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Image enhancement in Kerr microscopy

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The paper presents some useful features of digital image acquisition and processing, which can be used in magneto-optical microscopy: image transforms (e.g. Fourier transform), spatial and frequency filtering, image filters (linear, non linear, adaptive or morphologic filters), objects handling, etc.

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1. Introduction

The magnetic materials can be analyse by magneto-optical effects (Kerr, Faraday or Voigt effects [1]), using a polarizing light microscope. Unfortunately, the method sensitivity is very weak and the obtained images must be processed with care. Digital image processing [2] allows the separation of magnetic information from a composite image, the enhancement of the brightness and the contrast, the noise filtering and the manipulation of objects like magnetic domains or walls.

The knowledge of these methods for digital image enhancement is crucial in the investigation of the magnetization structures which are developed in magnetic materials under magnetic field excitation. These tools allow reducing the image noise, to segment the grains from the image background and to detect the walls within an image.

The paper presents some useful features of digital image acquisition and processing, which can be used in magneto-optical microscopy: image transforms (e.g. Fourier transform), spatial and frequency filtering, image filters (linear, non linear, adaptive or morphologic filters), objects handling, etc. The examples are focused on Kerr microscopy by Axiolab equipment (Carl Zeiss®). The features of image processing software, like KS 300 or AxioVision (Carl Zeiss®) [3] are also analysed.

2. Image acquisition

The image acquisition is the most important step within image analysis because it is the only instant when we have all the original data available. Poor image information can lead to a situation in which a sample is no longer analyzable, as the system can no longer recognize the image objects. Information that is not acquired during image acquisition is very difficult to reconstruct during image enhancement; in many cases this is not possible at all. Therefore, all the technical possibilities offered by the microscope and camera must be carefully used. The quality of the sample, especially its surface, must be improved at maximum.

An important noise source is the stray field from magnetic parts of the microscope, so it is better to replace them with non-magnetic parts. Also, the mechanical vibrations or thermal drifts in the microscope cause artifacts in the Kerr image. Light source fluctuations in amplitude, focal position and polarization can also occur [4], especially for mercury arc source.

3. Image processing

The magneto-optical observations produce an image where the imperfections of the sample surface and the noise of the acquisition electronic channel influence the magnetic contrast by a strong "non-magnetic" component. Digital image processing allows us to eliminate this component - quasi-constant for any magnetic state of the sample - by subtracted a reference image from the analysed image. The image processor can perform this task in background, live observation of magnetization processes being possible in this way [5].

The frame subtraction may be performed using the same reference image for all the frames or a sequential subtraction, in which pairs of frames are subtracted each other. The constant reference image can be obtained from a saturated magnetic state or by N frames averaging. The live view of the domain areas expanding or shrinking is possible if the reference state is magnetically saturated. A reference image corresponding to an arbitrary magnetic state allows the observation of trace patterns of wall displacements.

Different views of the same domain pattern can be obtained by using different reference images, relating to a modified microscope setting [6,7] (e.g. at the beginning and the end of measurement). In this way, different magnetization components can be made visible by changing the plane of incidence or the depth sensitivity is modified by rotating the compensator.

The resulting image may still contain structural or non-magnetic contrast contributions. These artifacts can be removed by enhanced digital procedures, using point operations, spatial filtering, Fourier frequency methods or morphological filtering.

4. Image enhancement by point operations

Image enhancement can be accomplished in the spatial domain with algorithms [8] which are easily implemented in specialized hardware, providing real-time image processing [9]. The point processing can be the changing of a pixel's graylevel (by constant, algebraic or logical methods) or the nonlinear (histogram) techniques. In this way, it is possible to manipulate the image's graylevels, changing its contrast and brightness by mapping the original graylevels (i_k) to a new set of graylevels (o_k). This mapping function can be either linear or nonlinear, involving or not a constant.

