THE PROGRAM SYSTEM FOR IMAGE PROCESSING AND ITS APPLICATION TO AUTOMATIC INTERPRETATION OF CHEST X-RAY FILMS

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(Received October 25, 1968)

1. Introduction

The problem of two-dimensional pattern recognition has been studied by many investigators in various fields. Most of them, however, treat rather simple patterns such as type-written or hand-written alphanumerics and only a few investigations are found in processing of complex patterns as photographs. Perhaps, the works such as computer processing of various photographs in physiology by R. S. Ledley *et al.*[1], particle tracking in bubble chamber photographs by Pless *et al.*[2]~[4], automatic object detection in aerial photographs by J. K. Hawkins[5] and by W. S. Holmes[6], and processing of photographs transmitted from satellite by R. D. Joseph *et al.*[7][8] are seemed as the prominent ones so far published.

This paper also belongs to the above mentioned field, that is, we describe in this paper design of the recognition system for complex photographs and its simulation program system together with the application to automatic interpretation of chest x-ray films.

We first state properties of the treated patterns from a general viewpoint in 2, the constitution of the processing system in 3, and the program system simulating its functions in 4.

We present in 5 an example of application, the program system developed for automatic interpretation of chest x-ray films (automatic detection of abnormal shadows due to tuberculosis, lung cancer and so on).

As is known from many other studies, automatic recognition of two-dimensional patterns (especially in the case of complex photographs) is very difficult. So it will be not so easy to complete the entire system for automatic interpretation of x-ray films. On the other hand rapid increase of amount of medical x-ray films to be examined (*e.g.* those of screening survey) requires development of automatic interpretation system by any means. Concerning this problem our results will be expected to serve as the basic data showing to what extent automatic interpretation of the x-ray film is possible.

From another viewpoint it is challenging problem in the information science to know what part (or what functions) of pattern recognition system is most difficult to be realized by a modern digital computer and why it is so. To approach this problem we need to try various recognition experiment using complex patterns consisting of several components and noise, properties of which are very different each other. We believe that chest x-ray films are suitable for this purpose because they include various kinds of patterns such as ribs (which are clear patterns and relatively easy to be recognized), vessels (which have irregular shapes and are difficult to be recognized correctly), random noise and so on. The results in this paper will be useful for the above problem.

2. Properties of patterns

Any complex photograph such as x-ray films and aerial photographs usually consists of several component patterns, whose properties are very different each other. Generally speaking, this fact puts serious difficulties in the interpretation of complex photographs.

Most of component patterns mentioned above can be classified into the following three groups:

(*1*) *Line pattern:* Length, continuity and shape are significant, but width or extent of the area is not significant. For example, roads and rail ways in aerial photographs, thin vessel shadows in x-ray films, etc. Borders of some kind of figures or boundary between two large figures are also included. Examples are a coast line in aerial photographs, borders of rib shadows in chest x-ray films, etc. Their distinguishing features are position, curvature, continuity, direction, length, density, etc.

(*2*) *Mass pattern:* Patterns have some finite area and whole of the area is significant as a pattern. For example, lakes and buildings in aerial photographs, shadows of tuberculous lesions in chest x-ray films, etc. Features are position, width, shape, density, etc.

(*3*) *Random noise:* Irregular component which cannot be regarded as any significant pattern. For example, irregular figures due to sunlight in aerial photographs, those due to the lung markings or thin vessel shadows in chest x-ray films. Noise is caused also by electric devices used for the measurement of film density or by photographic granularity.

It should be noted here that some special pattern may be often regarded to belong to both of group (1) and (2) at the same time, while in another case, it may not be decided definitely which class a pattern belongs to. Detailed discussion about this is omitted here.

3. Constitution of the processing system

As is stated in 2, patterns to be processed consist of various types of component patterns, of which characteristics are different each other. So the system first needs to find what kinds of component patterns exist in the input pattern and then to proceed to the processing of higher level basing on the above obtained results to give the desired output.

In order to recognize component patterns, the system must have many small processers (fundamental processers), each of which is very effective for recognition of a particular component pattern. Before considering the constitution of a fundamental processer, we should note the followings:

(1) In order to recognize a particular component pattern, it is sufficient to know the state of each sample point concerning the given pattern, that is, to find whether each sample point is on that pattern or not so. For example,

in order to recognize a straight line of a given density, it is sufficient to know whether each sample point is on a straight line of the given density or not.

(2) Since the input pattern is always corrupted by noise, the state of the sample point cannot be known exactly. However, accuracy of the state estimation at a particular sample point will be improved to some extent by making use of observations in the neighborhood of that point (Use of local information).

(3) Some component patterns may be almost as large as the entire field of the input pattern (*e.g.* a straight line may extend from one edge to an opposite edge of the input pattern). Therefore the information obtained from observation of the entire field, as well as the local information, must be taken into account in the state estimation of any sample point (Use of global information).

(4) Since only one input pattern is given to the system at one time, the number of available sample point is finite. But the input pattern is assumed to be time invariant (that is, a static pattern), and so it may be observed repeatedly as many times as necessary.

Now, taking into account the above, we suggest a constitution of the fundamental processer as shown in Fig. 1. This processer performs state estimation of each sample point sequentially using the local information and the global information alternately and gets some desired output. Contents of the information to be employed in the estimation are changed basing upon the results of processing in the past, if necessary. Values of necessary parameters (*e.g.* features of patterns to be recognized, accuracy of estimation etc.) are given to the processer from the instructer of higher level in the system.

