KAWASAKI STEEL TECHNICAL REPORT

No.23 (October 1990)

R&D of High-Technology Research Laboratories,

Commemorating the 20th Anniversary

of the Technical Research Division

Image Processing Technology for Material Evaluation

Akira Miyajima, Osamu Furukimi, Mitsuru Yanagisawa, Fumio Saito

Synopsis :

Application of image processing technology to material evaluation is useful in determining the shape features of a material. A summary of image processing techniques applied to material evaluation and the examples of application of these techniques are introduced. In association with our practical application to material evaluation, the following three findings have been obtained; (1) By applying a pattern matching technique to the recognition of etch pits, the accurate quantitative data can be extracted from indistinct picture images of etch pits; (2) Through discrimination between brittle fracture surfaces and ductile fracture ones using a texture analysis technique, it is possible to measure the crystallinity of Charpy fracture appearance; and (3) By applying a stereovision technique, the three-dimensional shape of metal powders can be reconstructed by using the SEM stereograph. The outline of a real-time general purpose image processing system is also reported.

The body can be viewed from the next page.

Image Processing Technology for Material Evaluation*

Akira Miyajima
Senior Researcher,
Mechanical Processing,
Instrumentation &
Control Research
Center

Osamu Furukimi
Dr. Engi. Senior
Researcher,
New Materials
Research Center,
High-Technology
Res. Labs.

Mitsuru Yanagisawa
Factory Automation
Engineering Dept.
Kawasaki Steel
Systems R & D Corp.

Fumio Saito
Factory Automation
Engineering Dept.
Kawasaki Steel
Systems R & D Corp.

Synopsis:

Application of image processing technology to material evaluation is useful in determining the shape features of a material. A summary of image processing techniques applied to material evaluation and the examples of application of these techniques are introduced. In association with our practical application to material evaluation, the following three findings have been obtained: (1) By applying a pattern matching technique to the recognition of etch pits, the accurate quantitative data can be extracted from indistinct picture images of etch pits; (2) Through discrimination between brittle fracture surfaces and ductile fracture ones using a texture analysis technique, it is possible to measure the crystallinity of Charpy fracture appearance; and (3) By applying a stereovision technique, the three-dimensional shape of metal powders can be reconstructed by using the SEM stereograph.

The outline of a real-time general purpose image processing system is also reported.

1 Introduction

Image processing technology is a set of techniques which treats images as data, refining the quality of the image to meet the needs of various applications and quantifying particular features of the image. Broadly defined, it comprises a comprehensive image and information processing technology which includes image recognition, image storage, image generation, and image telecommunication. Practical applications include production lines, where it has been adopted for the measurement of dimensions and shape, non-destructive inspection, and the analysis of materials.[1,2] It is also a powerful, frequently used tool in materia research.

The application of image processing to material evaluation is effective in improving the efficiency and accuracy of data analysis in various types of material evaluation experiments and in statistical evaluations where large volumes of data must be handled.[3] Image processing also provides a quantitative means of elucidating material characteristics when the feature quantities extracted and quantified by image processing techniques are related to the physical and chemical phenomena of these materials.[4]

Image processing has a long history[5] of application to iron and steel-related research, where it has been widely used in the observation of metallurgical microstructures and the processing of various types of experimental data. A number of image processing techniques originally developed for steel have been applied directly to the new materials research and development activities of Kawasaki Steel's Technical Research Division, and as one method of material evaluation, their range of applications is rapidly expanding.

This report presents examples of material evaluation applications of image processing methods developed by the Technical Research Division, including particle analysis, texture analysis, and three-dimensional analysis. The report also describes in outline a general-purpose image processing system (tradenamed "**Dr. Image**") developed by Kawasaki Steel which is based on the accumulated image processing technologies of the Tech-

* Originally published in *Kawasaki Steel Giho*, **21**(1989)4, pp. 362-367

nical Research Division.

2 Material Evaluation Using Image Processing

2.1 General Description of Image Processing Technology

Progress in the development of image processing techniques for material evaluation has to date centered on the quantification of metallographic data (i.e. the quantification of images of the metallurgical microstructure). The value of image processing is widely recognized in this application, since the mechanical properties of metals are intimately related to their microstructures. Further, the image processing techniques used in the quantification of metallographic data have general applicability, and can normally be applied to any field where the evaluation of materials is required.

