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W. Petruk*

ABSTRACT

Performing image analysis involves digitizing and analyzing an image to characterize the features in it. A few researchers use image analysis to solve specific problems by writing their own computer programs, but widespread usage requires the availability of commercial image analyzers. Manufacturers have built a wide variety of image analyzers whose price and capabilities vary by a large factor. All image analyzers consist of image input, image digitizing, image processing, and data output. The image input can be (i) a digitizer tablet on which an image is drawn with a special stylus; (ii) a TV camera for collecting an image from an optical microscope or an epidiascope; (iii) a SEM interface for collecting a SEM image; and (iv) an image from computer memory. Image processing varies from simple processing such as determining the area % of a specific phase, to measuring a wide variety of parameters for each feature, as well as determining the reflectance and transmittance of features observed with an optical microscope. Furthermore, the electron beam of a SEM can be steered to scan each feature and to identify the feature on the basis of its composition. Image analyzers, therefore, vary from the simplest one which uses a digitizer tablet and can perform only a few measurements such as area % and size analysis of the features, to a fully equipped one that can automatically identify all the phases in the image and characterize each feature by using a wide variety of parameters.

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ANALYSE D'IMAGES: UN APERÇU DES DÉVELOPPEMENTS

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RÉSUMÉ

L'analyse d'images est une opération consistant à numériser et à analyser une image afin de déterminer les caractéristiques du point exploré. Quelques chercheurs utilisent l'analyse d'images pour résoudre des problèmes spécifiques en rédigeant leur propre programme machine, toutefois un champ d'application étendu de l'analyse d'images nécessite l'emploi d'analyseurs d'images commerciaux. Les fabricants de ces appareils ont produit une grande variété d'analyseurs d'images dont le prix et les possibilités varient de beaucoup. Tous les analyseurs d'images sont constitués d'une entrée des images, d'un convertisseur numérique d'images, d'une unité de traitement des images et d'une sortie des données. L'entrée d'images peut s'effectuer à l'aide (i) d'un numériseur sur lequel une image est dessinée avec un stylo spécial; (ii) d'une caméra de TV effectuant la saisie d'images provenant d'un microscope optique ou d'un épidiascope; (iii) d'un MEB (microscope électronique à balayage) avec interface pour recueillir une image émise par un MEB; et (iv) d'une image provenant de la mémoire de l'ordinateur. Les champs d'activité du traitement d'image varient du traitement simple, tel que la mesure du pourcentage de la surface d'une phase spécifique, à la mesure d'un grand nombre de paramètres pour chacune des caractéristiques et comprennent aussi la mesure de la réflectance et de la transmittance des caractéristiques observées à l'aide du microscope optique. En outre, le faisceau électronique d'un MEB peut être dirigé de façon à balayer chaque caractéristique du point observé à identifier la caractéristique d'après sa composition. Par conséquent, les analyseurs d'images diffèrent les uns des autres en partant du modèle le plus simple qui utilise un numérateur et n'effectue seulement que quelques mesures telles le calcul du pourcentage de la surface et l'analyse de la dimension des caractéristiques, jusqu'au modèle complètement équipé capable d'identifier automatiquement toutes les phases de l'image et de déterminer chaque caractéristique à l'aide d'un grand nombre de paramètres.

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CONTENTS

DEVELOPMENT AND PRINCIPLES OF IMAGE ANALYSIS

Image analysis is used in many disciplines to characterize objects by their physical properties. The most frequent early applications were made in medicine to provide clear crosssections of the brain and body (1). Researchers began using image analysis when methods for digitizing and analyzing TV images were developed. The early researchers wrote computer programs to solve specific problems. However, commercially available image analyzers were required to bring about wide usage. The first widely used commercial image analyzer was developed in about 1965, but it had limited capabilities and scope. It was not until the versatile, hard-wired, modular image analyzers were developed, in about 1969, that image analysis was brought into most fields of physical sciences (2). Around 1979, the hardwired instruments were replaced by computer-based versions.

Image analyzers consist of an image input, image digitization, image processor, and data output. The standard image input for the hardwired and computer-based image analyzers is a TV camera. It can be mounted on any optical microscope to collect a TV image of a polished or thin section, or on an epidiascope to collect a TV image of a 35-mm slide, a 16-mm film, a negative, a photograph, a line drawing, a map, etc. The image is digitized and displayed on a video screen. Each phase that has a different shade of grey in the image is detected separately by using a variable threshold. If the detected image has some electronic noise or is otherwise poorly detected, the computer-based image analyzer can "clean" it so that the features in the detected image appear the same as in the video image. The detected features are analyzed (image processing) by making a variety of measurements. Four categories of measurements are possible: field-specific, field-feature specific, feature-specific, and reflectance or transmittance. In the field-specific mode, parameters that refer to the entire field are measured. This includes the number of features in the field, total area, and area % covered by the features. In the field-feature mode, the measurements are for the entire field but they pertain to certain characteristics of the features, e.g., all features that are larger (or smaller) than a particular size, all features that are free, all features that have a certain orientation, certain shape, etc. Parameters that can be determined in this mode are size analysis, % free, % having certain orientations, etc. In the feature-specific mode, data are obtained for each feature instead of for the entire field. The data include maximum, minimum, and mean diameters; aspect ratios; grain orientations; surface area; % free; etc. In this mode nearly every type of evaluation that characterizes an object is possible. In the reflectance or transmittance mode, the grey value of the feature is measured and compared to a standard.

