

Optical Microscopy and Metallography: Recognition of Metal Structures using Customizable Automatic Qualifiers

Mikhail V. FILINOV, Andrey S. FURSOV, Association "SPEKTR_GROUP", Moscow,
Russia

Abstract. Some approaches to the solution of the important task such as processing of complicated images for structural analysis, classification of images according to the available standards for various fields of nondestructive testing, were considered. Algorithms of automatic qualifier creating using software application SPECTR MET [1] for examination of image types obtained by means of the portable microscope for the metallography are provided. The developed algorithms are shown as classification of microstructures of metallographic specimens.

Introduction

When solving of many tasks of quantitative metallography often there is a problem of recognition and classification of metal structures according to the certain standards. It is necessary to note that the most of available standards in metallography require visual comparison of microscopic object structure and reference images. It is obvious that accuracy of such examination depends on some human reasons, for example, an operator's fatigue because analyzing great volumes of the information or in the case if the solution of a classification task demands the analysis of lots attributes changing over a wide range because the structure is too complicated. In such cases it is often enough to make only over-all observation of a microscopic picture, but not quantitative studying of microscopic objects. Therefore it is seems relevant to automate comparison of a metal specimen and the standard using computer. Application of computer techniques allows to realize the quantitative analysis of examined structures [2, 3] that enables to obtain more objective analysis. The quantitative estimation of microstructure assumes also gathering of huge amount of statistical data since correctness of the quantitative description of structure depends on the number of the measured objects; it is possible to obtain exact data only by means of statistical methods of the analysis. It is clear, that visual ways of microscopic measurements are not adapted for the mass analysis.

Thus, computer classification of images of microscopic structures possesses in comparison to visual once with following advantages: objectivity of gained data in view of quantitative character of examinations; expansion of solved tasks; substantial increase in speed and accuracy of examinations; a researcher is free of tiresome repeating operations.

The work provides algorithms of automatic qualifier creating using software application SPECTR MET. Examples of the specified algorithm applicable to the task of microstructures and reference specimen comparison are provided.

1. The basic stages of automatic qualifier creating

When using computer systems for the analysis of metallographic specimen, the recognition of the image from digital video- or camera attached to the microscope is usually implemented. The digital images obtained also make an object of examination during comparison with reference images.

It is possible to specify two basic approaches [2-5] to recognition of specific types of images:

- 1) Introduction of space of so-called receptors and search of appropriate division of this space into the areas matching various classes of objects;
- 2) Introduction of so-called attribute space and its further division into the areas matching various types of structures.

The space of receptors used at the first approach is a set of points; each point is characterized by the ordered set of the integers representing luminance of pixels making the examined image. It is important to note that an essential disadvantage of the first approach is the necessity of comparisons for two images pixel by pixel, it means that solutions are available only if the objects for each class have many common points or fragments (on luminance). "Similarity" in this case is similarity at superposition of images against each other. It is clear that such approach in some cases does not work for the task of recognition because, for example, images can refer to the same class if their objects have some certain sizes, but they can have any space arrangement.

The second approach assumes degenerate mapping of receptors space in space of attributes, each attribute represents some quantitative characteristic of structure. Attributes can be, for example, average luminance of the image, the average square of examined objects and other statistical data. Advantage of such approach is defined by the fact that when using attributes the information on specific features of structures is lost, but the information about the rule according to which they are generated is kept.

When automatic qualifier creating based on attribute space, it is possible to specify the following basic stages:

1. Creation of base for reference characteristics and an attribute space. This stage includes obtaining of quantitative characteristics of reference object images, each of objects is analyzed using different areas and different orientations. As a result, the acceptable range of characteristics values is provided for each standard.
2. Division (clustering) of attribute spaces into not crossed areas, objects reflecting a specific types.
3. Development of a solving rule for reference of object to any type. Criterion of a certain class of structure examined for the image is matching of its quantitative characteristics to generated once during the first stage of qualifier creating on numerical ranges.

