社団法人 電子情報通信学会
THE INSTITUTE OF ELECTRONICS,
INFORMATION AND COMMUNICATION ENGINEERS

信学技報
TECHNICAL REPORT OF IEICE

[フェロー記念講演]　Image Analysis and Medical Applications Forty Years

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Abstract This special talk is set to commemorate the author's fellow title of IEICE Japan. Researches between these forty years related to image analysis and medical applications is introduced in this talk. They include wide range of research of learning, registration, classification method, spatio-temporal image processing, 3D display, and sign language communication-aid system.
Keyword Medical image, 3D display, Registration, Sign language, Fuzzy relation

It was 1966 when the author begun the research of pattern analysis/recognition at Graduate School of Engineering Science, Osaka University. This special talk is set to commemorate the author's fellow title of IEICE Japan. Researches between these forty years related to image analysis and medical applications are introduced.

1. Basic research for pattern analysis

1.1. Learning of unknown pattern

The author's first major research work as a graduate student was learning and recognition of unknown signal pattern. When the pattern shape is unknown under the Gaussian noise environment but the pattern class is given by a teacher, pattern classification is a simple optimum estimation problem (learning with teacher). However, when the pattern class is unknown, it is a nonlinear estimation problem. One solution to such problem is to compensate the instruction of the teacher by a decision of the classifier itself (decision-directed machine). Another approach is to exclude outliers, and this improves the estimation accuracy (robust estimation). However, these approaches give biased estimator. To obtain the unbiased estimator, we proposed some machines including a non-decision-directed machine for two class problem [1]. Further, some other problems including time-varying pattern [2], synchronization for unknown period of sequence [3], and with feedback link [4] were studied.

1.2. Classification method based on fuzzy relation

Besides the above, the author dealt with fuzzy set theory, and developed fuzzy classification method based on fuzzy relation [5]. Although Prof. Zadeh, the originator of fuzzy theory seems also felt need of such method, I could publish the paper earlier than him. This paper was introduced in many books, and after 21 years later from the original publication, reproduced paper was published from IEEE Press [6] as well as the extended analysis paper [7]. An extension of the theory is awarded with the Best Paper Award in Japanese Society for Artificial Intelligence Annual Convention.

1.3. Registration: Esp. for industrial applications

Image registration is one of the most fundamental techniques in image analysis. As a matter of course, it is important in medical image analysis and also in industrial applications such as dicing saw for silicon wafer. Functionally it is also called "positioning", "localization", or "alignment".

We developed an alignment system for IC wafer with Disco Co. which is the leading company in the world in dicing saw. First we developed an alignment system using straight line detection [8], which uses direct detection of straight lines on surface of IC wafer. Direct straight line detection method using sequential detection algorithm is faster than Hough transform [awarded with Daily Industrial Newspaper Ten Most Important New Product Award]. Then, we also developed a pattern matching circuit based on normalized correlation for practical use in dicing saw in 1984 [9]. In that time it was impossible to calculate normalized correlation in real time. So, we developed a normalized correlation between only on pseudo-random sampling points selected one point from each raw and each column. This type of hardware may be the first one in the world though Cognex, leading industry in machine vision spinned out from MIT, declares in their home page [10] they are the first in 1987. However, it should be noted that Cognex developed a pattern matching machine for industrial applications using mutual information soon after Viola (1995)

1.4. Spatio-temporal image: Hough, Radon, and LG transform / filtering for tracking blood cells

Motion of blood cells (platelet stained by fluorescent dye

(Fig.1), leukocyte, etc.) is depicted as lines of traces in 2D spatio-temporal images [11]. Then, they can be detected by directional Laplacian-Gaussian filter [12]. On the other hand, if they are straight line, they can also be detected by Hough transform. We have shown that Laplacian-Gaussian filter and Hough transform are essentially the same detection method, and also the same as Radon transform [13](Fig.2).

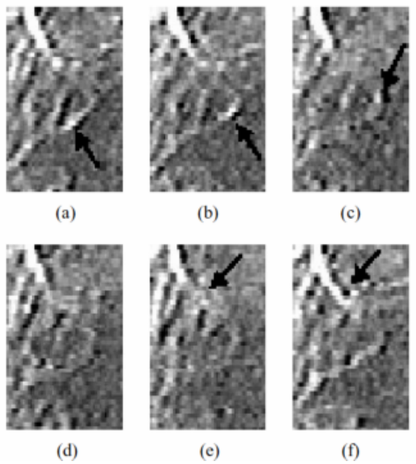

Fig.1. Enlarged image sequence of moving fluorescent dot (see arrow) in scanning laser ophthalmoscope (SLO).