The fully equipped, hard-wired and computer-based image analyzers are expensive; consequently, the manufacturers have built simpler versions that are less expensive but have reduced capabilities. These simpler versions have retained the basic characteristics of image analyzers, and therefore the units are still rightfully called image analyzers. One version retains the TV image input but provides only field-specific and limited field-feature specific measurements. Another version uses a digitizer tablet to input the image by drawing the image with a special stylus. The digitizer tablet analyzer also provides only field-specific and limited field-feature specific measurements.

The TV image obtained with an optical microscope does not have the same resolution as an image produced with a scanning electron microscope (SEM). Consequently, many phases that cannot be discriminated from each other in an optical microscope image can be readily differentiated in a SEM image. A workable interface to collect an image from a SEM was developed by about 1980. The collected image can be a secondary electron (SE), a backscattered electron (BSE), a transmission electron, or an auger electron image. In addition, if the SEM is equipped with an energy dispersive X-ray analyzer (EDXA), a dot-map can be collected. The collected image is processed by the image analyzer in the same way as processing a TV image.

Beam steering capability on a SEM or microprobe equipped with an EDXA led to the development of identifying each particle separately and performing image analysis on the identified particles (3). The first approach was made in about 1974 by building a separate image analyzer and interfacing it with an EDXA. This image analyzer had only field-specific, limited field-feature specific, and limited feature-specific capabilities but it was inexpensive.

The capabilities of the separate image analyzer interfaced with an EDXA have been transferred to an EDXA program (4). Since some EDXA manufacturers are extending the capabilities of the EDXA programs, it is possible that the EDXA image analysis programs will soon have the capabilities of the standard computer-based image analyzers. A group of researchers at CSIRO in Australia have already developed such an analyzer, the QEM-SEM, and it is now commercially available.

The manufacturers of the standard computer-based image analyzer have developed an interface that allows steering the electron beam of a SEM or a microprobe with the image analyzer. The EDXA is used as a slave for identifying the features. At the present state-of-the-art, the SEM-EDXA-IA image analysis system probably has more capabilities than any other image analyzer.

Dr. M.P. Jones (5) of the Royal School of Mines has developed an image analysis system using a Cameca microprobe. He performs the analysis by moving the sample along a line at fixed intervals to analyze each spot. No image is necessary since only X-ray count data from the spectrometers are evaluated for each spot.

A final approach to image analysis is writing computer programs to solve special problems.

CAPABILITIES OF IMAGE ANALYZERS

1. DIGITIZER TABLET IMAGE ANALYZER

The simplest image analyzer available is one that uses a digitizer tablet to input an image. The image is generally focused on a tablet with a special microscope and the features are outlined with a special stylus. Since only simple images are likely to be input by this method, only basic image analysis capabilities are warranted. The analyses that can be made with digitizer tablet image analyzers are counting the number of features; determining area % covering the features; determining a size analysis; and determining maximum, minimum, and average diameters of the features in the field of view.

2. SMALL IMAGE ANALYZER USING TV OR SEM IMAGE

This model of image analyzer was built by the manufacturers to provide a low-priced, image analysis system that collects an image from an optical microscope or from a scanning electron microscope. The analyzer has similar image analysis capabilities to the digitizer tablet image analyzer, but it uses a TV camera for image input from an optical microscope or from an epidiascope, or a SEM interface for image input from a SEM. The small image analyzer is useful when only simple image analyses, such as determining area % and size analyses, are required.

3. STANDARD, HARD-WIRED IMAGE ANALYZER

The standard, hard-wired image analyzers are the versatile modular image analyzers that were developed in 1969. The analyzer uses a TV camera for image input. The image is scanned every 1/10 second with instantaneous analysis of the live image. Only one reading is taken per scan. If a series of readings is required for a field, each reading will be taken from a new image (live image) of the field. Using a live image requires a high-precision 2D detector to eliminate halos around the light grey phases; even then, precise detection is difficult because the electronic noise in the image varies from scan to scan. Furthermore, using a TV image requires a shade corrector to reduce the effect of uneven lighting.

In practice, an interactive image editor is required for the hard-wired image analyzer to eliminate the electronic noise, to reduce over-detection of features in some parts of the field, and to enhance under-detection in other parts. Consequently, fully automatic image analysis is seldom possible with this instrument. Analyses that can be performed are field-specific and full field-feature specific. This includes all the analyses that can be performed by the above two types of image analyzers plus analyzing % free. The hard-wired image analyzer cannot classify unliberated features.