Reference characteristics here are understood as various attributes of objects which are measured or calculated for reference objects. The list of all characteristics, ready for recognition (for example, numerical), refers to as a base of characteristics. The certain set of characteristics and ways of their calculating define an algorithm of recognition.

Selecting of the source description of objects is one of the central tasks for pattern recognition. If selecting the source description (space of attributes) was successful, the task of recognition can appear trivial and, on the contrary, unsuccessfully chosen source description can result either in very complicated further data processing, or even to an absence of the solution. Depending on a task the reference descriptions will contain various sets of dividing attributes. It is necessary to note that the task of search for a set of dividing attributes is one of the most

complicated during qualifier creating as many standards operate with the qualitative attributes and translation of these attributes into quantitative language sometimes is not possible at all. The basic steps of work of the automatic qualifier intended for definition of a specific type of microscopic structures, in case of using method of division for attribute space will be as follows:

1. Processing data on a microscopic structure with the purpose of extraction of the certain parameters.
2. Comparison of the received parameters with reference once which are put in the qualifier by the operator, or developed during "instructing" of the system.
3. Definition of the class for microscopic structures to which the examined image belongs.

2. Implementation of automatic recognition function using the application SPECTR-MET

Development of SPECTR MET - the metallographic imaging, processing and analysis software - nm was started in 2000. The main principles which the team of developers tries to adhere during their work are the maximum simplicity when using functions, automation of routine operations, adhering to valid Russian standards related to materials technology. The important place among SPECTR MET options is occupied by function of automatic qualifier creating which is intended for automatic procedure of object structure recognition and their distributions into scales of metallographic structures according to the available standards. The function can be considered as convenient when analyzing of metal structures for comparison with the standard. To use specified function, it is necessary to create an automatic qualifier for recognition, which actually depends on used standards. Qualifier creating includes examination of reference images with the purpose of creating a set of reference characteristics and technical implementing of recognition algorithm using software.

2.1. Structure of the qualifier.

For SPECTR MET application the qualifier is an object which can be presented as the following tree (Fig. 1).

Where each level reflects passing of the image to be recognized through the qualifier.

Basic elements of the qualifier are: *nodes* (marked by circles on the figure) and *ribs* (marked by lines on the figure).

Nodes of the qualifier are classes to which source images are automatically allocated. Images to be recognized originally lay on the zero level of the qualifier. *One attribute* (the reference characteristic of examined structure) or one or several reference images for which the attribute was created are connected with each node. The node of a zero level is an entry of the qualifier. Each node since the first level has one entry and generally a few exits (entries and exits are marked by lines connecting various nodes). The situation when the node does not have an exit is also possible.

The result of work of the qualifier is distribution of entrance images for nodes (classes) in conformity with the attributes connected with each node. The image submitted to a node can be let in or not. If the image entered the node it moves along ribs (communication lines) to the nodes of a underlaying level.

So, the image submitted to the entry of the qualifier moves along ribs via sequence of nodes as a result having stopped in one or several nodes. The image is considered *as completely recognized* if it is reached the node which has an entry and does not have an exit, and it is accepted by the node; *as partially recognized* if it is has reached the node (at least on the first level) which has exits; *not recognized* if it remains on the zero level.