For a singular image, there are four linear mapping functions (addition, subtraction, multiplication and division) and four logical (boolean) operations (*OR*, *AND*, *XOR* and *NOT*). A useful generalized linear function is:

$$o_k = c \cdot (i_k - B) + (B + b) \quad (1)$$

where B is the average brightness of the image, c is the contrast parameter and b is the brightness parameter. The values of c and b influence the general perception of the image. Also, the logical operations, especially *OR* and *AND*, can filter a noissy image. The most common nonlinear mapping functions are the exponential and the logarithmic functions, which are used to enhance either dark or light regions of an image.

Similar to these constant operations, there are four linear operations between images, that can be used separately or in combinations. For example, the subtraction and addition are used for reducing the uncorrelated additive zero mean noise generated by the electronic camera, in a method known as "image averaging". Image subtraction plays an important role in finding changes or differences between images, being used for eliminating the non-magnetic information or outlining the wall evolution in dynamic magnetization processes. The image multiplication may remove the non-uniform camera response, due to the differences in gain sensitivity and in offset voltage between the sensor elements.

The nonlinear methods based on histogram play an important role in the enhancement of the perceived brightness and contrast of an image. Indeed, a dark, low contrast image can be automatically improved, making features observable that are not visible in the original image. In facts, the histogram shows the distribution of graylevels within the image – see Fig. 1.

The histogram equalization (or histogram flattening) is a method which produces a new image with a uniformly distributed histogram, increasing the brightness and the contrast of a dark and low contrast image like in optically filtered Kerr image. This technique is also used to standardize the images because all the images will have approximately the same brightness and contrast, being possible to compare them. The method of histogram specification generalizes this process, mapping the image's graylevels to a new set that produce a desired histogram. The brightness and the contrast can be so controlled with a greater accuracy.

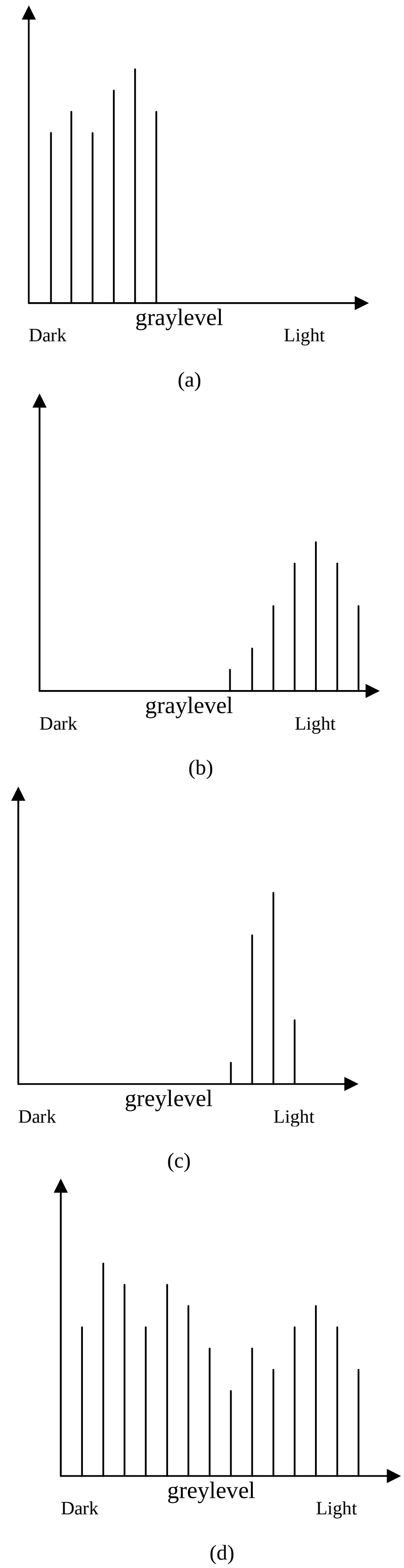

Fig. 1. Histograms for: a) dark and medium contrast image; b) light and medium contrast image; c) light and low contrast image; d) high contrast image.