The main expectations placed on image processing in material evaluation are the quantification of images and extraction of characteristic shape features. Although some image processing methods require special purpose hardware for each evaluation function, the objects of measurement in research and development are continually changing, and in fields where trial and error methods are prevalent, a general-purpose image processing system which can be easily adapted to a variety of processing tasks is more desirable than special purpose hardware. Using a general-purpose system (such as the "Dr. Image," which is discussed below), it is possible not only to determine the length, area, circumference, fillet diameter, and other characteristics of plural objects within an image field, but also to perform statistical operations such as the calculation of length and area distribution. It is also possible to obtain the morphological characteristics of the object under observation, including circularity, degree of complexity, Euler characteristic, and moment, among others.

Recent progress in image processing has included texture analysis, based on the quantification of local differences in the image pattern, Fourier analysis, in which repetitions of two-dimensional image patterns are quantified, and three-dimensional analysis techniques for obtaining solid feature quature quantities from complex irregular shapes such as fracture surfaces. Using a programmable general-purpose image processing system with a high-speed capability, these image processing techniques can be applied to the evaluation of materials.

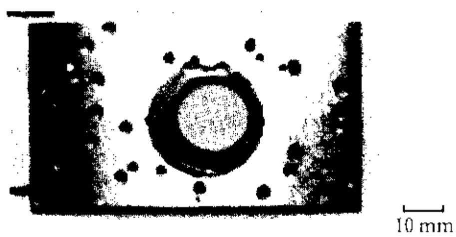
2.2 Particle Analysis

Particle analysis, which broadly refers to the enumeration of particulate and other discrete objects of measurement and the quantification of their morphological characteristics, is commonly used in the evaluation of materials and manufactured products. Because this method makes it possible easily to obtain consistent, reliable counts, areas, area distributions, the diameters of equivalent circles, and other information on insular and multi-particle objects, it has wide applicability in the analysis of experimental data in steel and new materials research.

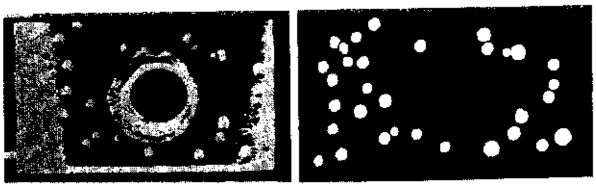
While particle analysis is used with steel materials to measure grain size and the grain size distribution of metal powders, the same algorithms can also be applied to a great many other steel-industry tasks, including the measurement of rust generation conditions in corrosion experiments and the porosity distribution of sintered bodies, examination of gas bubbles in enamel layers, abrasion loss inspection of mill rolls, and the analysis of peeling experiment results with coated steels.

In the field of new materials, which include ceramics, magnetic materials, superconductors, superfine powders, and specialty metals, many products are produced in particle form. Particle analysis techniques have a diverse range of analytic applications such as measurement of the grain size distribution of metallic powders and grain diameters in ceramic substrates, measurement of rust generation conditions in metallic materials, and measurement of voids in porous bodies.

Although a great many objects of measurement can be processed using a relatively simple image processing algorithm, an appropriate adjustment of input conditions is necessary when gray level information within the image is to be processed. For example, **Photo 1** shows the recognition process for etch pits in an austenitic stainless steel. Original image (a) is a photograph of the specimen as input with a television camera. In (b), where only binary processing has been applied, it is impossible to distinguish between the corrosion pits and lighting irregularities inherent in the photographic conditions. Elimination of the reflective areas within the pits has also resulted in distortion of the essentially circular shape of the pits. In contrast, the image processing



(a) Original image



(b) Binary image (c) Recognized etch pits

Photo 1 Recognition of etch pits using gray level pattern matching technique

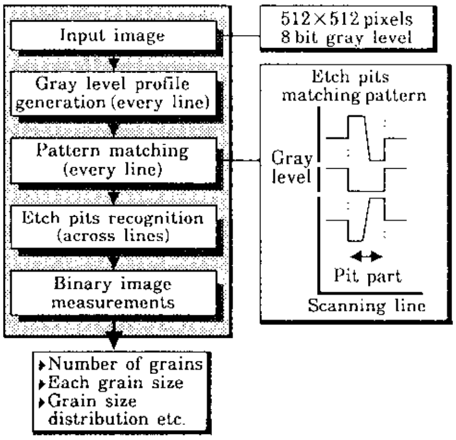


Fig. 1 Image processing flow by gray level pattern matching technique applied to recognition of etch pits

algorithm in **Fig. 1** makes it possible to extract the corrosion pits areas, as shown in (c), in a clean, precise image which is free of extraneous data induced by lighting irregularities.