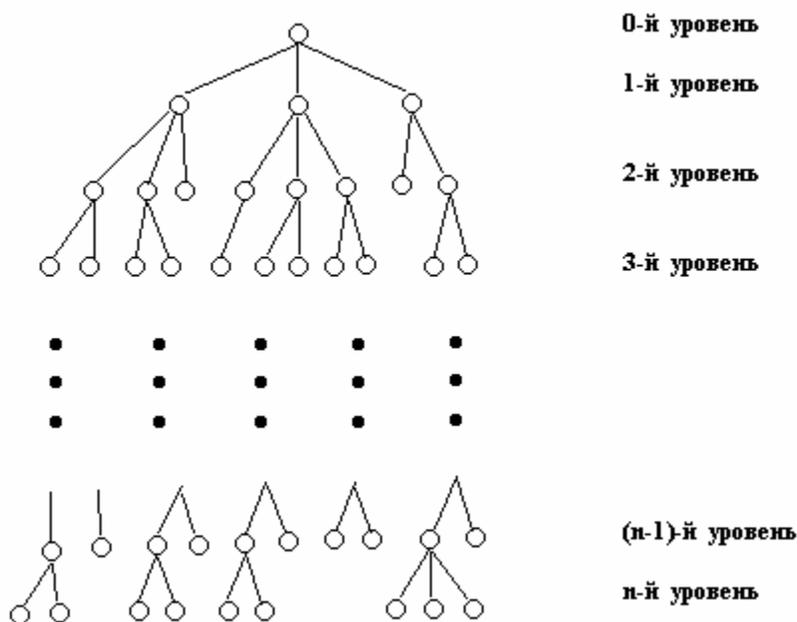


Fig.1. Structure of the automatic qualifier

2.2. Creating of attributes.

The attribute of the qualifier is a converter of the image into a logic variable. The image moves to the entry of the converter and the logic variable (false - "no", true - "yes") is generated on the exit. The attribute entering into the qualifier shall be connected with any node. The image accepted by a node if a true variable is generated on the exit of the relevant attribute. We shall notice that the image can be accepted by several nodes of one layer. If the node has several exits the image moves at once to all of them, but can pass only into those nodes which attributes have true exit for this image. Actually, the attribute of the qualifier checks quantitative characteristics of the image.

To use attributes while creating of the qualifier it is necessary to create them in advance. Creating of attributes is carried out on the basis of quantitative analysis of reference images. Examination of images is partially automated by functions available in the application and should be performed under the control of the user.

Each attribute is creating by means of a set of functors implemented in the application (*functional operators*). *The functor of the qualifier* is a transformation which, generally, has entrance arguments and target values. As entrance arguments and target values of functors can serve images, binarized images, constants, morphometric analysis data, chord analysis data.

The images used as arguments of functors are source images; the reference images are used during creating of attributes, but images of recognized structures are used during work of the qualifier.

Binarized images can be received applying to the examined images of the morphological analysis implemented in SPECTR MET application. The result of the morphological analysis is the binary image with the allocated coherent areas which are objects of examined structures. Some algorithms of the morphological analysis [6, 7] implemented in the program allow to obtain optimum results of search for the necessary objects on images of structures.

Constants can be of various types: integers, real numbers, logic variables, units of measurements, etc. Values of constants can be obtained as results of using practically all functions of SPECTR MET application allowing to calculate quantitative characteristics of objects and histogrammic attributes of luminance properties for examined structures [7].

Morphometric analysis data include statistical data about distribution of such values of objects, as the square, perimeter, form-factor, Fere diameters, maximum diameter, length, width, anisotropy factor.

Chord analysis data include statistical data about sizes of the examined objects received by means of chord method for definition of linear dimensions of objects.

Since before analyzing the image with the purpose of obtaining of various quantitative characteristics, it is necessary, as a rule, to carry out preprocessing of the image for removal of noise and raising of contrast there is an option in SPECTR MET application to include into attributes the various functions of preprocessing (averaging and median filters, filters for accentuation of boundary lines, functions of luminance changing, etc.).

It is necessary to note that many standards existing in metallography contain only the qualitative description of the structures belonging to one or another class. And images of the structures belonging various classes can differ slightly from each other according to a number of quantity indicators. Therefore the task of search for dividing attributes for recognition of structures is divided into two problems, the first one is a task of the quantitative description of structures and the second one is finding of those parameters on which it is possible to recognize the images of different classes.

