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Role of Digital Image Processing in Morphology

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1. Introduction

Processing of morphological information or processing of "form" appears in all aspects of information processing by both man and computer. A general flow of morphological information processing is shown in Fig. 1. Generation of "form" is divided into two categories: the one observed in natural phenomena and the other produced in the process of human activities. The latter includes the "form" created intentionally and the one found in the results of human activities without specific consideration about the "form". All of such "forms" are usually recorded or observed in an image like photographs, diagrams, paintings and printed documents. Thus almost all of the processing of morphological information necessarily has the close relationship to image processing.

In this paper, we briefly introduce image processing technology which may be applicable to morphological information processing (or processing of "form") by machine. In particular, image pattern recognition is important for measurement, detection and classification of "forms" in all kinds of images. Computer graphics is also extremely significant as a tool to visualize the "form" existing in invisible data and to assist creation of the new "form" by man. After short description of techniques for image processing in the wider sense which may be available for study of "science on form", we introduce three examples; three dimensional image processing and measurement basing upon X-ray CT images with the application to analysis of an Egyptian mummy, image pattern recognition applied to computer diagnosis of double contrast stomach x-ray images, and computer

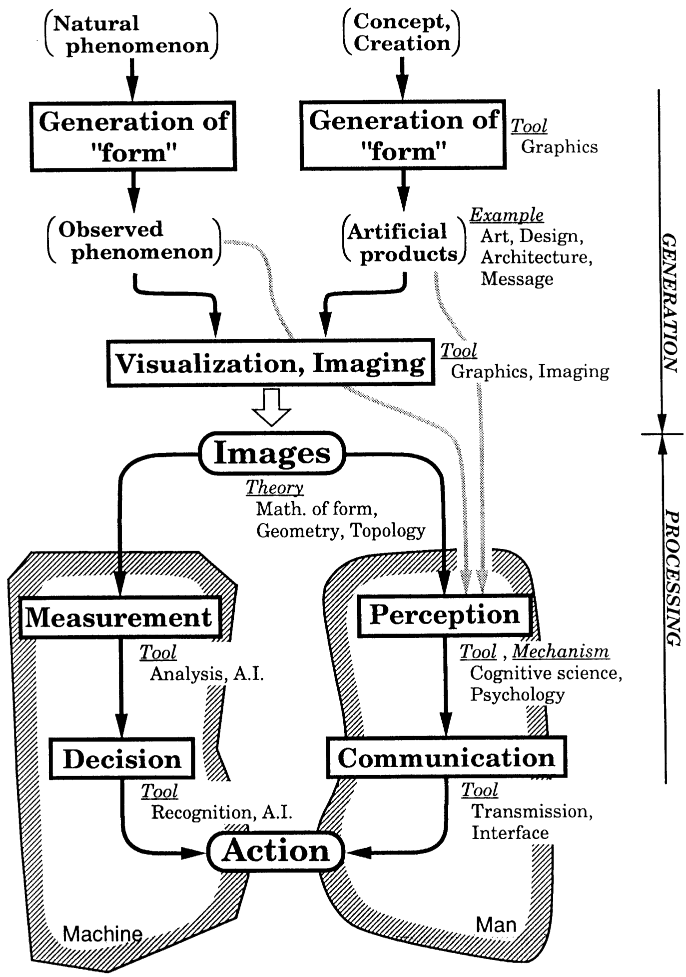

Fig. 1. General flow of processing of information relating to "form" (or morphological information) and tools of image processing.

graphics used to visualize or to create virtual objects defined in computer.

2. Generation and Processing of Morphological Information

2.1 Generation and visualization of "form"

(1) *Generation of "form"*

"Form" is created in the process of both natural phenomena and human activities. The "form" generated in the natural phenomenon becomes apparent as a result of various laws underlying observed phenomena associated with different boundary conditions. Human observers such as scientists try to find such fundamental laws and to understand the essential nature of phenomena from the "forms" included in the observations. Some people believe that all "forms" themselves carry essential information concerning relating phenomena. This suggests a reason for the "science on form" being significant.

The "forms" being produced through human activities are divided into two subcategories. One is the products of creative activities such as painting, sculpture and arts in general, architecture, characters and symbols, and industrial design. The other is those resulted in unconsciously from natural activities for living such as the distribution pattern of houses in a village.