The entire system for processing complex patterns consists of many fundamental processers, the decision part, the input part and the output part (Fig. 2). The decision part collects results of fundamental processers and makes necessary decisions to get the final output as is desired. The control part gives values of necessary parameters to each fundamental processer and controls the order of the fundamental processing. Several fundamental processings of same type, each of which corresponds to different values of parameters may be executed in parallel by several processers or may be executed sequentially by a single processer (*e.g.* two line detectors adjusted for a line of density K_1 and density K_2 respectively may be applied at the same time, or a single line detector may be first adjusted for detection of a line with density K_1 and then for a line with density K_2). On the other hand, if various component patterns exist overlapping each other, one of them must be first recognized and eliminated before other component

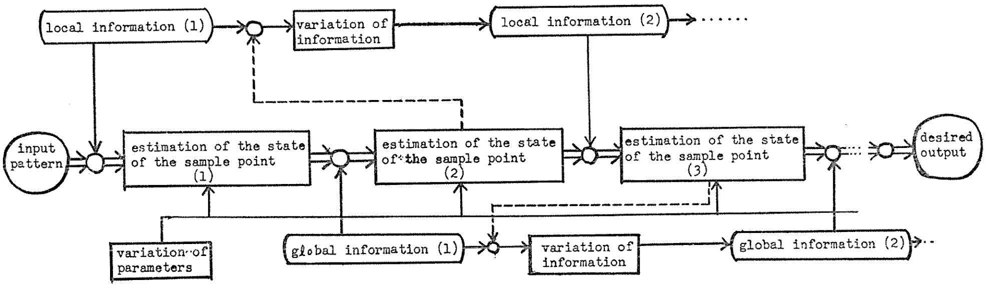

FIG. 1. Constitution of the fundamental processer.

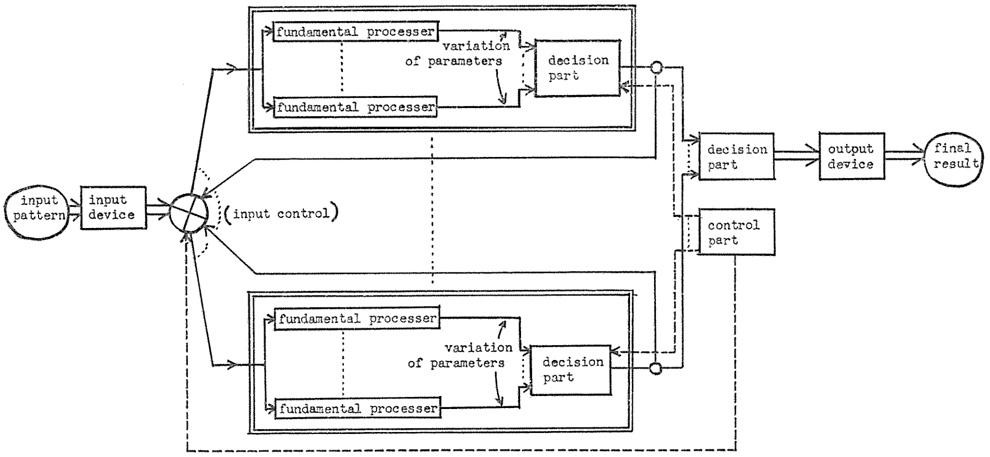

FIG. 2. Constitution of the entire system.

patterns are recognized (*e.g.* in the processing of x-ray films, rib shadows are first recognized and eliminated before abnormal shadows are recognized---see 5). In such a case order of execution of fundamental processings (and therefore the function of the control part) is very important.

4. Computer program system for simulation

The entire system stated above will become of very large scale if it is realized in a complete form, and even if it is simulated by a digital computer, the software system will become very complex and of almost the same complexity as an operating system of a modern large computer system. Besides, concerning the processing technique, an efficient method has not been developed even for a simple fundamental processing. From these facts it seems to be difficult to realize the entire system at once, so we have provided a program system of smaller scale as a first step and tried some basic experiments. In this chapter we state the constitution of our program system from a general viewpoint.

4.1. Constitution of the program system

The program system developed here is divided into the following four parts.

(I) Part of analog pattern processing (Part of feature extraction):

To perform various operations on the input pattern (analog pattern), or to extract features as an analog data. Threshold operation or any type of decision-making is not included here. Therefore both the input and the output are analog data.

(II) Part of logical operation:

To obtain a binary pattern from the input (analog) pattern by means of threshold operations or any other logical decisions, transform binary patterns and perform various logical operations, etc. The input is analog data and the output is binary data.

(III) Part of preprocessing:

To perform various kinds of preprocessings on the input pattern so that the pattern may coincide with a theoretical model and the operations in Part I and Part II may be made easier.

(IV) Part of input/output operations:

To control input/output devices and to transfer data between core memory and auxiliary memory.

4.2. Principles in programming

We kept in mind the followings in programming.

(1) Special operations necessary for the input pattern of special characters are included in Part III as much as possible, so that Part I and II may be applicable to wide varaiety of patterns.

(2) Programs are written in FORTRAN IV so that compatibility among different computer systems may be maintained.

(3) The program system should have module structure in its each level for the convenience of debugging and modification of the system. The system employed in 5 consists of many FORTRAN subroutines.

(4) Since the method of processing itself is on its way of development, change or extension of the system in the future should be possible with much flexibility.

5. Application—automatic interpretation of chest x-ray films

As an example of application of the system stated above, we explain the program system for automatic interpretation of chest x-ray films.

5.1. Outline of the processing procedure

x-ray films given to the recognition system are processed by the following procedure (Fig. 3).

(I) Measuring the film density at each sample point (distance between sample points is 0.8 mm in the vertical direction and 1 mm in the horizontal direction).

(II) Recognizing boundaries of ribs (dorsal portion of ribs).

(III)* Eliminating rib images (dorsal portion) by subtracting their density value from that of sample points which were recognized as on rib shadows in step (II).

(IV) Equalizing average density level in the horizontal direction.

(V)** Recognizing boundaries of ribs (ventral portion of ribs).

(VI)** Eliminating rib images (ventral portion). This step is quite the same as the step (III) except for replacing dorsal portion

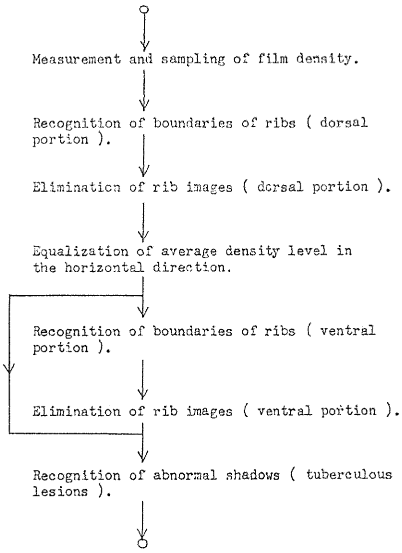

FIG. 3. Block diagram for automatic interpretation of chest x-ray films.