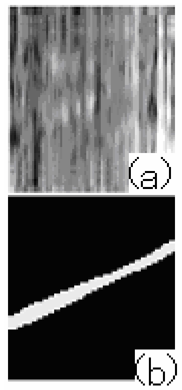

Fig.2. Spatio-temporal image along capillary vessel (a), and extracted trace by LG filter (b).

2. 3D display: Esp. for echocardiography

3D display is the most basic function of 3D image processing.

2.1 3D image processing

On-line connection of the echocardiograph to the computer was not so popular in the 1970s. Then, we scanned the tomograms by a FSS (flying spot scanner) connected to PDP-8 computer, which are taken at intervals of 5mm using 2-3 MHz ultrasound with cardiac synchronization. Then we extracted boundary lines of each tomogram and composed a binocular stereoscopic image on a

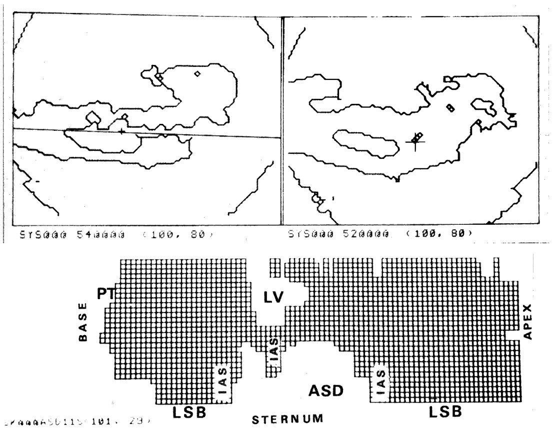

Fig.3. Specifying desired plane (upper) and extracted ASD (lower).

storage type CRT [14,15]. Also they are processed to extract arbitrary plane image [14,16] (Fig.3) and measured volume of ventricle [17].

2.2 Multilayer 3D display

To show the real 3D image for serial tomograms, we have devised a multilayer display using half mirrors and by making optical length to each monitor surface different [18,19]. Example of three layer display is shown in Fig. 4. This can be expanded up to 25 layers or more. This method is introduced in the recent Japanese handbook [20] after 24 years later, and also in web site [21].

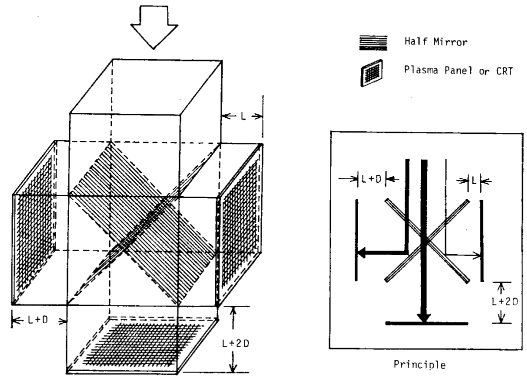

Fig.4. Multilayer display in case of three planes.

2.3 Special purpose 3D display system

Further, in 1978, we developed a three-dimensional display system using an overlaid display with different gray levels corresponding to depth. The input to the system is a set of serial tomograms on paper media (in photographs) derived from either ultrasound or CT etc. The system is composed of a hierarchical distributed microprocessor system with loose connections via an external bus (Fig.5) [22]. The global processing unit (GPU) controls the five local processing units

Fig.5. Special purpose 3D display system with multiprocessors.

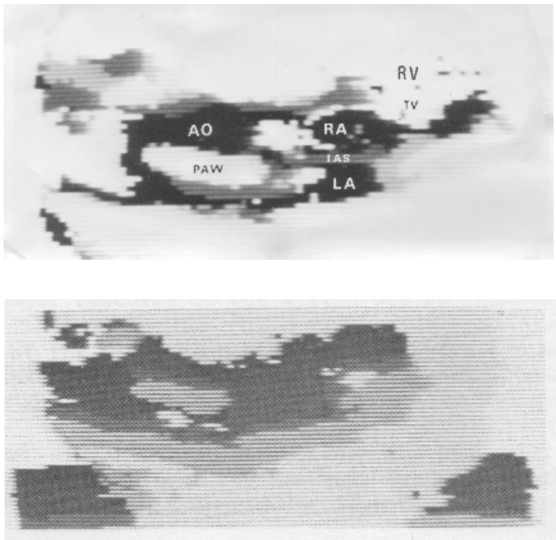

Fig.6. ASD heart. Depth is expressed by gray level as black being far (Lower panel shows from 20 ° upward than upper one).

(LPUs). Example of the 3D display of ASD (atrial septal defect) heart is shown in Fig.6, where the front side of IAS (interatrial septum) is defected and depicted as gray corresponding to the depth. The defect is the same place as Fig.3.

