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Entropy Calculation Method in a Duplicating Series System

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Since 1978, Uchida *et al.* have applied the concept of entropy in information theory to assess a radiologic imaging system.[1-3] All of these applications were to a single system. In this note, however, we discuss the method of entropy calculation for a series system.

Here we consider the transmission of information in a series system to be composed of two systems, say systems A and B. In this series system, a discrete input $X(x_i, i=1, 2, \cdots, r)$ is first transmitted through a system A and is transformed into discrete output $Y(y_j, j=1, 2, \cdots, s)$. Then, this output Y, which is a discrete input to the next system, is transmitted through a system B and transformed into discrete output $Z(z_k, k=1, 2, \cdots, t)$.

For the system A, entropies such as input entropy, output entropy, joint entropy, conditional entropies, and transmitted information can be calculated from the frequency matrix of (X, Y) obtained experimentally.[1-3]

We take the output frequencies of y_j of system A as the input data to system B, in order to simplify the experiment and calculation. For the system B and the series system AB, the entropies can be given from the frequency matrices of (Y, Z) and (X, Z), respectively, which are also obtained experimentally.

Now we assess the radiographic duplicating series system. An original image (O) was prepared as follows. LTII-A system of medium speed screens-standard speed medical X-ray film (Sakura, double emulsion) was exposed under X-ray tube conditions of 61.4 kVp, 50.3 mA, 1/30 sec, and 180-cm focus-film-distance. The object used was 1-mm lucite stepped-wedge varying from 0 mm to 3 mm placed on a plate of 30-mm lucite. The exposed film was developed by a tank method at 20°C with a 4-min development time. Duplicated image (D_1) can be obtained by duplicating O by use of a duplication printer FINEX and Kodak X-ray radiograph duplicating film (DUP) of single emulsion. The duplicating film exposed was processed by an automatic processor Fuji Ru at 30°C for 3.5-min processing time. The twice duplicated image (D_2) was made from D_1 in the same procedure.

In the present experiment the density of O and the densities of D_1 and D_2 in order to make the frequency matrices for O to D_1 (system A), D_1 to D_2 (system B), and O to D_2 (system AB) needs to be measured in the same position. For this reason, circular marks (with inside diameter of about 1 mm) were drawn on the original radiography (O). This is one of the differences in density measurement for the entropy method applied before.[1-3] A hundred circles were drawn at random position on each step image, so there were four hundred circles in all on the original radiography. With this method then, the density at the same position could be measured. The densitometer used was a PDA-15 (digital display type) with an aperture size of 0.5 mmϕ, and the quantized density value was 0.01. Measured density ranges were 0.93−1.06 for X, 0.81−1.04 for Y, and 0.67−1.04 for Z. Calculated results are shown in Table I, where the relative efficency of transmission, η, is defined as the ratio of the transmitted information to the input entropy.[1-3] These results are relative values for the quantized density 0.01, but are sufficiently valid for relative comparison in this study.[4]

It is found, by the comparison of the value of transmitted information or η for $O \rightarrow D_1$ and $O \rightarrow D_2$ in Table I, that the amount of information transmitted through the duplicating series system constructed by two single systems ($O \rightarrow D_2$) is smaller than that by a single system of $O \rightarrow D_1$. $H_X(Y)$ or $H_X(Z)$ represents the noise, i.e. granularity,[3] and these values show that the noise in $O \rightarrow D_2$ is greater than that in $O \rightarrow D_1$. There is no significant difference between η in $O \rightarrow D_1$ and η in $D_1 \rightarrow D_2$, but the noise in $D_1 \rightarrow D_2$ is clearly more increased than that in $O \rightarrow D_1$. More detailed assessment of three different brands of radiographic duplicating film is investigated in another paper.[5]

We have discussed here how we can obtain the entropies on the transmission situation in a series system constructed by two systems, and this can be easily expanded to a series system composed of n such systems.

Table I. Numerical results.

$O \rightarrow D_1$	$T(X;Y)$ [bits]	η [%]	$H_X(Y)$ [bits]
	1.739	49.1	2.467
$D_1 \rightarrow D_2$	$T(Y;Z)$ [bits]	η [%]	$H_Y(Z)$ [bits]
	2.105	50.0	2.739
$O \rightarrow D_2$	$T(X;Z)$ [bits]	η [%]	$H_X(Z)$ [bits]
	1.429	40.4	3.415

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