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* The density value of rib shadows is assumed to be known beforehand.

** The step (V) and (VI) are executed only when they are necessary for the step (VIII).

by ventral portion.

(VII) Recognizing abnormal shadows.

Details of the processing in each of the steps above are presented in references (9), (10), (11) and (12). The program system discussed below includes the step (II)-(VII).

5.2. Constitution of the program system

(I) Part of analog pattern processing:

Subroutine AVLIKR: Two-dimensional moving average by a given weight function. Range of averaging is a square of 9×9 sample points. Values of the weight are determined taking into account the properties of the pattern. Theoretical studies about derivation of the weight, estimation of performance etc. are presented in detail in the reference (11) and (12). Two kinds of weights are employed here, one for line pattern (boundaries of rib images) and the other for mass pattern (abnormal shadows) (Fig. 4)[*].

(II) Part of logical operation:

(a) Subroutine HANTE 3: (1) To obtain a binary pattern from an input pattern by threshold operation with given value of the threshold. That is, if the value of the input pattern $f_i(x_j, y_k)$ at the sample point (x_j, y_k) is larger than the given value T, the value of the output pattern $f_o(x_j, y_k)$ is put equal to 1 and otherwise equal to 0. We call the part of value 1 in the binary pattern a "digitized picture". (2) To extract a "connected component" with the size larger than a given value from a given digitized picture and to label each of the extracted components. Here a point Q in any place of $1, 2, \dots, 8$ in Fig. 5 (a) is called a neighbor of the point P, and a subset of a digitized picture is called a "connected component", if for any two points P and Q of the subset there exists a sequence of points $P=P_0, P_1, P_2, \dots, P_{n-1}, P_n=Q$ of the subset such that P_i is a neighbor of P_{i-1}, $1 \leqq i \leqq n$. The maximum value of the length of the connected component in the vertical or horizontal direction is called the "size" of the component (Fig. 5 (b)).

(b) Subroutine HANTE 4: To detect the points on a curve, assuming that

1	0	0	0	0	0	0	0	1
2	1	0	0	0	0	0	1	2
2	3	2	0	0	0	2	3	2
2	3	4	3	0	3	4	3	2
1	1	3	7	15	7	3	1	1
2	3	4	3	0	3	4	3	2
2	3	2	0	0	0	2	3	2
2	1	0	0	0	0	0	1	2
1	0	0	0	0	0	0	0	1

(i)

4	5	6	6	8	6	6	5	4
5	8	9	9	13	9	9	8	5
6	9	12	12	18	12	12	9	6
6	9	12	13	20	13	12	9	6
8	13	18	20	35	20	18	13	8
6	9	12	13	20	13	12	9	6
6	9	12	12	18	12	12	9	6
5	8	9	9	13	9	9	8	5
4	5	6	6	8	6	6	5	4

(ii)

FIG. 4. Two weights used in the program system.
(i) Weight for line pattern.
(ii) Weight for mass pattern.

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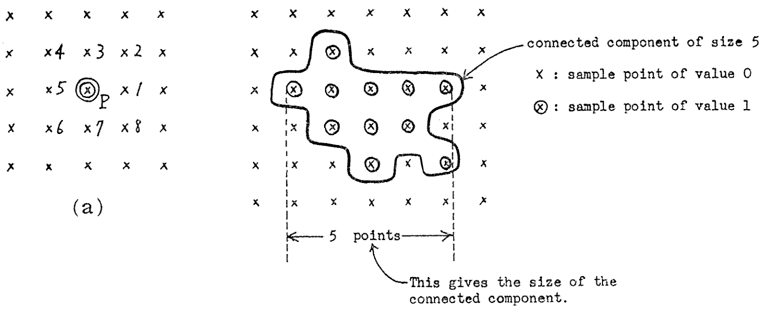
[*] In addition to these subroutines we are programming subroutines MOMEN 1-MOMEN 4 to calculate moments of each connected part extracted by HANTE 3 in (II).



(a)

(b)

FIG. 5. Illustration for subroutine HANTE 3.

each connected component contains only one curve in it. Input is a binary pattern obtained from HANTE 3. For details of the process see the reference (9) and (11).

(c) Subroutine HANTE 5: To modify the result of HANTE 3 according to the given criteria. In the processing of real chest x-ray films, a connected component including boundaries of rib images is often recognized as not connected by HANTE 3 due to overlap of rib images and abnormal shadows. So two connected components satisfying the given criteria are modified and are mutually connected by this program. Details of the criteria are omitted here.

(d) Subroutine HANTE 6: To modify the result of HANTE 4 by smoothing the curve according to the given criteria. In the processing of real chest x-ray films, rib boundaries recognized by HANTE 3-5 have slight irregularities due to vessel shadows or other noise. These irregularities are eliminated (smoothed) by HANTE 6. Details of the algorithm are omitted here.

(e) Subroutine HANTE 7: To decide which pair of the curves detected by HANTE 3-6 gives upper and lower boundaries of one image of ribs. Every boundary has already been distinguished into upper and lower ones as the results of HANTE 3-6. HANTE 7 only decide which of upper and lower boundaries should be paired as corresponding to one image of ribs. The algorithm is rather simple. First, all curves which start from one edge of the pattern field and terminate at another edge are extracted. Then they are paired successively from the top to the bottom of the field (Fig. 6).

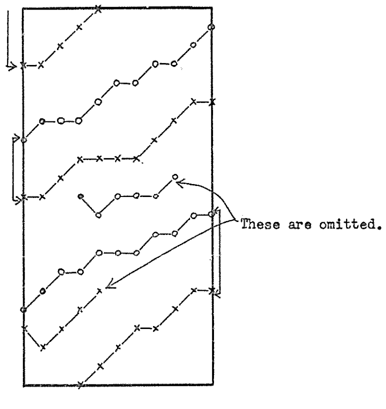


FIG. 6. Illustration for subroutine HANTE 7.

o——o upper boundaries,

x——x lower boundaries,

→o——o / →x——x pair of boundaries recognized by HANTE 7.

In these subroutines, HANTE 3 is used for recognition of rib boundaries in the step (II) (also in the step (V)) and recognition of abnormal shadows in the step (VII). The others are used for recognition of rib boundaries in the step (II) (and in the step (V)).