To produce this image, a gray level profile was taken for each perpendicular line segment in Photo 1 (a), and areas with some degree of similarity to the etch pit pattern were extracted as possible etch pits. The candidate etch pits were then evaluated at a number of perpendicular positions, and those falling within a specified range of area values were recognized as true etch pits. This step represents the extraction of the object of measurement (and thus corresponds to binary processing step in conventional image processing). Following this step, desired numerical values such as number of pits, area, and area ratio are obtained by conventional binary image analysis techniques.

2.3 Texture Analysis

In image processing, texture may be defined as a two-dimensional pattern comprised of repeated local variations in the gray level of the image. Texture analysis is the process by which the characteristic features of the texture are quantified and the texture is categorized.

One example of the practical application of texture analysis is in the measurement of fracture surface ratio in the Charpy impact test, which is used to evaluate the toughness of materials.[6] **Photo 2** (a) shows the Charpy fracture appearance of a JIS Z 22024 specimen taken from an 80 kgf/mm^2 tempered steel (HT-80). The ductile portion of the specimen is smooth with a finely textured structure, while the brittle area is of a rough, granular appearance. This difference in the fracture pattern is identified automatically by image processing. Photo 2 (b) shows the extraction of the brittle fracture surface by texture analysis, with the extracted brittle surface indicated by the overlaid white area.

In the texture analysis algorithm, the screen is first divided into small regions 8 × 8 pixels in size, which are then classified as either brittle or ductile using the co-occurrence matrix method proposed by Haralick.[7] The co-occurrence matrix is a composite of all the changes in gray level in a given image based on the probability of change from i to j in the gray levels of adjacent pixels within the small regions obtained by partitioning the image. The textural regularities which are described qualitatively as "Fine," "Dense," "Strip," or "Projecting" can be quantified in equations defined by the co-occurrence matrix. As shown in **Fig. 2**, in the discriminative analysis used to extract the brittle area, the ratio of the angular second moment (F_1) to the contrast parameter (F_2) is adopted as a discrimination parameter. The values F_1 and F_2 are defined as follows for the co-occurrence matrix $P(i, j)$:

(1) Angular second moment

$$F_1 = \sum_{i=1}^{LVL} \sum_{j=1}^{LVL} [P(i, j)]^2$$

In this equation, LVL denotes the gray level of the image. The 256 level at the time of input was requantified in this experiment to give gray level information for each pixel at the 8 gray levels.

(a) Original image of Charpy fracture appearance (b) Extraction of brittle fracture surfaces

Photo 2 Measurement of Charpy fracture appearance using texture analysis technique

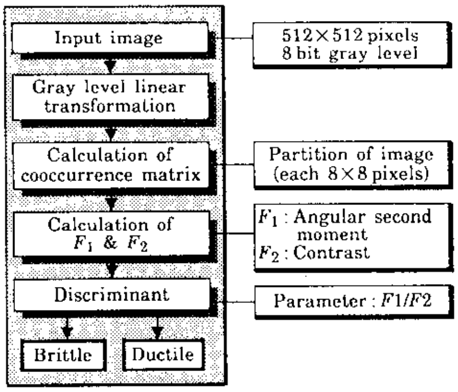


Fig. 2 Image processing flow by texture analysis technique applied to measurement of Charpy fracture appearance

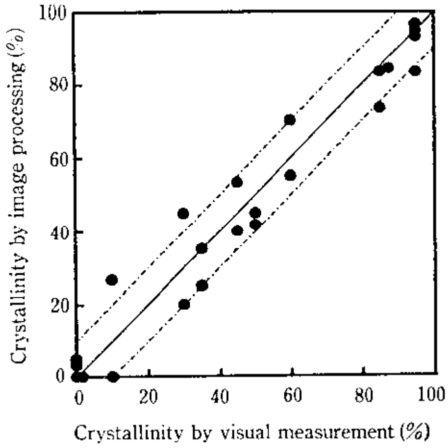


Fig. 3 Comparison of crystallinity by visual measurement with that by measurement using image processing technique