The former is the realization of "images" or "concepts" existing in the brain of designers. It may be regarded as a kind of "message" or "visual language", which is created to communicate what a designer is thinking or feeling to other people [Thompson82]. Various letters and symbols which were used by people in ancient days are also interesting from this viewpoints [Hinata 81]. Nowadays large numbers of new symbols and signs are used everywhere in the world [Egawa85]. Thus manipulation of "form' and relating information has a close relationship with communication technology too. Computer graphics has become extremely important as a powerful tool of such activities by men of creative minds, and is expected to be used in the future much more effectively and flexibly.

(2) *Visualization and imaging*

Two categories of information technology are available to generate images containing morphological information. One is the "visualization"and "imaging" technologies and the other is computer graphics. Imaging is the technology to produce images from volumes of numerical data collected by various sensors. Typical examples are remote sensing [Sabins87] and computed tomography [Kak88]. In the remote sensing artificial satellites measure the reflection of the earth surface at a few frequency bands and transform it into numerical data. The data is transformed further and arranged to make what we call earth satellite images.

Computed tomography (CT) is a surprisingly useful system of technology which collects large numbers of one-dimensional projections of a three dimensional object using x-ray, magnetic field or ultrasound and reconstructs images of two-dimensional cross sections of the solid object. It is becoming more important as a method to observe internal structures of both living organs and industrial products. It is also significant as a means to "visualize" variety of "invisible" information.

Computer graphics (CG) is the technology to generate or to draw pictures by computer basing upon numerical data, symbolic description and algorithmic specification stored in memory [Foley90]. This is highly important because of its flexibility which makes it possible to draw any form of images if it is suitably specified and its potential capability of simulating arbitrary modification or dynamics of morphological information. Therefore CG is remarkably useful for visualizing observation records of natural phenomena, producing morphological information, and creating new shape data through creative activities of human brain. In fact CG is now becoming popular even among some artists.

Many other interesting techniques specific to each application field have been developed as follows.

(a) Flow visualization techniques to observe gaseous and fluid flows [Yang85].

(b) The moire topography to measure surface shapes.

(c) Scientific visualization which generates pictorial presentation of numerical solutions provided by super computer [Corcoran91].

2.2. Processing of image data

(1) *Processing information of "form" by human vision system*

Researchers have paid much attention to the mechanism by which the human brain perceives "forms" as critical keys to realize pattern recognition machines or what we call artificial intelligence. Large numbers of papers have been published concerning models of vision and information processing in the visual cortex of the brain [Marr81, Levine85]. Traditional field of psychology and the recent cognitive science also treat the mechanism of human perception and cognition from different viewpoints.

Since any kind of the "form" can become a target of researches only after it is perceived by human eyes, to know the mechanism of human vision is undoubtedly important in order to find essential characteristics of the "form". Unfortunately researches from such viewpoints are few in the field of science on form.

Considering that the "forms" generated in human activities often work as a kind of "message", technology for information transmission or communication is also related closely to the science on form. Communication in recent days and in the future includes not only that among men but also human-machine communication and the communication among computers [Toriwaki90a]. In particular the intelligent man-machine interface is of importance. The "visual language" and "icons' in the computer language contain many examples of applications of "forms" as a communication tool, although this fact has not been explicity understood as the application of the science on form [Myers90, Chang90].

(2) *Processing of morphological information by machine*

Machine processing of morphological information includes image pattern recognition and understanding, and measurement from pictorial data ("image measurement", "pattern information measurement"). Image processing/recognition has made great progress in these years [Ballard82, Levine85, Rosenfelds82, Toriwaki88]. As a result various image analyzers and hardwares specific to image processing are available for image analysis [Exhi90]. Software packages are also becoming popular for all types of computers including personal computers, engineering workstations and super computers [Toriwaki81, Tamura89]. Analysis or measurement of large samples became much easier by utilizing computer. Therefore classical stereology as a means to estimate properties of objects basing upon relatively small size of samples becomes less significant except for the special case that only very limited numbers of samples are obtainable.

Pattern recognition (or understanding) is the technology to detect existence of "form" in a given sample image, to measure its features, and to make decisions concerning its contents automatically. This is much more difficult to be realized than the measurement or simple analysis, but still basic methods are being established [Toriwaki85c, Toriwaki88]. For example, most of image analyzing systems commercially available now can provide facilities to classify objects in an input image by employing typical processing sequences such as
<<Smoothing filtering—spatial difference—thresholding—thinning—connected component selection—feature extraction—statistical decision>>.
In particular direct manipulation and measurement of three-dimensional objects by computer based upon a slice sequence obtained by CT are important in that manual measurement of such objects is hardly possible.