To facilitate the task of creating attribute space for recognition of structures within the certain standard the function of creating tables of attributes containing data about textural characteristics of images, morphometric analysis data, quantitative values of the attributes created by users is provided in the SPECTR MET application. As a result, analyzing this table of data, it is possible to find those quantitative characteristics on which it is possible to divide images into classes. The described qualifier is flexible while creation and check of the various attribute sets serving for creating of automatic qualifiers.

3. Selecting of dividing attributes, example

The following is the example of using the table of attributes and creating of a dividing attribute for two reference images for a ferrite-pearlite structure.

In conformity with the Russian standard titled Steel. Standards of a microstructure the ferrite-pearlite structure of steel can be subdivided into 10 scale numbers depending on ferrite quantity. For this purpose there is a special scale for pearlite and ferrite ratio in the standard. Fig. 2 and 3 show ferrite-pearlite structures related to the numbers 2 and 4.

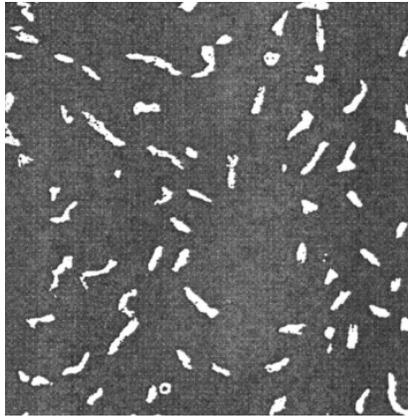


Fig. 2. Ferrite-pearlite structure related to the number 2

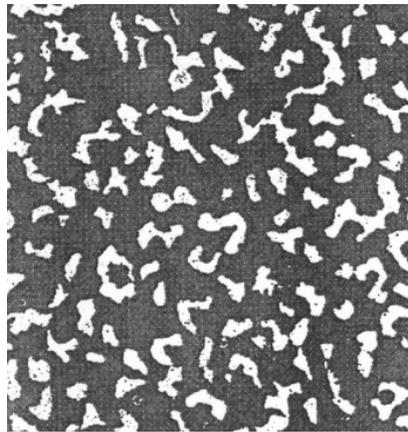


Fig. 3. Ferrite-pearlite structure related to the number 4

To make more contrast images of light objects (ferrite) and to remove noise, images were preliminary processed by functions of luminance and contrast adjusting. The following images were received as a result.

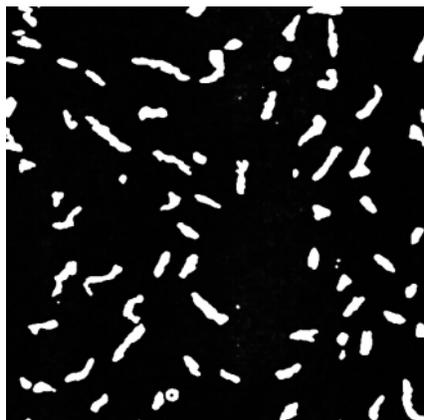


Fig. 4. The image of ferrite-pearlite structure (scale number 2) after processing



Fig. 5. The image of ferrite-pearlite structure (scale number 4) after processing

Then the table of attributes (Fig. 6) including histogrammic attributes and the attributes estimating average values of square, perimeter, length and Fere diameter of light objects on the image was created according to images using a relevant function of the SPECTR MET application.

According to the table (Fig. 6) it is visible that two resulted images are divided well enough by a number of attributes, namely, by an average for luminance, dispersion, asymmetry factor, excess (these are all histogrammic attributes), and also by average square and by perimeter of light objects.

It is necessary to notice that the last four attributes are created by means of the same software which allow to create automatic qualifiers. Fig. 7 shows the sequence of commands written in language built into the SPECTR MET application implementing a quantitative estimation of the average square of light objects which is included into the table titled "Area_mean".

On the basis of this information it is possible to create attributes of the automatic qualifier allowing dividing above structures according to classes in accordance with a scale number of structure. The following is the example of creating the attribute dividing the images according to the average square of light objects (ferrite).