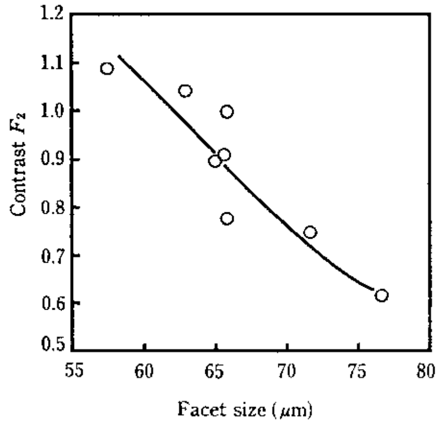


Fig. 4 Relationship between contrast and facet size in HT-80 steels

$P(i,j)$ indicates the probability that a pixel adjacent to a second pixel with a gray level of i will have a gray level of j.

(2) Contrast

$$F_2 = \sum_{k=1}^{LVL-1} k^2 [\sum_{\substack{i=1 \\ |i-j|=k}}^{LVL} \sum_{j=1}^{LVL} P(i,j)]$$

Here, k is the difference in the gray levels of adjacent pixels.

With the equation for angular second moment, it is possible to evaluate the uniformity of the gray level pattern within a particular area by obtaining the sum of the squares of the probability of appearance of various gray levels, for a composite of gray level changes in adjacent pixels. The contrast parameter on the other hand, is a feature quantity which signifies expected values of the second power of changes in gray level between certain pixels having a specified spatial relationship within a subject area. The contrast parameter gives a large value in cases where changes in the gray level within the subject area are frequent or sharp.

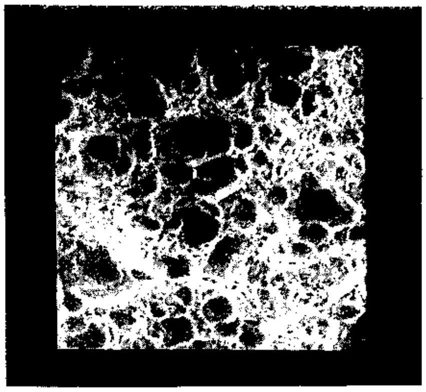
The brittle fracture surface ratio in the Charpy test is obtained by dividing the total number of small regions recognized as brittle areas by the number of small regions in the entire fracture surface. The range of error in the results of fracture surface measurements using this method, as shown in **Fig. 3**, is within approximately ±10% of the results of expert visual inspection, indicating that image processing is of adequate accuracy for practical application.

For facets as well, as shown in **Fig. 4**, a good correlation exists between contrast as calculated from the cooccurrence matrix and actual facet size, making it possible to use texture analysis to quantify facet size.[8]

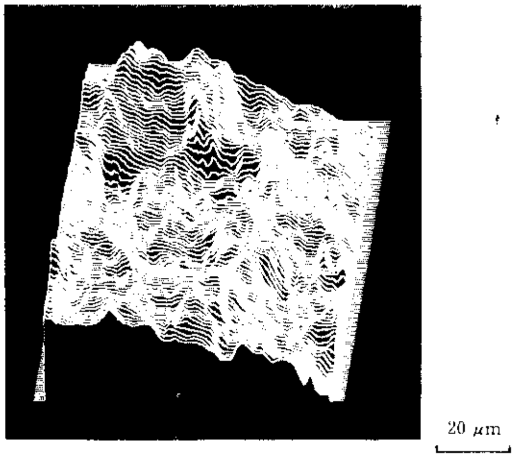
2.4 Three-dimensional Image Analysis

Because three-dimensional image analysis based on the principle of binocular parallax permits easy stereoscopic visualization of microscopic structures without special equipment, its range of applications has expanded rapidly. The application of three-dimensional techniques to objects such as the facet fracture surface in the Charpy fracture test, dimple fracture surfaces, corrosion pits, and stretch zones, provides a clearer, more precise understanding of the relationship between morphological features and material properties than was possible previously, when the scientific discussion of this issue was limited to two-dimensions. **Photo 3** (a) is a two-dimensional view of the dimple surface of an HT-80 specimen, while Photo 3 (b) is a bird's eye view of the same material obtained through three-dimensional analysis.