Vision expert systems and related works [Hasegawa86, Matsuyama89] are also interesting because they will help researchers who are not specialists of image processing to develop the procedure to analyze images of their own fields and extract morphological information from them.

(3) *Mathematical theory for studying "form"*

There is no general theory of "form" or morphological information processing applicable to every aspect of the problems. A few theories which can treat rather limited areas of image processing and morphological information processing have been studied and systematized recently as follows.

(a) *Digital geometry*: Geometrical and topological properties of a figure defined in the two- or three-dimensional (3-D) digitized space [Toriwaki85b, Toriwaki88].

(b) *Morphological operations of pictures*: Shrinking and expansion of a figure in the continuous space and feature extraction using them, distance transformation and skeleton, etc. [Serra82, Haralick87, Maragos90].

(c) *Shape feature analysis*: Collection of ad hoc methods of shape feature extraction rhather than a unified theory to cover the whole of shape analysis. For example, moment, Fourier descriptor, Hough transformation and Voronoi division [Ballard 82, Toriwaki85a, Toriwaki90b].

(d) *Mathematical Theory of computer vision*: Relationship between 3-D solid objects and their projections to the two-dimensional plane, and reconstruction or understanding of objects or three-dimensional scenes from small numbers of two-dimensional images [Ballard82, Kanatani90, Saito91].

(e) *Computational geometry*: Geometry of a finite point set in the continuous space and algorithms to calculate features of such set. For example, Voronoi division, convex hull, alpha-hull, and separability [Preparata85, Toussaint88].

3. Examples of Image Pattern Recognition and Graphics for Morphological Information Processing

3.1 Reconstruction and measurement of an Egyptian mummy

X-ray CT provides us a powerful tool to observe the whole of three-dimensional objects including human body. This is available for morphometry of 3-D objects with high accuracy. We applied this to reconstruct and measure an ancient Egyptian mummy without causing any physical damage to its plaster case which is also a very valuable historiacal relic (Fig. 2a) [Yokoi89].

First cross sections of the whole of mummy were recorded by an x-ray CT scanner with the sampling interval 0.8–1.3 mm along the body axis. The results consisted of about 750 trunsaxial cross section images, each of which is a digital picture of 320 × 320 pixles (Fig. 2b)

Surface (border) of the body and the bones were extracted from each slice by using thresholding and by tracing borders manually in some parts. After doing this 3D images were constructed by employing CG techniques of shading and rendering (Fig. 2c). Furthermore we manipulated the 3D object reconstructed and stored in computer memory in a flexible way. For instance we eliminated parts of bones to observe the occluded part, and moved other parts to correct the distortion caused by being fixed for more than three thousand years. For example, we removed the upper part of the skull and calculated the diameter and the volume of the skull (Fig. 2d). By shifting hands left and right side we could measure the size of the hip joint (Fig. 2e). For these processings we utilized effectively the simulation system for planning surgery operations NUCSS we developed beforehand [Yasuda90].

This example shows surprising effectiveness of CG and 3D image processing techniques for visualizing invisible data and measuring shape features of 3D objects.

As another example, a 3D image of moving heart was constructed from a time sequence of slice sets of heart obtained by magnetic resonance imaging system [Okada90, Toriwaki90b].

3.2 Computer aided diagnosis of X-ray image

Large numbers of X-ray images are used in medicine for mass screening of cancer in the lung, stomach and breast in Japan. To save doctor's load to diagnose so many images within limited time, introduction of computer diagnosis is greatly expected. Diagnosis or reading of X-ray images primarily depends on morphological features of shadows observed on those X-ray images. Thus it is required to develop the procedure to detect by computer abnormal shape features which may suggest existence of cancer or marignant tumor.