Qualifiers Table - default*			
	Qualifiers	r1.bmp	r2.bmp
Add File	Auto Threshold 2	73	24
Add Qualifier	Contrast	0.19047447	0.041161913
	Homogeneity	0.7784193	0.8119496
New Qualifier	Energy	0.14220726	0.16141273
	Entropy	3.0465941	2.7012758
Edit Qualifier	Mean	73.11207	24.329319
	Variance	12743.846	5040.1763
Delete Qualifier	Correlation	1.3413801	1.0337738
	Max. Probability	0.27625117	0.2765284
Open Table	Inertia	1989.7552	843.37964
	IDM	0.00557265	0.008436772
	Dispersion	12743.846	5040.1763
	Asymmetry	0.9669539	2.9002018
	Excess	1.9440947	9.438488
	Area Mean	658.07166	280.48962
	Perimeter Mean	122.04044	68.38277

Fig. 6. The table of attributes

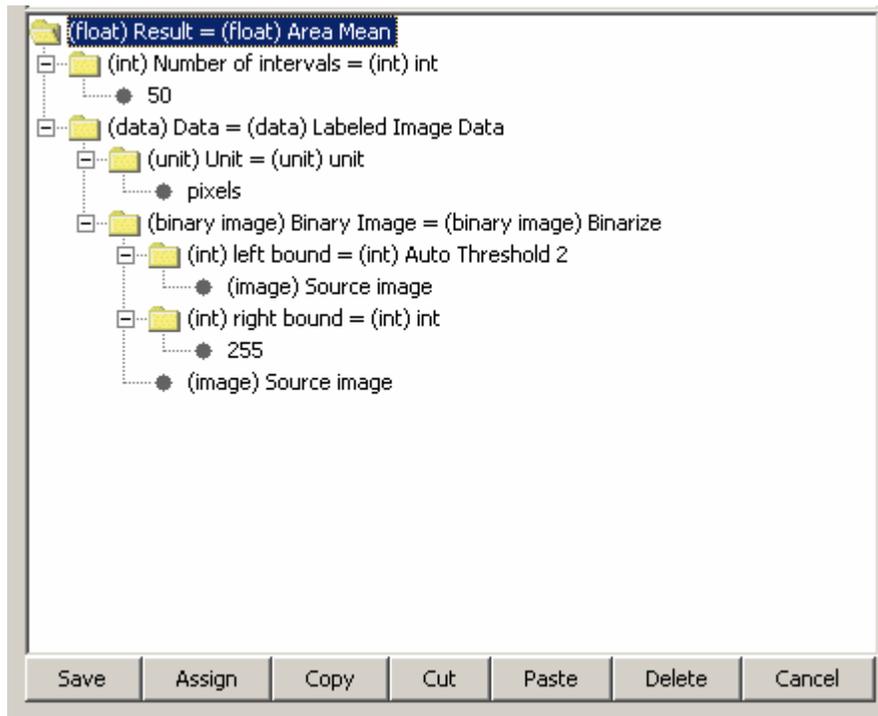


Fig. 7. "Area mean" attribute for the table of attributes

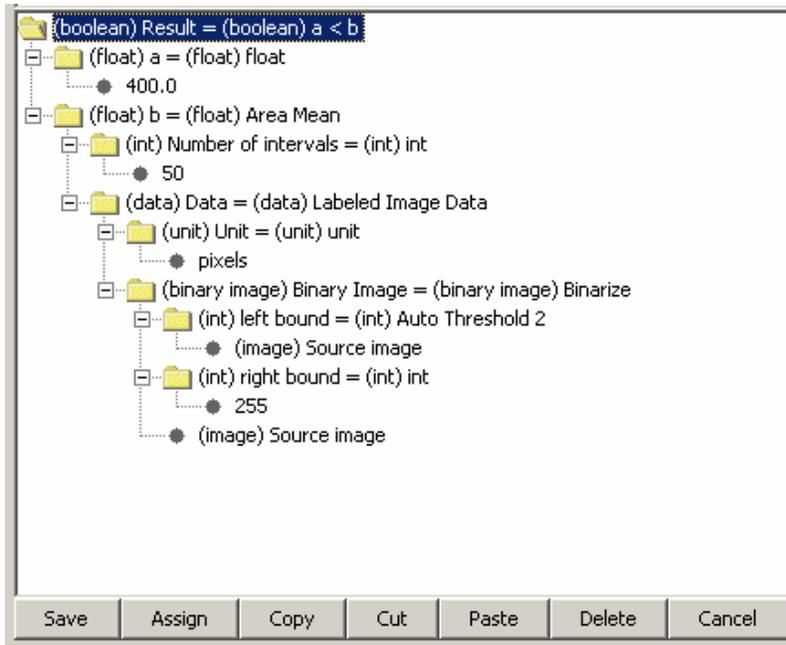


Fig. 8. Implementing of an attribute for the qualifier

The attribute accepts for processing the source image at the entry and generates the true or false answer at the exit, depending on that, the average square of light objects on the image is more or less than 400 pixel^2 .

Also it is possible to create an attribute which checks several parameters simultaneously, for example, average values for square and perimeter. For this purpose operations of logical comparison are used at creating of an attribute (Fig. 9).