Three-dimensional image analysis is also useful in the quantification of the three-dimensional features of metal powders, because powder morphology would be related to the material properties of sintered metal products. An algorithm for producing a three-dimensional mor-



(a) Original image of dimples



(b) Birds-eye view of dimples

Photo 3 3D analysis of dimples on Charpy fracture appearance

phological reconstruction of a metal powder by means of image processing is given in **Fig. 5**. In order to produce a three-dimensional view, a scanning electron

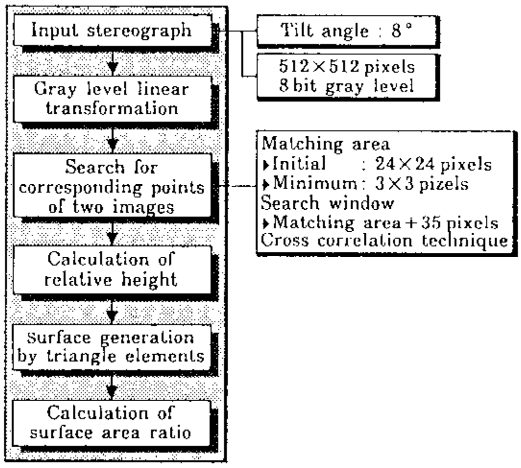
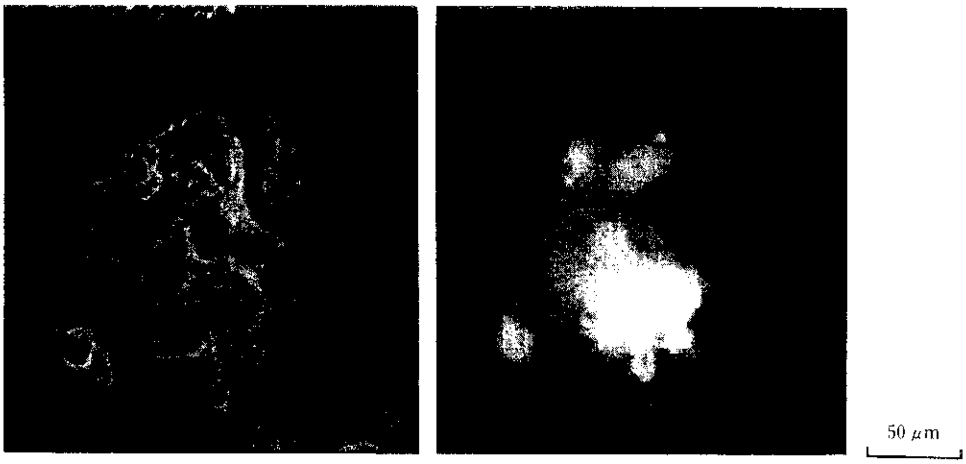


Fig. 5 Image processing flow of 3D shape reconstruction of metal powders

microscope is used to obtain separate inputs for a reference image and an 8° tilt image. These two inputs are processed as 512 x 512 pixel images, with each pixel having gray level information for 256 gray levels.

The dynamic-region-partitioning technique is used to search for points of correspondence between the reference image and the tilt image, while the correlation coefficient technique is used to evaluae the degree of similarity of such points. In the search stage, the dynamic-region-partitioning technique makes it possible to establish optimum regions of correspondence by first performing a quantitative evaluation of the gray level variation in the portion of the image identified as a matching area, and then dynamically adjusting the size of the matching area.[9] The initial size of matching areas in the reference image is 24 x 24 pixels, which can be reduced to 3 x 3 pixels as the minimum partition area as necessary. The search area in the tilt image is 35 pixels greater in size in both the X and Y directions



(a) Original image of metal powder (b) Hight-gray level transformation view

Photo 4 3D shape recognition technique applied to SEM picture image of metal powders than the matching area in the reference image.

