BELARUSIAN STATE UNIVERSITY

PATTERN RECOGNITION AND INFORMATION PROCESSING PRIP'2009

PROCEEDINGS
OF THE 10th INTERNATIONAL CONFERENCE
(19—21 May, 2009, Minsk, Belarus)

Minsk
"Publishing center of BSU"
2009

Structure Shape Description Approach for Magnification Images

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Abstract: *This document presents the approach for robust, accurate and comprehensive structural magnification image analysis using the image pyramids. The approach is based on the fact that different magnetic structure types prevail on different levels of the image pyramids. These structures have different fractal characteristics according to which it is possible to make conclusions not only about the structure types, but also about their different physical characteristics. The approach proved to be efficient applied to the magnetic image analysis and recognition, but can also be used with other types of images.*

***Keywords*:** Image pyramids, fractal characteristics, structures, analysis.

1. INTRODUCTION

The problem of structure shape description is very important for a variety of image analysis tasks. Therefore, it is necessary to apply the most informative functions to the image data according to which values it would be possible to make efficient and usable conclusions. For this reason, we used fractal characteristics, such as fractal dimension, for structure shape description while conducting the research described below.

To make the research more comprehensive we applied these functions not only to the image, but also to the image pyramid constructed based on the initial image.

The data structure used to represent image information can be critical for the successful completion of an image processing task. The image pyramid is a data structure designed to support efficient scaled convolution through reduced image representation. It consists of a sequence of copies of an original image in which both sample density and resolution are decreased in regular steps [3].

If the basal function of a pyramid layer is shape descriptive, use of the image pyramids provides an opportunity to broaden the structural parts of an object shape description significantly. For instance, the usage of convexity as a basal function of the image pyramid leads to determination of smoothness quality of the object borders. This characteristic is used for the boundary data analysis. For example, the structures which are initialized by the growing processes (living organism parts, minerals, corrosion, magnet domains, etc) can be used as descriptive structures. According to their characteristics it is possible to conjecture the reasons which caused growing and describe interactions which occur while growing. However, different structures refer to different zoom levels. According to the set of peculiar properties of the structures during the pyramidal conversion the dependency of structure type prevalence on the scale level can be determined. As a result, not only can the global influence on the sample be judged by the pyramid, but the local influences and their interactions on different scale levels can also be determined.

Fractal characteristics, such as fractal dimension and fractal intercept, are the most suitable for description of the image objects shapes, as they represent smoothness and difficulty of the objects borders.

There is a limited set of the structures, which can be located on the magnetic image. And all these structures have their own properties determination of which can influence the image processing and analysis process significantly.

Therefore, using of the image pyramids in a combination with fractal characteristics can be very efficient while extracting the shape border smoothness. This can be efficiently used while tracking of a process different structures development. Moreover, the combination of fractal characteristics and image pyramids provides a wide area of application for different training algorithms such as neural networks and vector machines, which allows to make the process of image analysis as independent from a person as possible, reduce the human factor and to make the estimation of any values referred to the image more precise.

2. IMAGE PYRAMIDS

Image pyramids have shown to be efficient data structures for digital images in a variety of vision applications. An image pyramid is a stack of images with exponentially decreasing resolutions. The bottom level of the pyramid is the original image. In the simplest case each successive level of the pyramid is obtained from the previous level by a filtering operation followed by a sampling operator. More general functions can be used to yield the desired reduction. We therefore call them reduction functions.

Image pyramids have the following merits [2]:

- The influence of noise is reduced in the lower resolution images by smoothing.
- In the low resolution images, the regions of interest for correspondence analysis in levels of higher resolution can be found at low cost because irrelevant details are no longer available there.
- This reduces computational cost as the divide-and-conquer principle can be applied: in high resolution images, the region of interest can be split into several patches which can temporarily be handled individually.

Each layer of the pyramid can be processed and analyzed. And if the way of analysis is the same for all the levels, the sequence of descriptive data is received. This sequence of data provides an opportunity for the comprehensive image analysis leading to determination of some specific image characteristics which haven't been available before.

Image pyramids combine the advantages of both high and low resolutions of digital images compared in Table 1 without increasing the demand for disk space too much. The lower levels of an image pyramid provide detailed information, but a great amount of data, whereas the higher levels contain less information but give an overview and require a smaller amount of data.

Image pyramids showed to be efficient in combination with different image processing and analysis algorithms. For instance, a shape preserving resolution pyramid can be used in the framework of image segmentation via watershed transformation. The most significant components perceived at high resolution will also be perceived at lower resolution. So, for example, the seeds for the watershed transformation can be found at the low resolution images and migrated to the higher resolution images. And, therefore, the watershed partition obtained at the selected pyramid level will include only the most important components. [5].