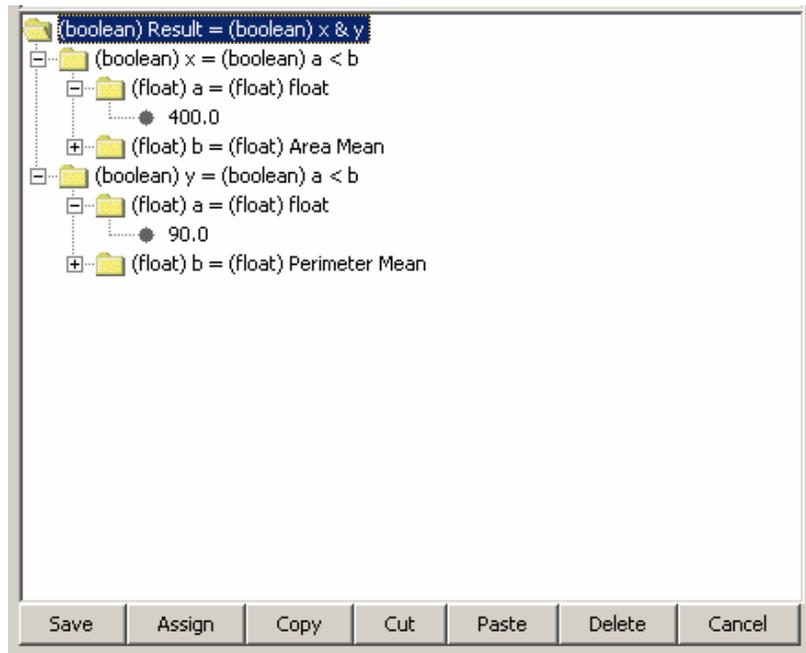


Fig. 9. “Averages values for square and perimeter” attribute

Further the specified in the Fig. 9 attribute will classify images according to the average values of the square and perimeter for the objects found on them. It is natural that using the similar way it is possible to create the attributes including check of three and more quantitative image parameters.

As soon as the necessary attributes are created, SPECTR MET application allows easily to build the qualifier using them.

4. Creating of the elementary qualifier, example

On the basis of the above examinations it is possible to build the simple qualifier which recognizes images of ferrite-pearlite structures related to the scale numbers 2 and 4. Since the images shall be preprocessed to eliminate noise and to raise contrast before recognizing it is possible to build for the above qualifier the modified attributes allowing automatic preprocessing images to be recognized. The following (Fig. 10) is the modified attribute for recognition of a ferrite-pearlite structure according to the scale number 2.