An original SEM image of a metal powder which was later subjected to three-dimensional shape reconstruction is shown in **Photo** 4 (a). A height-gray level transformation view of the same image after processing using the algorithm in Fig. 5 shown in Photo 4 (b). In the transformation view, the highest point is indicated by white, the lowest by black, and intermediate points by levels of gray corresponding to their respective heights. The actual vertical distance between the areas represented by black and white was approximately 180 μm, and the error in the calculation based on the tilt angle was about $\pm 5\ \mu$m. In producing this view, mismatched and unmatched areas were eliminated by the relaxation technique, and a three-dimensional surface was generated from triangular elements. This three-dimensional surface serves as a model with surface data plotted in three-dimensional coordinates, making it possible to obtain a grasp of surface features and calculate the surface area in three dimensions. Relating this information to material properties, for example, by calculating the ratio of shadow area to total surface area, provides a convenient method of evaluating the degree of morphological complexity.[10)]

3 "Dr. Image" Image Processing System

Because image processing requirements in research include a wide variety of activities, there is a need for a multi-functional, high capacity general-purpose image processing system. The Technical Research Division of Kawasaki Steel has incorporated its long experience in the field of image processing technology in a system of this type, the "Dr. Image," an easy-to-use system developed for technical and research applications. The configuration of the system is shown in **Fig. 6**, and its hardware specifications in **Table 1**. The "Dr. Image" combines a high-speed, high-performance programmable image processor and a Sun workstation by means of a VME bus. The Sun computer is used to input processing commands and to display process menus. **Figure 7** shows a typical process menu, in this case for the surface area distribution results of a particle analysis. Operations are selected from the screen by a mouse, which permits the execution of successive operations as desired. Since the system is provided with memory, editing and repeat functions using the auto-logging function for processing operations, it can also be applied to any routine image processing task.

Table 1 Hardware specification of "Dr. Image"

IMAGE PROCESSOR	NTSC interlace input	▸RGB color camera ▸Monochrome-camera ▸VTR (with TBC & decoder)
	Analog non-interlace output	▸RGB monitor ▸Image hardcopy unit
	Image memory	▸512×512pixels×8bit×8units
	Image processing size	▸512×432pixels×8bit
	Processor	▸Partially parallel pipe-line processor ▸Characteristics extraction processor ▸Graphic processor (TMC43010)
	Others	▸Image input accumulator (1-256 times)
WORKSTATION	Workstation	▸Sun 3/100, 200, 400 series ▸Sun 4/100, 200 series
	Main memory	▸4 MB or more
	Display	▸19" color/monochrome ▸1152×900 bit-map
	Operation	▸Mouse (3 buttons) ▸Keyboard

The features of the "Dr. Image" are as follows:

(1) A wide variety of more than 350 image processing functions.
(2) Convenient native language menus for Japanese users.
(3) High speed image processing capability of 30 frame/s maximum.
(4) Advantages associated with use of standard-model workstation.

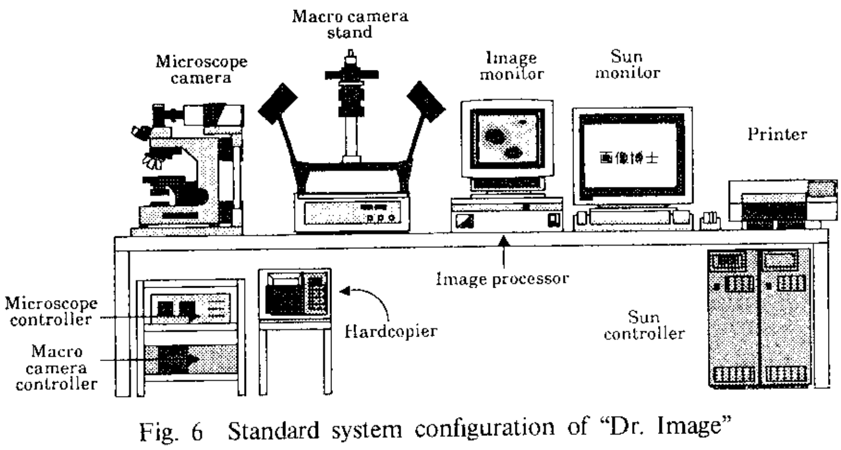


Fig. 6 Standard system configuration of "Dr. Image"