(III) Part of preprocessing:

(a) Subroutine SABUN: To get a difference pattern from the input pattern. The difference pattern $g(x_i, y_j)$ is defined as follows,

$$g(x_i, y_j) = f(x_i, y_{j+1}) - f(x_i, y_j),$$

where (x_i, y_j) = coordinate of a sample point,

$f(x_i, y_j)$ = the input pattern,

$g(x_i, y_j)$ = the difference pattern.*

(b) Subroutine RIBS: To eliminate rib images by subtracting the given density value (density of rib images) from the density of each sample point in the rib images. It is assumed here that all rib images (dorsal portion) have the same density and its value is known beforehand.

(c) Equalization of average density level: This is not a subroutine but is built in the main program. The processing included here is as follows:

(1) Calculating average density for each column of an input pattern and plotting these values in the graph to obtain a curve of density level variation in a horizontal direction.

(2) Expanding the curve in Fourier cosine series.

(3) Subtracting the constant term and the fundamental component from the input pattern.

For details of these processings see the reference (10).

Application of subroutine SABUN makes it possible to recognize rib boundaries with little influence of other component pattern (vessels or abnormal shadows etc.). Other programs in this part are prepared for making recognition of abnormal shadows easier.

(IV) Part of input/output operations:

Contents of this part strongly depend on what kind of devices are available in the computer system in use. In the experiment stated here we could use only a card reader and a line printer, so we prepared several subroutines for reading and writing in various formats, *e.g.* subroutine READIN, subroutine PRITR 1, PRITR 2, . . . , PRITR 5, etc. We are planning to use a graphic display system in the near future.

Correspondence among these programs and the constituent of the system shown in 3 is given in Fig. 7.

5.3. Results of recognition experiment

Each program of the system mentioned above is applied to the input pattern in the order shown in Fig. 8.

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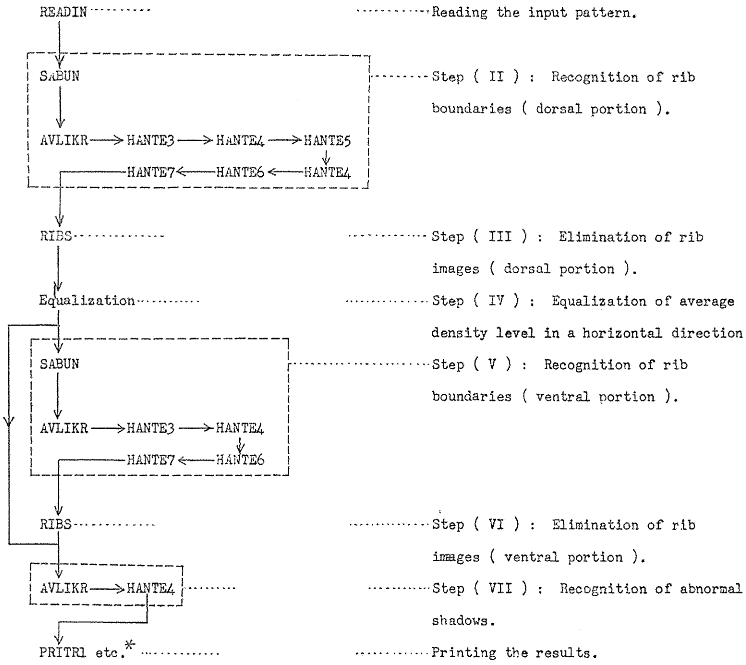
* $g(x_i, y_N)$ is not defined if j moves from 1 to N.

1. fundamental processer:
    - (1)
        - AVLIKR (with the weight (i) in Fig. 4)
        - HANTE 3
        - HANTE 4
        - HANTE 5
        - HANTE 6
        - HANTE 7
    - (2)
        - AVLIKR (with the weight (ii) in Fig. 4)
        - HANTE 3
    - (3) SABUN
    - (4) RIBS
    - (5) equalization of average level variation
2. input device: READIN
3. output device: PRITR1, PRITR 2, . . . , PRITR 5 etc.
4. control part: main program

FIG. 7. Correspondence between the program system and the constituent of the system in Fig. 2.



*Subroutines for printing are used anywhere in a main program if necessary.

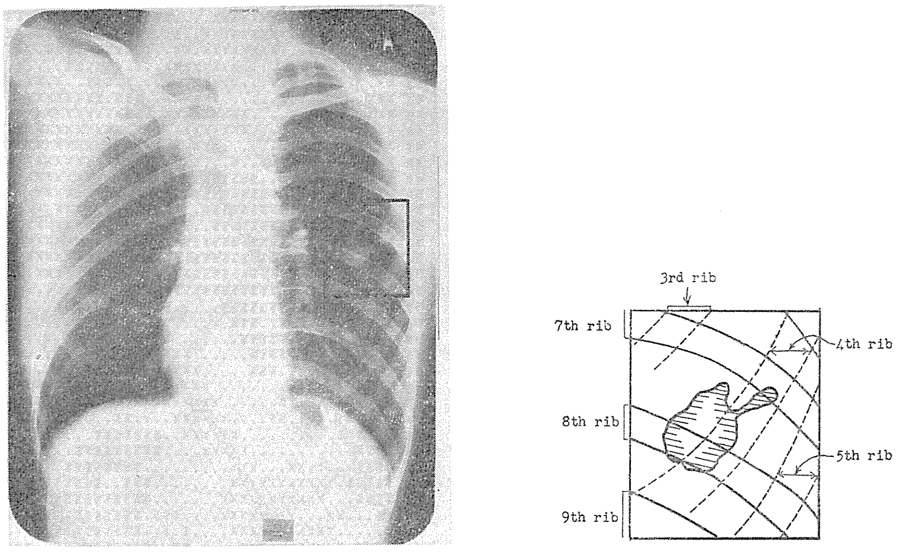
FIG. 8. Sequence of subroutines for the automatic interpretation of chest x-ray films.

Some of the results are presented in Fig. 9. The sample is a part of the chest x-ray films (squared region in Fig. 9 (a)), which is 5 cm wide and 6 cm long. Sampling interval is 1 mm in a horizontal direction and 0.8 mm in a vertical direction*, so that the input pattern consists of $75 \times 51 = 3825$ sample points. Density value for each sample point is represented by a decimal number of three significant digits.