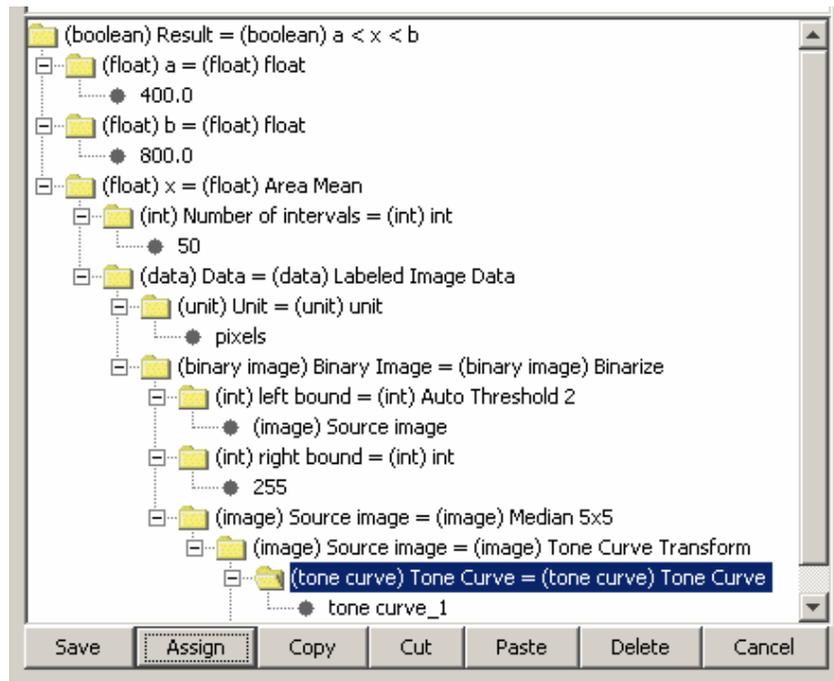


Fig. 10. The modified attribute for recognition of a ferrite-pearlite structure according to the scale number 2

The attribute except for calculating geometrical and statistical parameters of images includes processing images to be analyzed by a median filter (for removal of noise) and transformation of luminance by means of a luminance curve. The similar attribute is creating for recognition of a ferrite-pearlite structure according to the scale number 4. The elementary double-level qualifier (Fig. 11) is creating by means of these attributes.

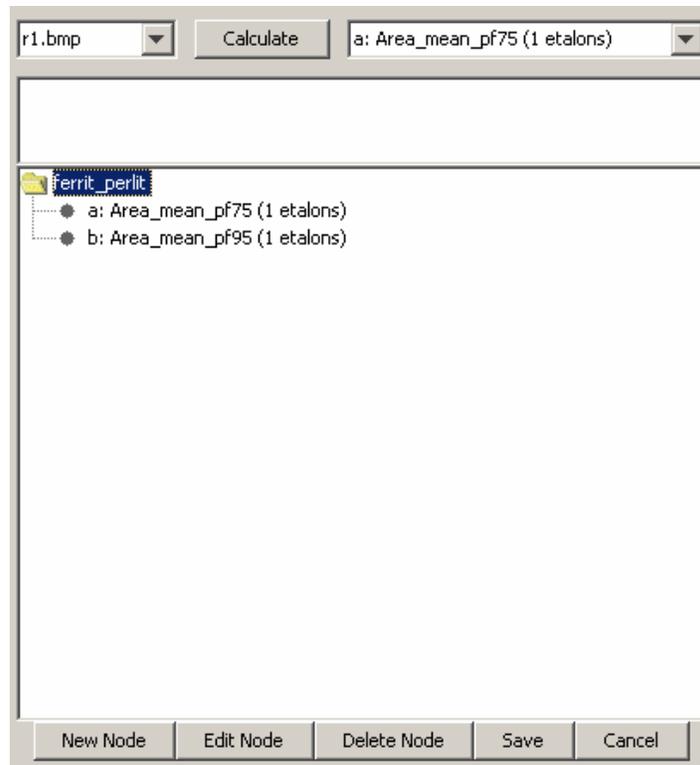


Fig. 11. The elementary qualifier

The built qualifier has correctly recognized ferrite-pearlite structures according to the scale numbers 2 and 4 (images of ferrite-pearlite structures according to the scale numbers 2-6 were sent simultaneously to the entry of the qualifier).