Table 1. Qualities of images in different resolutions

	High resolution	**Low resolution**
Data amount	Huge	Small
Details	Rich and many	Very few
Overview	Bad	Good
Position	High	Low

There are three important properties that characterize a pyramid:

- Structure: e.g. neighbors, father-son relations between levels
- Contents of a cell: e.g. pixel, edge, or more
- Processing preformed by the cells: e.g. filtering

The structure of a pyramid is determined by the relations within the levels of the pyramid and by the father-son relations between adjacent levels. We distinguish between

- regular structures and
- irregular structures

depending on whether the structural relations are the same for all pyramid cells (except on the boundary) or whether they may vary from cell to cell.

Two terms describe the structure of the regular pyramid: reduction factor and the reduction window. The reduction factor determines the rate by which the number of cells decreases from level to level. The reduction window associates to every cell in a higher level (called father) a set of cells in the level directly below (called sons). The cells which are neighbors on the same level are called brothers (sisters).

In irregular pyramids the regularity constraint of regular pyramids is relaxed. These pyramids operate on a general graph structure instead of the regular neighborhood graph as in the case of regular pyramids.

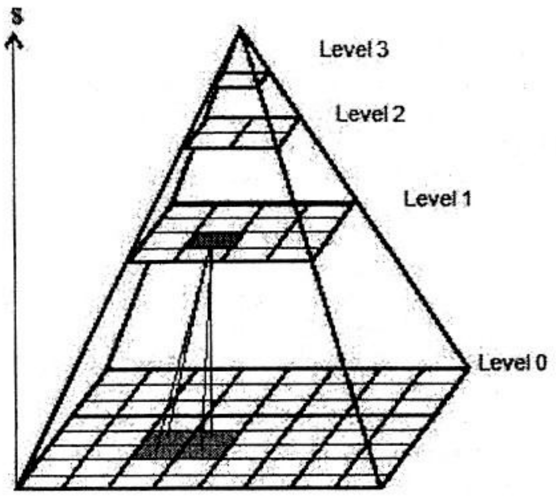

Fig. 1 - Structure of a regular image pyramid: the discrete levels and scales

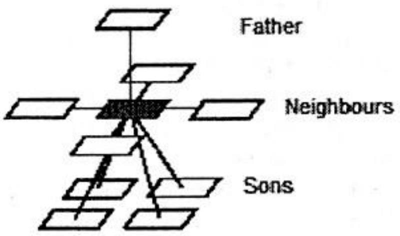

Fig. 2 - A particular cell of a regular image pyramid

There are two ways to construct a regular pyramid:

1. Parallel graph contraction
2. Decimation of the neighborhood graph

The main purpose for the introduction of irregular pyramids was the rigid behavior (e.g. shift variance) of regular structures. Irregular pyramids offer greater flexibility for the price of less efficient access.

One can consider the contents of a cell as a model of the region which it represents. In the simplest case a cell stores only one (grey) value. We call such pyramids grey level pyramids. In more complicated cases several parameters of general models are stored in a cell. But the basic property that numeral values are stored in a cell remains. Subsequently we will call these pyramids numerical pyramids.

Besides numerical values it is possible to store symbolic information in a cell. In this case we have a finite number of symbols, and a cell stores a symbol relation among them. We call such pyramid symbolic pyramid.

The main property of processing in a pyramid is that it occurs only local, the brothers, and/or the parents a new value and transmits it to one or more cells of its pyramid neighborhood. In the bottom-up construction phase input comes from the sons but for some algorithms the flow of information is also in the top-down direction.

The type of operations performed by the cells depends of course on the type of the cell's content. For grey level pyramids linear filters e.g. Gaussian are commonly used. But also other non-linear filters hove some significant properties, e.g. minimum and maximum filter or filters based on mathematical morphology. In the case of symbolic pyramids other types of reduction functions have to be used.

3. STRUCTURES

There are several different types of structures [4] determined on the magnetic images. We observe five basic configurations of image objects structures.

1. The object is characterized by many nucleation centers in observation area.

a. Blobs. They are the solid objects, without internal structure; a blob growing is isotropic.

2. The object is characterized by limited number of nucleation centers in observation area.

b. Front. This is a big object that is characterized by flat growing in one direction.

c. Needles. They are very elongated in one direction objects. Usually they have sharp terminations.

d. Dendrites. They are very complex objects. Dendrites represent connected structure of branch.

e. Nets are evolution of dendrite structures. They have all properties of dendrite structures expect preferential direction of growing. These structures appear in regions with filled band of structures blocks without global border conditions for convex region of structure. For this structure we cannot determine the center of nucleation. Nets have not border condition.

The basic image structures are represented in the Figure 3. Other objects are usually constructed by these four types of structures.