Errors in the recognition of rib boundaries are caused chiefly by confusion among borders of abnormal shadows and ribs in the case that abnormal shadows and images of ribs overlap. In most of these, however, true boundaries of ribs are detected together with borders of abnormal shadows, although the latter slightly exceeds the former in likelihood ratio, so correction of the results is possible by HANTE 5 and HANTE 6.

Generally speaking, most of rib boundaries of dorsal portion are recognized satisfactorily except for especially complex pattérns such as those in the upper lung field, but the recognition of ventral portion is difficult.

The abnormal shadow is also recognized rather satisfactorily in this example. The difference between recognition by a computer and a medical specialist is not so serious in this case, because the border of the shadow is obscure and the



(a) (b)

FIG. 9 (a) Input pattern (squared part).
Squared part on the film is 5 cm wide and 6 cm long.

FIG. 9 (b) Sketch of the material in (a).
solid curves: boundaries of dorsal portions of ribs.
broken curves: boundaries of ventral portions of ribs.
shaded area: abnormal shadow (tuberculous lesion).

FIG. 9. Results of computer processing of chest x-ray film.

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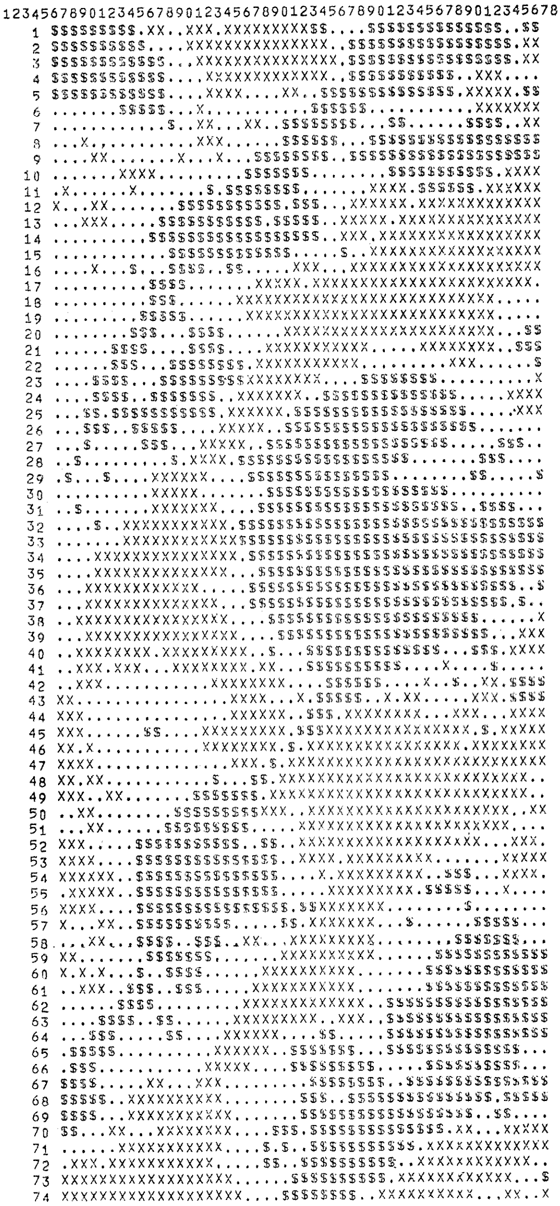
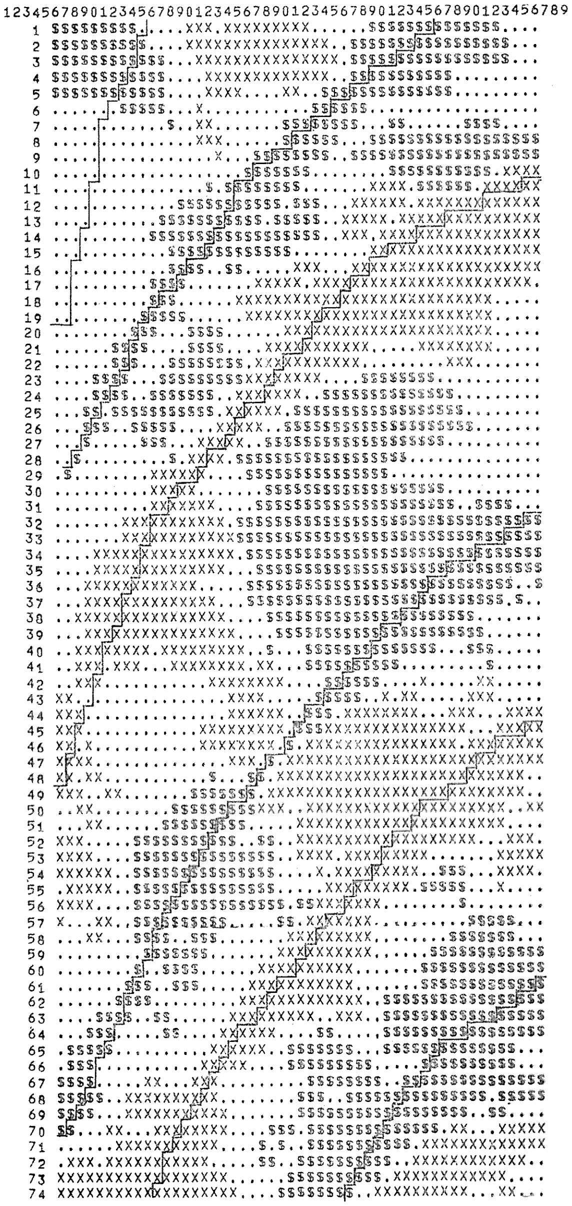
* There is no special reason why the sampling interval is different between two directions. It is only a matter of experimental convenience.