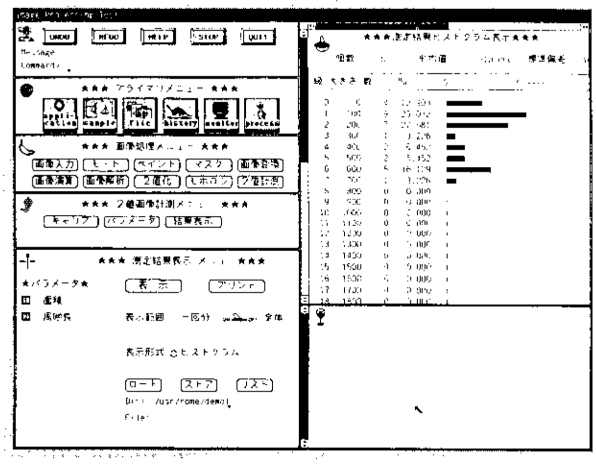


Fig. 7 Example of operation menu displayed on Sun workstation monitor

(5) Convenient function-groups for trial-and-error method.
(6) Visual image-filing function.

4 Conclusions

Examples of the applications of image processing techniques in the field of material evaluation have been discussed, including the identification and measurement of corrosion pits, extraction and measurement of the Charpy fracture surface, and the construction and quantitative evaluation of three-dimensional images of metal powders. The principal results may be summarized as follows for these three examples:

(1) Corrosion pitting cannot be properly evaluated using simple binary processing. With line-by-line pattern matching, however, it is possible to extract the pit portions while eliminating extraneous image data, and thus obtain an accurate measurement of the pits.
(2) Applying discrimination analysis to the angular second moment and contrast parameters obtained from the co-occurrence matrix, it is possible to isolate the brittle area of a Charpy fracture surface from the ductile area and calculate the fracture surface ratio.
(3) With the three-dimensional image construction method, which uses dynamic region-partitioning to search for points of correspondence between the reference image and tilt image, the morphology of metal powders can be expressed in three-dimensions.

This report has also described a real-time general-purpose image processing system called the "Dr. Image," which was used to carry out the image processing in these examples and is applied to a variety of other material evaluation activities performed by Kawasaki Steel's Technical Research Division.

In recent years, image processing has found rapidly increasing application in both steel and new materials research in the Technical Research Division. In addition, established image processing techniques are being incorporated in production lines for routine material and product inspection tasks.

Because the elucidation of the morphological features of materials is of profound importance in material research, the effective use of image processing is considered essential to progress in material science. In particular, the range of areas in which image processing technology can contribute to new materials research, where the development of applications, intermediate products, and finished products is required, is considerably greater than it has been to date in steel materials research. Recent years have seen remarkable progress in general-purpose image processing systems, of which the "Dr. Image" is a representative type, and in the development of more powerful image processing algorithms, promising continuing expansion in the range of applications and level of sophistication of image processing techniques for both steel and new materials.

References

1) H. Koshimizu: *PIXEL*, **66**(1988), 127
2) F. Ichikawa, K. Asano: *Keiso*, **30**(1987)8, 38
3) K. Kawaji and O. Furukimi: *Kinzoku (Metals and Technology)*, (1984)5, 46
4) M. Fukamachi: Proceedings of the symposium of the National Research Institute for Metals, (1983), 1
5) E.Nakata: *Kinzoku (Metals and Technology)*, (1981), 41
6) M. Yanagisawa and O. Furukimi: "Gazo-shori ni-yoru zairyo-sosiki-kaiseki no genjyo (Recent Microstructure Analysis of Metal by Image Processing)", The Iron and Steel Institute of Japan, (1986), 109
7) R. M. Haralick: "Documentation of procedures for textural/spatial pattern recognition techniques", NASA Lyndon B. Johnson Space Center, (1976)
8) O. Furukimi, M. Imanaka, Y. Ito, and M. Yanagisawa: *Tetsu-to-Hagané*, **71**(1985)14, 1655
9) F. Saito: Third Industrial Image-sensing Technology symposium, Proceedings of NDDI, (1988), 155
10) F. Saito, M. Yanagisawa, A. Miyajima, and O. Furukimi: *Eizo-jyoho*, **20**(1988)21, 41