S_{I,J+1},\ Z_3\equiv S_{I-1,J},\ Z_4\equiv S_{I,J-1}. \tag{21}$$

True maximum similarity S_{max} is approximated by:

$$S_{max}=Z_0+(1/2)[|Z_1-Z_3|+|Z_2-Z_4|], \tag{22}$$

and the positional deviation $\boldsymbol{a}'$ of centroid of the input pattern measured from the relative position $P_{I,J}$ as a basis, is given by:

$$\boldsymbol{a}'=\boldsymbol{i}pl+\boldsymbol{j}ql, \tag{23}$$

where
$$p=\begin{cases}(1/2)(Z_1-Z_3)/(Z_0-Z_3), & Z_1>Z_3;\\ -(1/2)(Z_3-Z_1)/(Z_0-Z_1), & Z_1<Z_3;\end{cases} \quad (24)$$
$$q=\begin{cases}(1/2)(Z_2-Z_4)/(Z_0-Z_4), & Z_2>Z_4;\\ -(1/2)(Z_4-Z_2)/(Z_0-Z_2), & Z_2<Z_4,\end{cases} \quad (25)$$

symbols $\boldsymbol{i}$ and $\boldsymbol{j}$ are unit vectors in the directions of horizontal and vertical, respectively.

The positional deviation $\boldsymbol{d}$ of the centroid of input pattern measured from the centroid $\boldsymbol{a}_0$ of the standard pattern as a basis is given as:

$$\boldsymbol{d}=\boldsymbol{l}_{I,\,J}+\boldsymbol{a}', \quad (26)$$

where $\boldsymbol{l}_{I,\,J}=\boldsymbol{i}(Il)+\boldsymbol{l}(Jl)$. (27)

It is assumed that the similarity varies linearly with relative positional translation of an input pattern and a standard pattern.

5. *Evaluation of Pseudo-Data*

Let us make an experiment using computer programs.

A character pattern is represented on a 65×87 matrix (sampling interval is 0.04mm). Pseudo-data are patterns which are added artificial noises to the strokes of a standard patterns and/or around the strokes in statistical manner.

Table 1. Probability of Attaching Artificial Noise.

number of black points in 3×3 submatrix / noise level	0	1	2	3	4	5	6	7	8	9
(1)	0.000	0.001	0.005	0.025	0.125	0.625	0.975	0.995	0.999	1.000
(2)	0.00	0.01	0.02	0.04	0.08	0.16	0.32	0.64	1.00	1.00
(3)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0
(4)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9

Table 2. Evaluated Results for Pseudo-Data.

	noise level	(1)	(2)	(3)	(4)
OCR-A	mean	0.017	0.027	0.171	0.294
	maximum	0.024	0.044	0.252	0.340
	minimum	0.003	0.004	0.114	0.217
	standard deviation	0.005	0.010	0.030	0.029
OCR-B	mean	0.022	0.030	0.160	0.287
	maximum	0.037	0.054	0.235	0.338
	minimum	0.005	0.004	0.038	0.205
	standard deviation	0.007	0.012	0.037	0.028
OCR-A and OCR-B	mean	0.020	0.029	0.165	0.290
	maximum	0.037	0.054	0.252	0.340
	minimum	0.003	0.004	0.038	0.205
	standard deviation	0.006	0.011	0.034	0.029

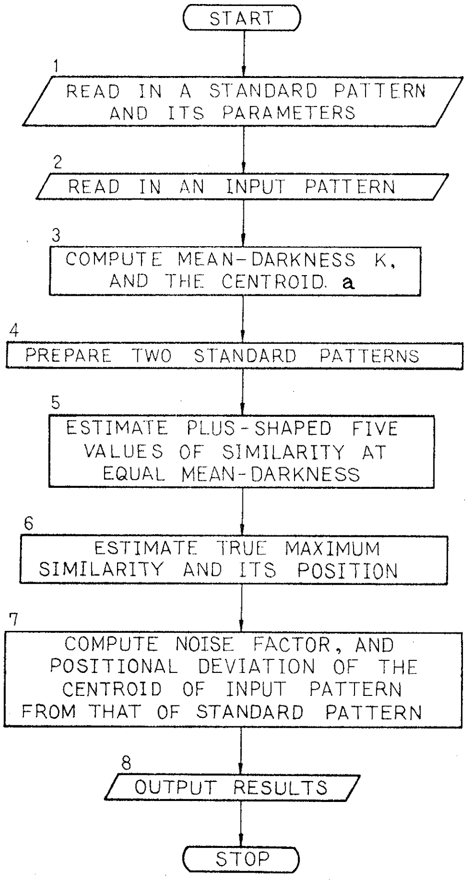

Fig. 4. A simplified flow chart of print quality evaluation.

The value (black "1" or white "0") of a sampling point ρ is determined by the number of black points in a 3×3 submatrix, centered on the point ρ. Probability determining the quantity of noise is shown in Table 1. Quantity of noise increases within the order (1), (2), (3), and (4).

A simplified procedure of evaluation is shown in Fig. 4.

Evaluated results for pseudo-data are shown in Table 2.

6. *Conclusion*

Results shown in Table 2 confirm that the noise factor ε^2 is useful for the purpose of quantitative print quality evaluation. Positional deviation $\boldsymbol{d}$ of centroids of an input and the standard pattern, other than the noise factor ε^2, also serves for the purpose of quantitative print quality evaluation.

To evaluate actual character patterns printed on a sheet of paper; sampling interval, stroke-width preparing for a standard pattern, interval of calculating similarity for estimating true maximum similarity and its position, and the value of threshold, should be determined. These subjects are now under further consideration.

Reference

[1] ISO RECOMMENDATION R 1831 : "Printing Specifications for Optical Character Recognition", Ref. No. : ISO/R 1831-1971 (E) (1971)