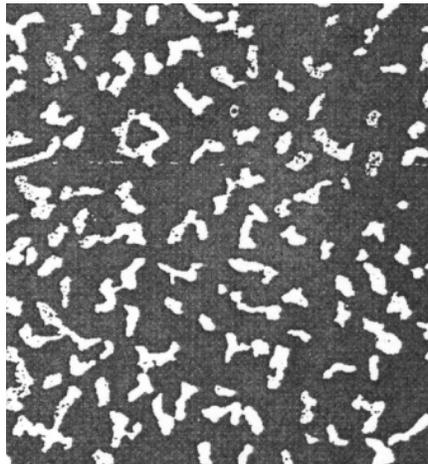


Fig. 12. Ferrite-pearlite structure according to the scale number 3

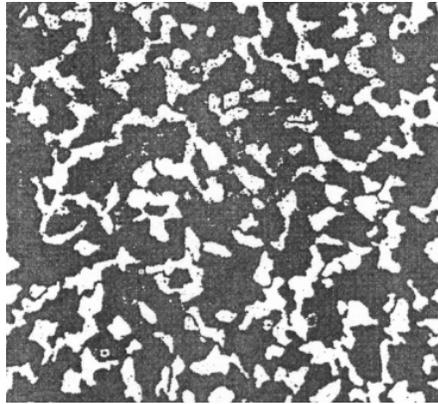


Fig. 13. Ferrite-pearlite structure according to the scale number 5

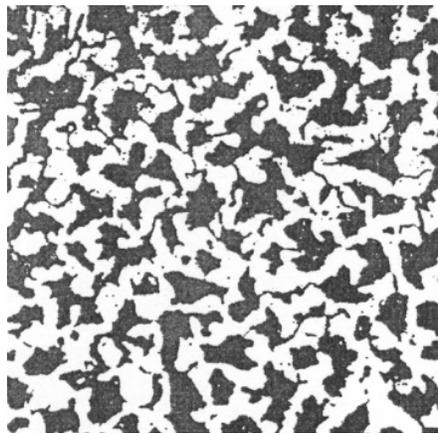


Fig. 14. Ferrite-pearlite structure according to the scale number 6

Conclusions

The offered tool of creating automatic qualifiers implemented in SPECTR MET application allows to develop in many cases quite effective systems for recognition operating according to the current standards. Advantage of the approach is an opportunity to use all accessible functions of the SPECTR-MET application for analyzing of metallographic images. The basic difficulty related to successful selection of dividing attributes is partially facilitated due to the table of attributes built in the application.

References

- [1] M.V. Filinov, A.S. Fursov, V.N. Filinov, Portable computer metallographic microscope for monitoring metal structures under operating conditions // Monitoring. Diagnostics, 2003, N 3 (57). Pages 17-23.
- [2] U. Pratt Digital processing of images. V. 1,2. - M.: Mir, 1982.
- [3] Methods of computer processing for images / Edited by V.A. Soyfer - M.: Fizmatlit, 2004.
- [4] Ivanitskiy G.R., Litinskaja L.L., Shikhmatova V.L., Automatic analysis of microscopic objects, M, L: Energiya Publishing House, 1967.
- [5] Bongard M.M., Recognition problems. - M.: Nauka, 1967.
- [6] Filinov M.V., Fursov A.S., Optical structure examination: modeling and analysis problems // Monitoring. Diagnostics, 2003, N 7 (61). Pages 8-17.

- [7] Filinov M.V., Fursov A.S., Improvement of measurement accuracy for computer optical structure examination // Monitoring. Diagnostics, 2003, N 10. Pages 19-24.