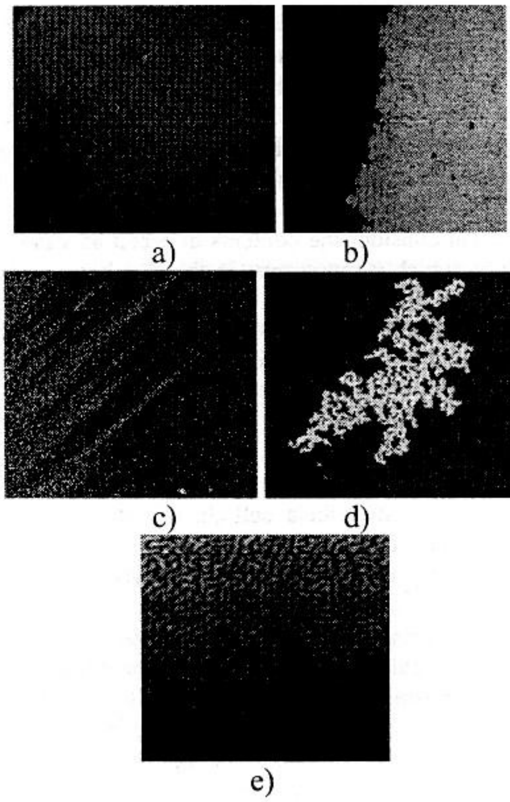

Fig. 3 – The basic structures: a) blobs, b) fronts, c) needles, d) dendrites, e) nets

4. STRUCTURE DESCRIPTION

Static object analysis is divided into two categories. They are specialized object analysis and random object analysis.

Random object analysis requires a specially prepared binary image with the explored objects displayed on by the binary data. The scale should be specified for the image (it can be determined by the calibration function) and calculated characteristics should be determined.

Specialized object analysis requires preliminary calibration only. This process is divided into four steps mentioned below.

1. Preprocessing
2. Image segmentation
3. Shape correction
4. Image characteristics determination.

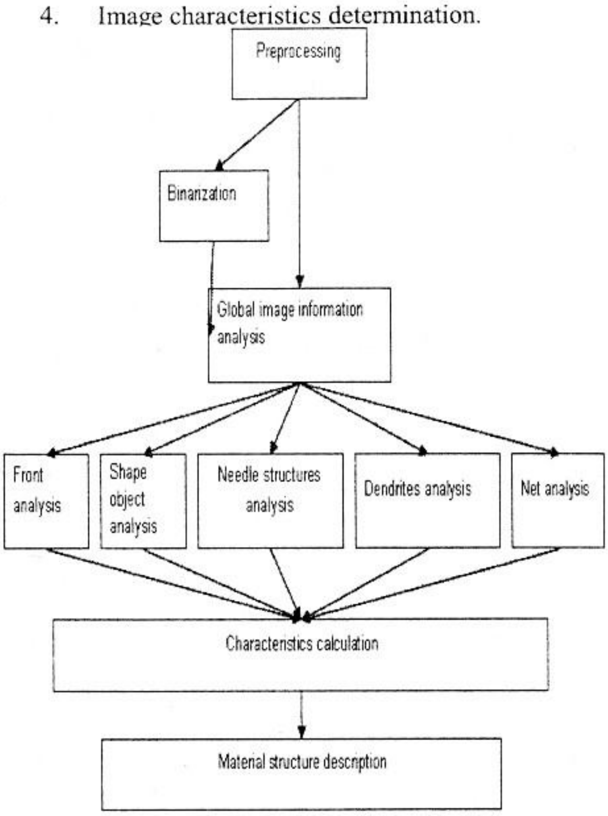

Fig. 4 – Specialized object analysis scheme.

Here is the specific description of the approach. Every image pyramid layer is analyzed and described by some value of the basal function. It is apparent that some descriptive statistic value can be associated with every level of the pyramid according to the values of basal function on this level. So, the dependence between the scale and pyramid level descriptive value can be analyzed and used for some conclusions or sometimes pattern recognition.

All these types of structures can be determined on different levels of the image pyramid of a magnetic image if the bottom level is represented by the nets or dendrites. The sequence of transformations is represented in Fig. 5.

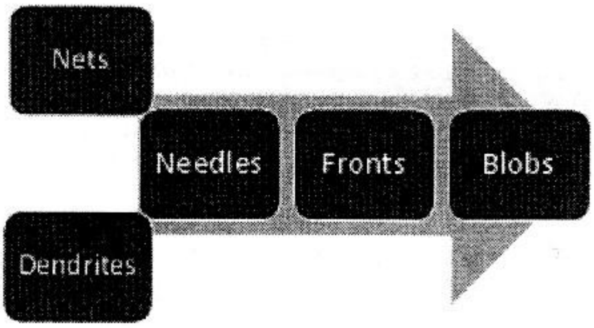

Fig. 5 – The way of prevailing magnetic structures transformations to each other on decreasing dimension levels of an image pyramid

Firstly, after dendrites or nets needles are prevailing structure on the lower resolution images. After that fronts start to prevail. And finally, the structure which refers to the lowest resolution levels is blobs.