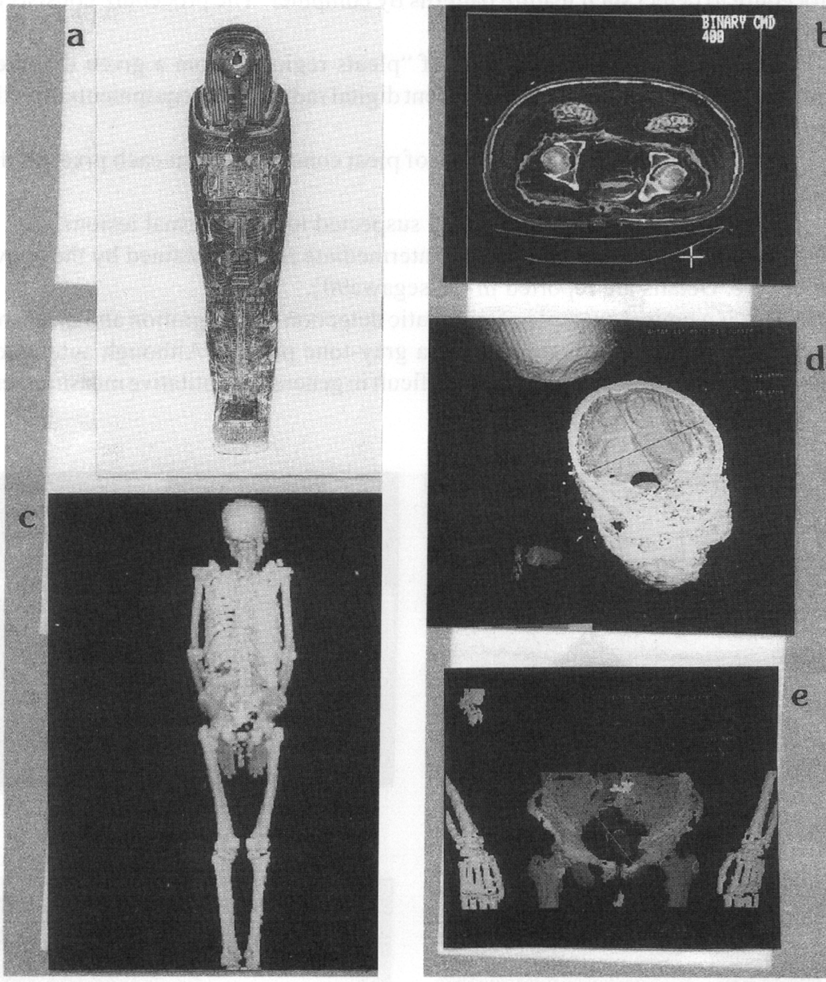

Fig. 2. Example of visualization and analysis of three dimensional form—analysis of an Egyptian mummy. (a) Appearance of the mummy, (b) Example of a cross section, (c) Reconstructed bone structure, (d) Measurement of the volume inside the skull, (e) Measurement of the hip joint.

We will show, as an example, computer diagnosis of stomach radiographs by extracting abnormal lesions from double contrast stomach radiographs [Hasegawa90]. A local radial pleat-like pattern appears at each of the affected parts on the inner wall of the stomach in more than 70% of stomach cancer, and can be observed in the above type of radiographs. We developed a processing procedure to detect such feature patterns by computer. The procedure consists of the following steps:

(a) Extraction of border lines of "pleats regions" from a given digitized stomach radiograph. Note here that recent digital radiography equipments directly produce a digitized X-ray image.

(b) Quantification of the degree of pleat concentration at each pixel on the image.

(c) Detection of parts which are suspected to be abnormal lesions.

Figure 3 shows examples of the intermediate results obtained by the above procedure. Details are reported in [Hasegawa90].

This is a typical example of automatic detection or recognition and measurement of morphological features from a gray-tone picture. Although automated recognition of a spatial pattern is still difficult in general, quantitative measurement