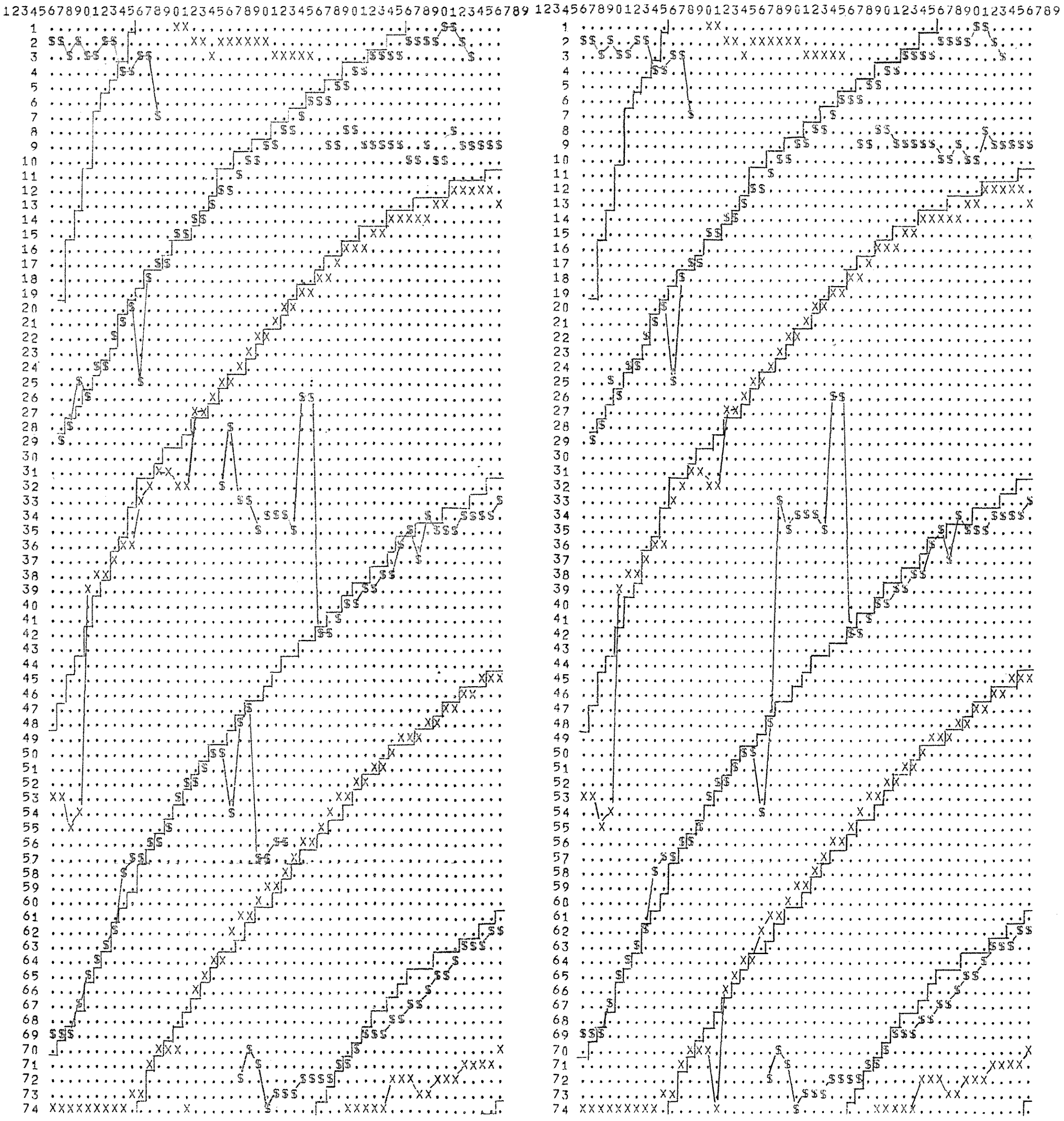
(c)



(d)

FIG. 9 (c) Result of HANTE 3—(1).
$: sample point of the value 1 (corresponding to upper boundaries of ribs).
×: sample point of the value 1 (corresponding to lower boundaries of ribs).
•: sample point of the value 0.
All the figures below see the material in (a) backward because of experimental convenience.

FIG. 9 (d) Result of HANTE 3—(2). Connected components of the size larger than 10 in Fig. 9 (c).
$: connected components corresponding to upper boundaries of ribs.
×: those corresponding to lower boundaries of ribs.
•: sample point of the value 0.
⅃‾: rib boundaries recognized by a medical specialist.



(e)

(f)

FIG. 9 (e) Result of HANTE 4.

$: curves recognized by computer corresponding to upper boundaries of ribs.

× : those corresponding to lower boundaries of ribs. (Solid lines between $ or × marks show connections recognized by computer)

• : sample point.

⌐ : rib boundaries recognized by a medical specialist.

FIG. 9 (f) Result of HANTE 4 following HANTE 5.

Symbols are the same as in Fig. 9 (e).