5. Image filtering

Filtering of an image reduces the noise present in an image. Filtering can be implemented in either the spatial or frequency domain [10]. The classification of noise is based upon its histogram shape. The noise can be:

- uncorrelated uniform – from a discrete noise source;
- gaussian – from the electronic camera and its sensors;
- negative exponential – from the laser-type illumination source;
- salt-and-pepper – from the malfunctioning pixels of electronic camera or from dust and lint that appears on the microscope optics.

The noise corrupts the image in two ways, resulting additive or multiplicative noise. The additive noise is much easier to remove from an image, using linear spatial and Fourier frequency domain methods, while the nonlinear image processing methods are needed to remove multiplicative type noise.

Images frequently contain noisy regions or inhomogeneous brightness, which impair the detection of the objects to be measured – walls, grains or domains. To achieve satisfactory segmentation, these kinds of images are processed using smoothing filters. All filter functions work using filter matrixes (filter mask), during the filtering process, the central pixel in the matrix being combined (with different weights A_j) with the gray values within the matrix, resulting a new value (Fig. 2).

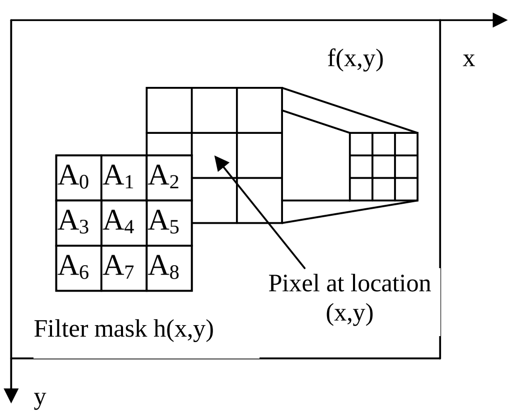

Fig. 2. Spatial filtering using a neighborhood mask.

The most suitable filter depends on the structures that are present in the image. For example, the AxioVision® (Carl Zeiss) software provides some useful tools:

1. The “Sigma function” is particularly appropriate for removing uneven brightness from within structures without influencing the edges of these structures (e.g. the walls of the magnetic domains). Fine structures are also preserved and strong smoothing has been achieved without the edges becoming blurred.

2. The “Gauss function” can be used to suppress noise. This reduces the dynamic range of the image and smoothes the entire image, including the object edges. With the Gauss filter, weak smoothing has been performed, the edges of the object having also been smoothed.

3. The “shading correction” is necessary for filtering uneven illumination, vignetting in the optical system or inhomogeneous sensitivity of the camera sensor. The brightness of the image is uneven, which greatly impairs the detection of the objects to be measured. This disruptive effect can be eliminated using a reference image corresponding to an empty field with no structures. If the sample is no longer available to allow the acquisition of an empty field, a pseudo-shading reference image can be used. This is generated by applying particularly strong smoothing (e.g. using a strong lowpass filter) to the original image.

Another method of image filtering is to manipulate the image’s real and imaginary Fourier components via Fast Fourier Transform (FFT) algorithm. The advantages of performing spatial frequency filtering are the computing speed, especially for large sized filter masks, and the possibility to filter the desired spatial frequency. The used filters can be of the following types: low-pass, high-pass, band-pass or band-reject. In Kerr microscopy, this feature is very useful for periodic magnetization processes, in order to reduce the effect of armonics in the applied magnetic field which is produced by coils. The removing of those parts of the spectrum not related to the magnetic image improves the image quality (e.g. the maze domains in a garnet film [13]).

Filtering effects could be better if the filters are nonlinear, adaptive or homomorphic [12,13]. Indeed, the adaptive filters change their filtering characteristics depending on the noise and the image features that are being filtered. The goal of adaptive filtering is to detect edges and homogeneous regions in the image and to perform heavy filtering within the homogeneous regions while performing no or minimum filtering to preserve the edges.

The multiplicative noise and image shading can be removed from poorly illuminated images by homomorphic filtering [14]. Often the image structures that we want to measure are present in the form of agglomerates, or are positioned very close together, which means that separation is required following segmentation. If only the object contours have been detected, these are frequently incomplete, and need to be reconstructed to form complete contours. The conventional separating functions are combination of binary dilation, binary erosion or skeletonization and are very useful to outline the walls and the grains in a magnetic structure.