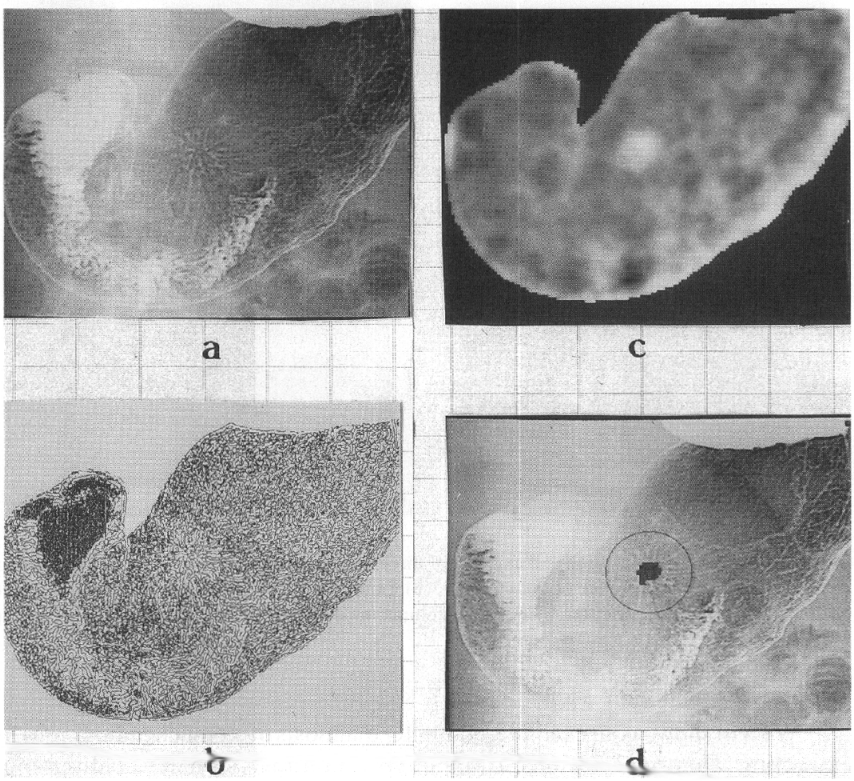

Fig. 3. Example of computer diagnosis of stomach X-ray images to detect stomach cancer. (a) Input double contrast stomach X-ray image, (b) Borders of fold patterns on the stomach wall, (c) Degree of concentration of the fold pattern, (d) Detected region.

of shape features would be possible only by computer processing of images.

3.3 Creation of "form" by computer graphics

As was stated earlier, computer graphics (CG) has great potentiality to become a flexible and surprisingly powerful tool of creating "form" in computer. Let us present an example to suggest such potentiality. Figure 4a shows a polyhedron with fifty-seven faces defined numerically in computer. By assigning suitable attributes to this solid we can create images of arbitrary objects in spite of whether they are physically realizable or not. For example, Figs. 4b and 4c are results obtained by giving the refractive index of diamond and glass, respectively and tracing the performance of light beam incident on the object (the technique called ray tracing in CG) [Toriwaki87]. Such ideas and techniques have already been applied to art and have become important parts of computer art. In some of them the manipulation of "form" is explicitly considered. In [Latham90], for

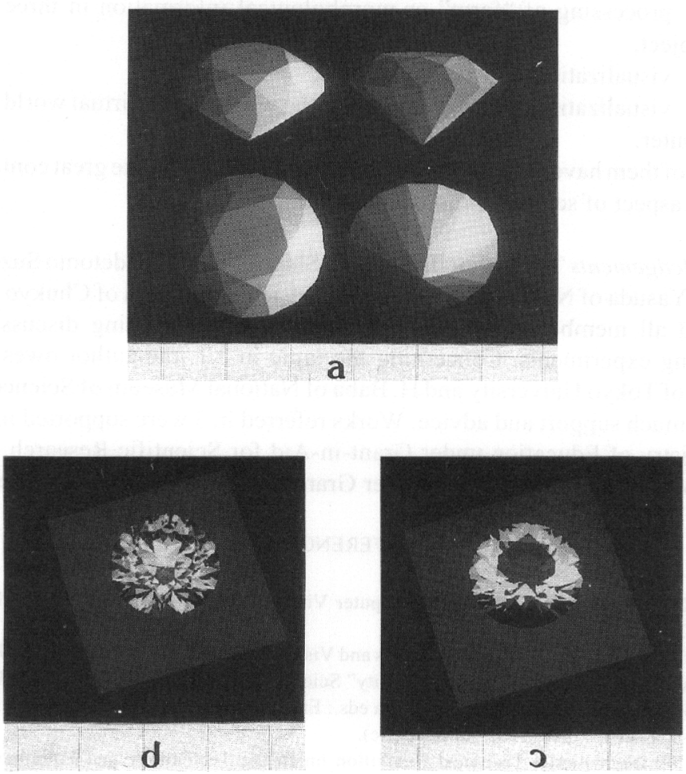

Fig. 4. Example of computer generation of "form". (a) Polyhedron defined in computer, (b) Diamond, (c) Glass.

example, associative generation of variation in "form" is described in terms of the tree structure representing continuously changing "form" sequences existing in the authors' brain.

4. Conclusion

In this paper we briefly discussed the potential use of image processing in "science on form" with the stress on image pattern recognition/measurement and computer graphics. We presented three examples selected from authors' researches; 3D image generation and measurement applied to the Egyptian mummy, pattern recognition utilized for the diagnosis of stomach X-ray images, and computer graphics for visualizing "images" in the brain.

Primary significance of pattern recognition and graphics in the study of science on form will be summarized as follows:

(a) quantitative measurement of morphological features,

(b) processing of a large sample set or large size of objects,

(c) processing of "form" or morphological information in three dimensional object,

(d) visualization of invisible objects,

(e) visualization of virtual objects or the whole of the virtual world defined on computer.

All of them have rich potentiality and are expected to make great contribution to every aspect of science on form in the future.

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