3. Eye fundus image

Extent of fluorescent dye leakage from the blood vessels on eye fundus will reflect damage to the retina by diabetes. Thus we analyzed area of fluorescent dye leakage of eye fundus images by automatically excluding blood vessels. If the result is improper, we can modify it interactively [23; awarded with Pattern Recognition Society Award Honorable Mention]. Then since the eye fundus camera has utmost 60 degrees of imaging angle at that time, it cannot cover all fundus simultaneously. Therefore, we developed a method of assembling/synthesizing wide range of fundus image from individual images [24]. Further, we have developed a method of measuring correctly the diameter of eye fundus blood vessels [25] and generating retinal sensitivity map [26].

4. Welfare: Sign language display/recognition system

Sign language is an important communication tool for hearing impaired people. In 1985 and 1988, we published papers dealing with Japanese sign language generation [27] and recognition [28; awarded with Pattern Recognition Society Award Honorable Mention] systems. Roughly speaking, Japanese sign language is composed of hand shape and arm motion. Some examples of sign language recognition are shown in Fig.7. These papers are the pioneering work in the field of gesture, non-verbal communication, facial expression, and motion whose researches were began and became popular and active afterwards. Our research is introduced by D.Rubin of Carnegie Mellon Univ. in his book "The Automatic Recognition of Gestures" (A.K.Peters,Ltd; 1994).

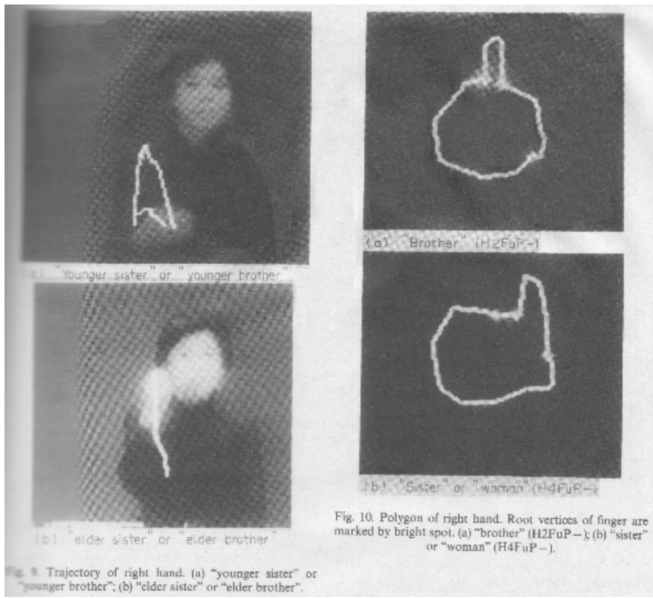

Fig.7. Extraction of arm motion and hand shape. These combinations expresses "Elder sister", "Younger brother", etc.

5. Surgical navigation

Between 1999-2004 we had a big research project of "Acquisition and utilization of multi-dimensional images during surgery" under the "Development of surgical robot" of Research for the Future Program of JSPS, Japan [e.g.,29].

6. Future CAD

Between 2003-2007, we also have a big research project of "Computational modeling of organ structures" under the "Intelligent Assistance in Diagnosis of Multi-dimensional Medical Images" of Grant-in-Aid for Scientific Research on Priority Areas of MEXT, Japan. This project is aiming developing the next generation CAD（Computer Aided Diagnosis）system which will be comprehensive and allow targeting multi-organ and multi-disease [e.g.,30,31].

7. Closing remarks

When the author begun the research, it was an era the large computer systems had set to major universities and the middle-size computers had begun to set to some laboratories in Japan. Between these forty years, it is noted that recognition techniques of character and voice advanced remarkably. On the other hand, CAD for medical images is clinically just at the beginning for limited diseases. The main difficulties of the CAD compared with character and voice recognition may be the dimension increase from 1D/2D to 3D and database problem derived from the privacy, although database is indispensable to develop CAD system. However, the computer shows its power in the well defined problem such as (1) generating 3D image and showing it suitably and quickly, (2) measuring / quantizing 3D data and showing diagnostic indices calculated from them, (3) elaborately tracing vessels in 3D space for e.g., discriminating artery / vein, (4) setting circumstances easy to compare temporally and spatially and supporting image reading, (5) predicting / estimating prognosis by simulation. These make the role of computer essential and indispensable in the medcal image more and more including emerging new field such as image guided surgery.

Acknowledgement: The author would like to express his thanks to all people in his lab. for supporting the researches especially to Dr. Y.Sato for promoting the projects (**5**,**6**). These include ones awarded with Herbert M. Stauffer Award, Certificate of Merit from Radiological Society of North America, and Paper Award from Japanese Society of Medical Imaging Technology

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