6. Image segmentation and evaluation

Image segmentation allows to separate various regions in the image and to separate the objects from the background. This operation can be performed by three methods:

1. Image thresholding – the image is separated into different regions upon a predetermined graylevel of the pixels.

2. Edge detection – the contours are identified by the discontinuities between graylevel regions.

3. Self-criteria segmentation – the image is separated upon desired criteria (e.g. pixels that are connected and that have the same graylevel).

The interesting objects (magnetic domains) can be separated on brightness or color information. Reference objects are outlined or highlighted in the image using the mouse. It is also possible to directly select the thresholds for the brightness or color ranges, but this requires a certain amount of experience. A digital measurement on the desired objects can be now automatically performed. Sometimes, however, this is not possible and all the artifacts which are not filtered and the objects which are not recognized as individual objects must be manually processed. Typical processing steps therefore involve the deletion of artifacts, the filling of gaps in objects and the automatic separation of objects. In difficult cases, subsequent interactive processing (deletion, separation, additional drawing in objects etc.) may also be required.

The measurement parameters are determined for every individual object (e.g. the area, circumference and shape of domains, or a densitometric values, such as the average gray value) or for the entire image (e.g. the number of walls, domains with a given magnetization etc.). The obtained data are stored and can be manipulated with special evaluation programs, such as Microsoft Excel. Advanced software gives the option of displaying the objects, e.g. by outlining their contours, and the measurement results directly in the image.

7. Conclusions

Digital image acquisition and processing opened a wide area of new possibilities in magneto-optical microscopy. There are a lot of magnetic structures which are visualized, for the first time, by Kerr microscopy and digital filtering. Unfortunately, these numerical tools can not diminish the main drawbacks of Kerr method: low sensitivity and restrictions on the sample surface preparation.

The image digital enhancement must be carefully used for quantitative Kerr microscopy because the graylevels are altered. A possibility could be the digital treatment of the acquired image only with linear mapping functions.

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References

[1] A. Hubert, R. Schafer, Magnetic Domains, Springer Verlag, Berlin (1998).
[2] A. R. Weeks Jr., Fundamentals of Electronic Image Processing, SPIE/IEEE Press (1996).
[3] Axio Vision User's Guide, version 4.4, Carl Zeiss (2005).
[4] B. E. Argyle, A magneto-optic microscope system for magnetic domain studies, Proc. Symp. Magnetic Mat., Processes and Devices, Electrochemical Soc., **90-8**, 85 (1992).
[5] B. E. Argyle, B. Petek, D. A. Herman, Jr.: Optical imaging of magnetic domains in motion, J. Appl. Phys. **61**, 4303-4306 (1987).
[6] W. Rave, R. Schafer, A. Hubert, Quantitative observation of magnetic domains with the magneto-optical Kerr effect, J. Magn. Magn. Mat. **65**, 7-14 (1987).
[7] R. Schafer, A. Hubert, A new magnetooptic effect related to non-uniform magnetization on the surface of a ferromagnet, Phys. Status Solidi, **A 118**, 271-288 (1990).
[8] I. Pitas, Digital Image Processing Algorithms, Prentice Hall, New York, (1993).
[9] E. R. Dougherty, P. A. Laplante, Introduction to Real-Time Imaging, SPIE Press, Bellingham (1995).
[10] A. Antoniou, Digital Filters: Analysis, Design and Applications, MacGraw-Hill, New York (1993).
[11] E. Kubajewska, A. Maziewski, A. Stankiewicz, Digital image processing for investigation of domain structure in garnet films, Thin Solid Films, **175**, 299-303 (1989).
[12] B. Widrow, S. D. Stearns, Adaptive Signal Processing, Prentice-Hall, Englewood Cliffs (1985).
[13] I. Pitas, A.N. Venetsanopoulos, Nonlinear Digital Filters: Principles and Applications, Kluwer Academic Publishers, Boston (1990).

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