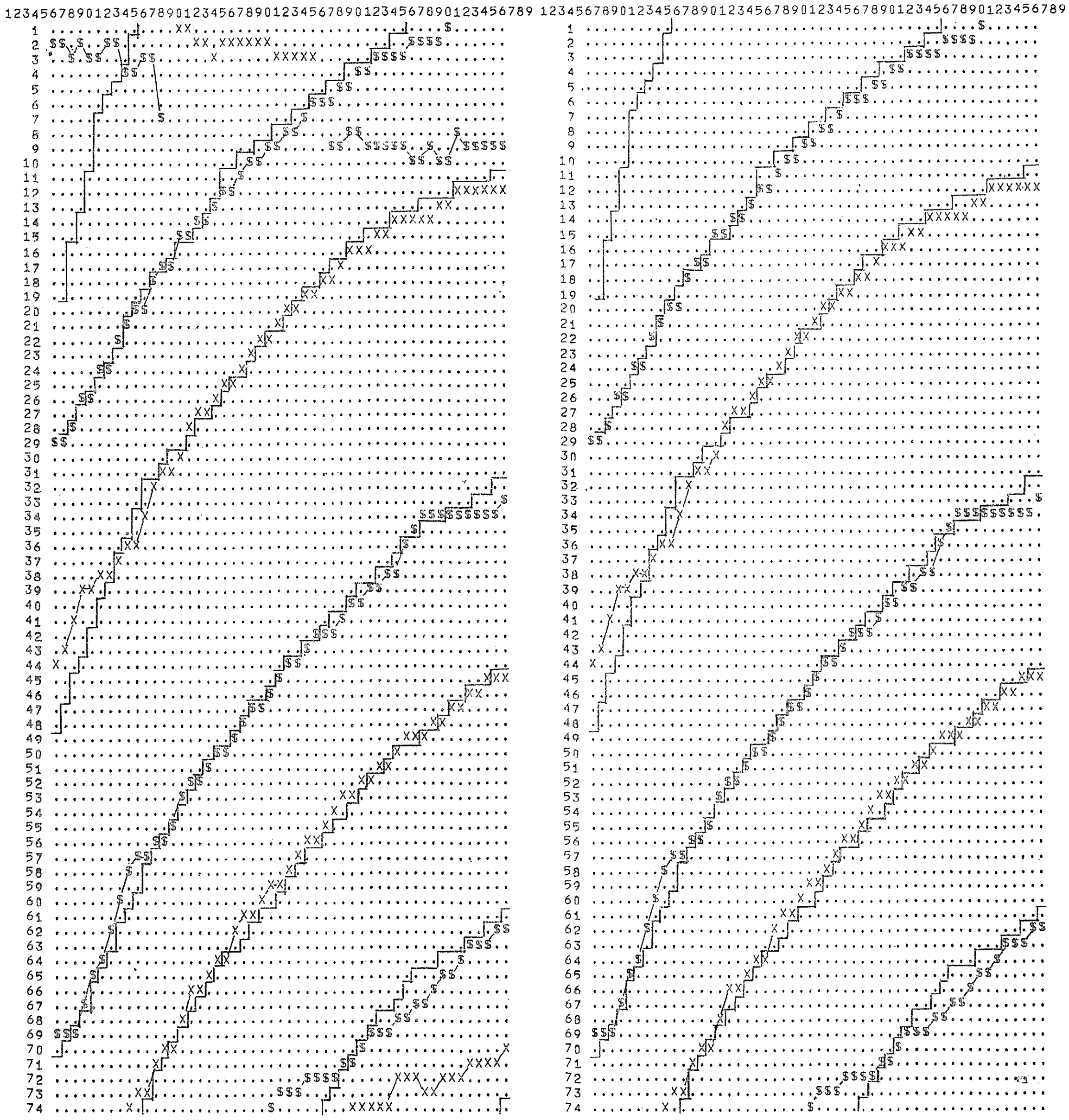

(g) (h)

FIG. 9 (g) Result of HANTE 6.
Symbols are the same as in Fig. 9 (e).

FIG. 9 (h) Result of HANTE 7.
$: upper boundaries of ribs recognized by computer.
× : lower boundaries of ribs recognized by computer.
• : sample point.
┌ : boundaries of ribs recognized by a medical specialist.

Result of recognition within four columns and four rows from edges of the field is unreliable because of the characteristic of moving average used here, so error in a left upper corner is unavoidable in this case.

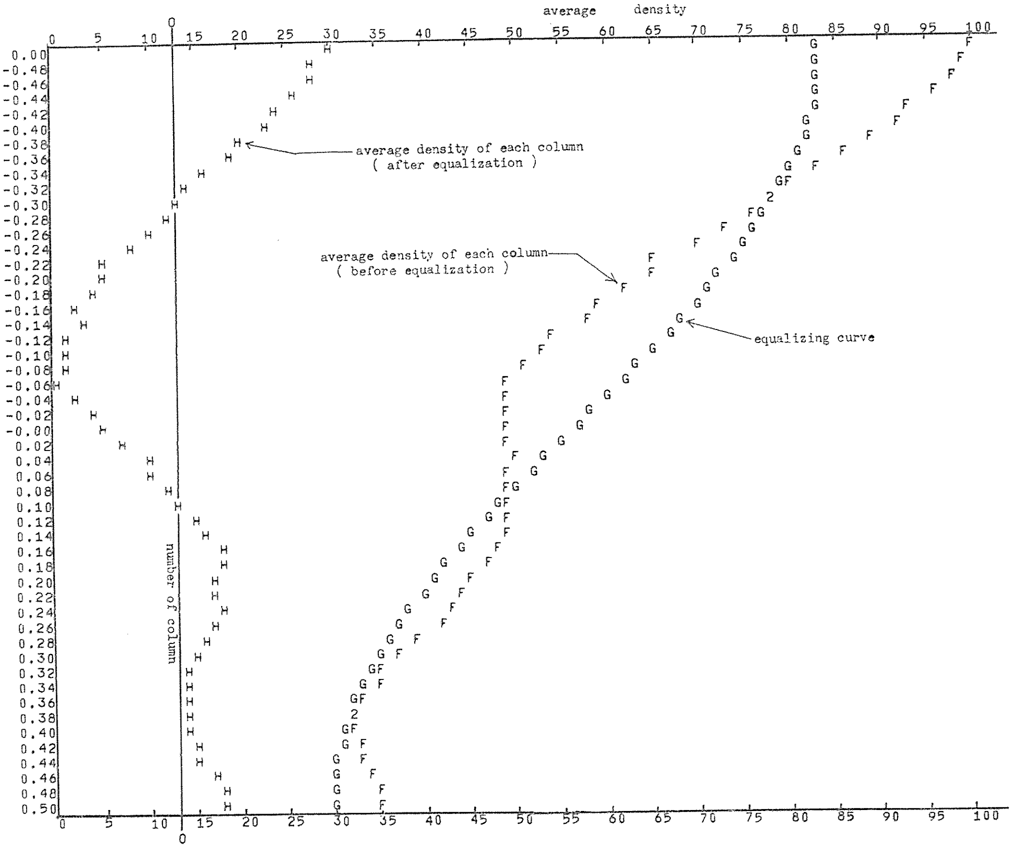


FIG. 9 (i) Equalization of average density level in a horizontal direction.

different specialists demarcate the shadow differently (Fig. 9 (j)).

Recognition errors occur in this example at the upper left and lower right corners, both of which are due to the overlap of two rib shadows or shadows of a rib and vessels. These error cannot be avoided unless observing outside of the given square of the film. Generally recognition of abnormal shadows is not so easy as that of rib images. One of the reasons is that the method employed here, that is, two-dimensional low pass filtering followed by threshold operation, is sensitive to the variation of low frequency component such as the variation of average density level in a horizontal direction. Another important reason is that characteristics of abnormal shadows are not known very well.