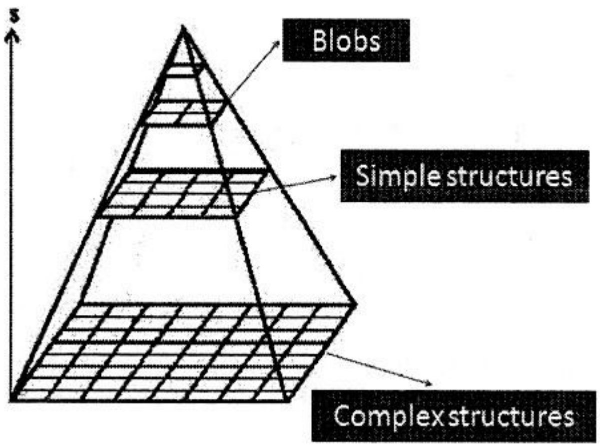

Fig. 6 – The dependency of the prevailing structures on the resolution levels of the image pyramid.

In the Figure 6 the dependency of the prevailing structures on the resolution levels of the image pyramids is represented. Where complex structures are represented by nets, dendrites or their combination and simple structures include needles and fronts.

According to the characteristics of the structures mentioned above and the corresponding pyramid layer resolutions it is possible to make conclusions about the specific physical characteristics of the observed magnetic objects. But this is a topic refers to another area and, therefore, is not to be covered in this article.

Each of them has its own fractal characteristics which can be used for pattern recognition.

All these structures can be described and determined automatically by the fractal characteristics of the images as their fractal dimensions differs significantly. It is, in fact, well known that the skeleton is also a useful shape descriptor and its representation power increases if it is transformed into a multi-resolution skeleton. The skeleton approach in combination with image pyramids proved to be efficient for shape description, [6] but for the magnetic structures we used fractal characteristics as they represent the structures more specifically. Fractal dimension of an object illustrated in the magnet domain image can be determined in two ways which are the most proper for this type of images.

Firstly, the grayscale image dimension can be determined according to the triangulation method. The method works as follows: a grid of unit dimension 1 is placed on the surface [1]. This defines the location of the vertices of a number of triangles. The surface is covered by triangles of different areas inclined at different angles with respect to XY pane. The areas of all triangles are calculated and summed to obtain an approximation of the surface area $S(1)$ corresponding to 1. The grid size is then decreased by successive factor of 2. And the same approach is applied to it after that the value $S(2)$ is extracted. After that the two results are compared to extract the value of fractal dimension.

$$d = \log_2 \frac{S(1)}{S(2)} \quad (1)$$

The other way to determine fractal dimension is to binarize the initial grayscale image and to determine and compare the shape area at two different scales. The binarization process for the structures described above can be most efficiently handled by the Otsu threshold algorithm applied not to the image on the whole but to it local parts represented by the aperture window. This leads to the important details not to be neglected or overlooked.

The values of fractal dimensions of the basic structures are represented in the Table 2. The high bounds and low bounds are extracted from the values received while conducting tests on the grayscale and binary images of magnetic domains. It is apparent that the dimension value ranges of different structures do not intersect and can be successfully used for the structure type determination.

Table 2. Fractal dimension values of the basic structures

Structure type	Fractal dimension low bound	Fractal dimension high bound
Blobs	2,142	2,185
Fronts	2,195	2,250
Needles	2,310	2,410
Dendrites	2,450	2,520
Nets	2,550	2,610

5. CONCLUSION

While conducting the research described above the following steps have been made:

1. The main image structures have been determined and analyzed.
2. Image pyramid data structure has been used for comprehensive image representation.
3. The dependency between the pyramid level and prevailing structure has been detected and analyzed.
4. The dependency between structure type and its fractal characteristics has been detected.
5. The developed technology has been tested for magnet optic structures from nano-images of thin metallic films, fibers and neural vessel structures from angiographic images of histology samples.

There are several directions which this approach can be efficient to be applied to. All of them refer to pattern recognition.

At the same time there is still an area for the research in this direction, as not only the magnetic images can be the target of such an analysis but there are for sure the dependencies in the other types of images and objects represented on them. And the approach described above shows to be an efficient tool of object shape analysis and processing.

6. ACKNOWLEDGEMENT

This work was supported by grant B-1489 of the International Science and Technology Center and EU project Transfer of Knowledge.

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