4. STANDARD, COMPUTER-BASED IMAGE ANALYZER

The computer-based image analyzer has replaced the hard-wired unit and is the basic image analyzer in use today. The analyzer collects a TV image and stores it in memory. The stored image can be cleaned electronically, with all analyses performed on the clean stored image. The system has at least four image memories for manipulating the image, but larger versions of the analyzer have up to 16 image memories. The image enhancement is much better than on the hard-wired system, but a high precision shade corrector is still required, and frequently an interactive image editor is needed. Analyses that can be performed are field-specific, field-feature specific, feature-specific, and transmittance and reflectance. Most of the commercially available, full-sized, computer-based image analyzers can count the number of features; measure area %; determine % free; characterize the unliberated features; determine shapes; determine aspect ratios; perform size analysis on the basis of chord length, area, maximum diameter, minimum diameter, and mean diameter of the features; and can measure other parameters that classify features on the basis of their physical characteristics.

5. ONE-WAY, SEM-TV IMAGE ANALYZER

Workable interfaces between standard, computer-based image analyzers and a SEM have made it possible to interface the analyzer with both a SEM and a TV camera. Such a unit can collect either a SEM secondary electron image (SE) or a SEM backscatter image (BSE), as well as a TV image from an optical microscope. The BSE image is preferrable because the grey level in it is proportional to the average atomic number of the features. Therefore, every feature can be separated on the basis of its chemical composition by using the grey level. The main advantage of using a SEM-BSE image rather than a TV image is that the SEM-BSE image is better, probably because there is a better signal-to-noise ratio from the SEM scan generator than from the TV camera. The most apparent improvement is that the grey level for the phase remains constant as the sample is moved from field to field; by contrast, it varies somewhat when using an optical microscope. Another advantage occurs when phases that are optically similar but have different compositions are analyzed. Such phases cannot be discriminated from each other in an optical image obtained with a TV camera, but they can be readily discriminated in the SEM-BSE image. The image analysis capabilities of the image analyzer, interfaced to collect an image from a SEM, are the same as for the computer-based image analyzer equipped with a TV camera.

6. SEM-IMAGE ANALYZER

Steering an electron beam on a SEM equipped with EDXA was first utilized in 1974 to identify features on the basis of their compositions, and to perform image analysis of the features. This was performed by a separate image analyzer that was interfaced with the EDXA. The image analyzer steered the beam to scan the features, and the EDXA sorted the X-ray spectrum, comparing it to a chemistry file to identify the features. The system uses a live image from a SEM. The image analysis capabilities of the separate image analyzer are less than in the standard, computer-based image analyzer. The instrument can determine area %; perform size analysis; count; and classify features on the basis of diameter, aspect ratio, and a few other parameters. It cannot determine whether the particles are free or unliberated.

7. SEM-EDXA IMAGE ANALYZER

Modified versions of the programs used for the SEM-image analyzer have been written as EDXA programs by several EDXA manufacturers, and one of them markets the EDXA programs for EDXA units sold by other manufacturers. The mode of operation and capabilities of the SEM-EDXA image analyzer are essentially the same as for the SEM image analyzer, but the EDXA programs of some manufacturers are different enough to warrant comparison when shopping for an image analysis system.

8. TWO-WAY, SEM-EDXA-IA IMAGE ANALYSIS

The manufacturers of standard, computer-based image analyzers have built an interface that allows two-way communication between the image analyzer, SEM, and EDXA. This interface has permitted the development of a very powerful image analysis system. A typical sequence of operation in the system is (i) collecting an image with the image analyzer from the SEM; (ii) cleaning the electronic noise and unwanted features from the image with the image analyzer; (iii) steering the electron beam of the SEM with the image analyzer to scan each feature in the "cleaned" image; (iv) collecting the X-ray spectrum from each feature with the EDXA and sorting it into elements; (v) comparing the sorted spectrum to a mineralogy or chemistry file to identify each feature; and (vi) performing image analysis of the identified features with the image analyzer. This image analysis system has the capabilities, versatility, and advantages of all the systems described above. The major disadvantage is the high cost because three interfaced units are required: the standard computer-based image analyzer, SEM, and EDXA.

9. MICROPROBE IMAGE ANALYZER

A Cameca microprobe equipped with four wave-length spectrometers is used as an image analyzer at the Royal School of Mines (5). The analysis is performed by doing a line scan in a predetermined pattern across the sample and taking a reading with each wavelength spectrometer every 2 micrometres for 1/10 second. A computer program provides the following: (i) phase identification on the basis of four elements; (ii) volume % on the basis of chord analysis; (iii) chord size analysis; (iv) % free grains; and (v) characteristics of the unliberated features.

10. COMPUTER PROGRAMS

Many researchers write computer programs for solving a wide variety of image analysis problems. These include (i) university projects for graduate students; (ii) specific problem-solving such as sorting crossed fibres in order to perform fibre analyses (6,7); (iii) problem-solving related to analyzing maps (8); (iv) major projects such as writing a complete set of programs to perform image analysis using an EDXA; and (v) other projects (9).

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