The computer system used in the experiment is HITAC 5020 E of Computer Center, University of Tokyo and whole of the processing required about sixty seconds and 50 K words core memory (of which the subroutines in 5.2 occupied about 6 K words).

6. Conclusion

We described in this paper the design of general image processing system,

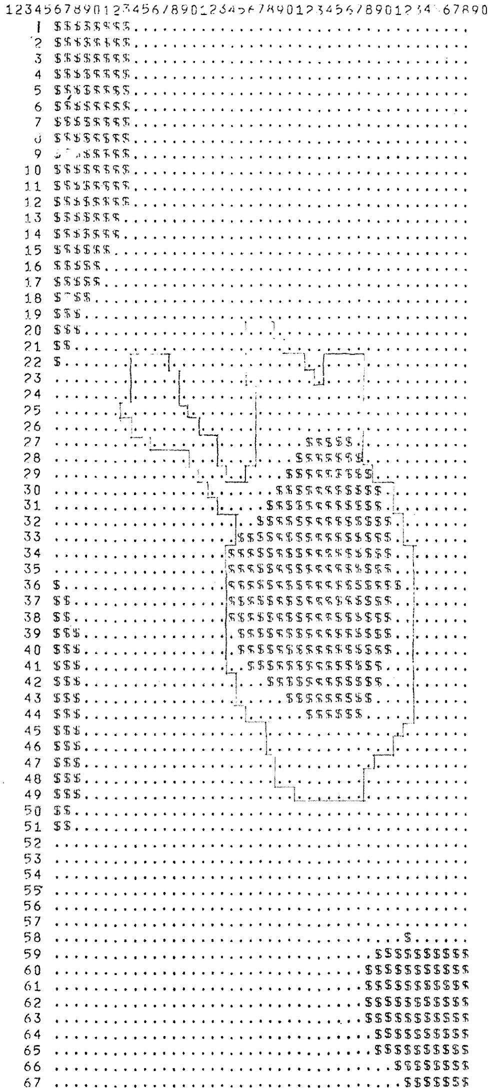


FIG. 9 (j) Result of recognition of abnormal shadows.
$: abnormal shadows recognized by computer.
• : sample point.
┘┌ : abnormal shadows recognized by a medical specialist.

constitution of the program system for simulation and its application to the automatic interpretation of chest x-ray films. Since the program system is of relatively small scale and has limited capability for automatic processing of photographs, many problems are left to be solved.

First, concerning the realization of more powerful system, various kinds of fundamental processers should be developed and their performance must be evaluated as exactly as possible. Then functional growth of the system by giving more advanced faculties such as self-organization or learning must be considered. Quantitative evaluation of performance is important also in this case for design of most effective and economical system.

Next, concerning the application to automatic interpretation of x-ray films, properties of the pattern to be recognized should be studied more precisely and quantitatively. In fact, what is the abnormal shadow is not known quite definitely. If the input pattern is represented in a mathematical expression, derivation of the optimal processer will be reduced to a problem of mathematical induction.

Lastly the important problem is how much a modern computer system can do in pattern recognition. It may be hardly possible to answer this question at once. But it seems to be sure that there is some obstruction for a modern digital computer in dealing with pattern recognition. Although simple skeptic must be excluded from the scientific field, this difficulty must always be kept in mind in the whole course of study.

Acknowledgement

The authors wish to express their gratitude for the advice and encouragement of Prof. N. Honda, Tohoku University and Prof. K. Ikegaya, Nagoya University. They gratefully acknowledge helpful discussions and assistance in the experiment with Dr. K. Koike and Dr. Y. Takagi of East Nagoya Hospital. Acknowledgment also is due to Miss. K. Ito for programming of the system in 5.

References

1) Ledley, R. S. *et al.*: "Pattern Recognition Studies in the Biomedical Sciences", AFIPS Conf. Proc., Vol. **28**, pp. 411–430 (1966).

2) Pless, I.: "PERP System (Precise Encoding And Pattern Recognition)", IEEE Trans. Nuclear Science, Vol. **NS-12**, pp. 279–290 (August 1965).

3) Wadsworth, B. F.: "PERP. A Development System for Rapid Processing of Bubble Chamber Film", Proc. Soc. Photographic Instrumentation Engrs. (June 1966).

4) Narasimhan, R.: "Labeling Schemata And Syntactic Descriptions of Pictures", Inform. and Control, Vol. **7**, No. 2, pp. 151–179 (1964).

5) Hawkins, J. K. *et al.*: "Automatic Shape Detection for Programmed Terrain Classification", Proc. Soc. Photographic Instrumentation Engrs. (June 1966).

6) Holmes, W. S.: "Automatic Photointerpretation And Target Location", PIEEE, Vol. **54**, No. 12, pp. 1679–1686 (December 1966).

7) Joseph, R. D. *et al.*: "A Pattern Recognition Technique And Its Application to High-resolution Imaginery", ARIPS Conf. Proc. Vol. **28**, pp. 457–475 (1966).

8) Joseph, R. D. *et al.*: "Pattern Recognition from Satellite Altitude", IEEE Trans. System Science and Cybernetics, Vol. **SSC-4**, No. 1, pp. 38–47 (March 1968).

9) Toriwaki, J. *et al.*: "Characteristics of Density Distribution of Chest Roentgenograms And Automatic Recognition of Rib Boundaries", JJME and BE (in Japanese), Vol. **5**, No. 3. pp. 182–191 (July 1967).

10) Toriwaki, J. *et al.*: "Automatic Recognition of Abnormal Shadows in Chest Roentgenograms", JJME and BE (in Japanese), Vol. **6**, No. 3, pp. 207–213 (June 1968).

11) Toriwaki, J. *et al.*: "An Approach to Boundary Recognition of Two-dimensional Noisy Figures", Trans. of IECE of Japan C, Vol. **51-C**, No. 2, pp. 43–50 (February 1968).

12) Toriwaki, J. *et al.*: "Recognition of Random Mass Patterns with Additive Gaussian Noise", JJME and BE (in Japanese), Vol. **6**, No. 6, pp. 449–456 (December 1968).