Technology for Acquiring Knowledge of the Syntax of Metallographic Images

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The main sources of information on the structure of metals and alloys (and, therefore, on their macroscopic properties) in modern metallurgical industry are metallographic images. In this work, the problem of analyzing images of the phase structure of deformable cast aluminum alloys is considered [2]. The problem of analyzing metallographic images includes a number of subproblems [5]; the least formalized one is the subproblem of obtaining significant image segmentation.

The semantics of images of the phase structure of a defect-free cast aluminum alloy is described by a tree of depth 5. The nodes at different levels, starting with the root level, represent, respectively, the subject field under consideration as a whole, the particular alloy, the method of imaging, phases and structural components, and features characterizing the shape and arrangement of the phases and structural components on a thin section surface. This structure is a fragment of the model of the metallography of ingots and semifinished aluminum alloys that was developed in [3].

The special features of the subject field under consideration make it possible to explicitly list all possible forms of semantically significant regions (phases and structural components) that may be present in an image of a particular alloy and the imaging method. In addition, fixing a node at the third hierarchical level of the semantic description tree specifies the set of all images with essentially similar syntaxes. This gives rise to the problem of synthesizing a syntax model that is invariant with respect to the range of features of an image subclass and makes it possible to partially or completely automatize metallographic analysis. In practice, this problem arises in, e.g., routine control of articles manufactured by established technological procedures.

The syntax of the images of the phase structure of deformable cast aluminum alloys [4] has the following special features: (i) the syntax of the images under consideration complies very closely with the conceptual model of images with a matrix structure; and (ii) these images are nontextured. For textured images, the organization of the icon-level analysis is very time-consuming, whereas the "center of mass" in the problem of analyzing the images under consideration shifts toward constructing and comparing structural (relational) and feature-based (geometric) models of segments.

Prior to system training, the initial image is low-level segmented; as a result, an attention zone is determined. An attention zone is a multiple-connected region on the image in which each component contains one or several segments with a semantic mark. The method described below is based on the assumption that each attention zone contains exactly one segment.

To describe the syntax S_i of the segments, we apply a combination of the feature-based and structural approaches. Within the framework of the structural approach, the syntax is described as

$$S_i = \langle \{W_j\}, \{b_k^1\} \cup \{b_k^2\} \rangle, \qquad (1)$$

where W_j are brightness blobs (primitives) and $b_k^1(b_k^2)$ are unary (binary) relations specified on the blobs. Within the framework of the feature-based approach, the syntax of a segment is described by the set

$$\{a_j^1(S_i)\} \qquad (2)$$

of unary relations.

The unary relations b_k^1 and a_j^1 are constraints on the values of the geometric characteristics of the structure that describe size, topology, edge shape, compactness, convexity, and the presence of "lobes." The binary relations b_k^2 describe nonstrict inclusion and region adjacency.

The method is first of all intended for determining decision intervals according to features and synthesizing a classification algorithm for assigning marks S^i to a maximum number of image regions. Six features with a metric scale of values (geometric characteristics of segments) and three features with a range of values based on a partial order are used. The second group is formed by features that describe the structure of the brightness blobs in a segment, the structure of the segment without taking into account blob shapes, and the structure of the segment taking into account the blob shapes.

The need to synthesize a new method arises from the nature of the feature system selected. Thus, the method suggested in [1] and similar methods make decisions based on information about the variation of

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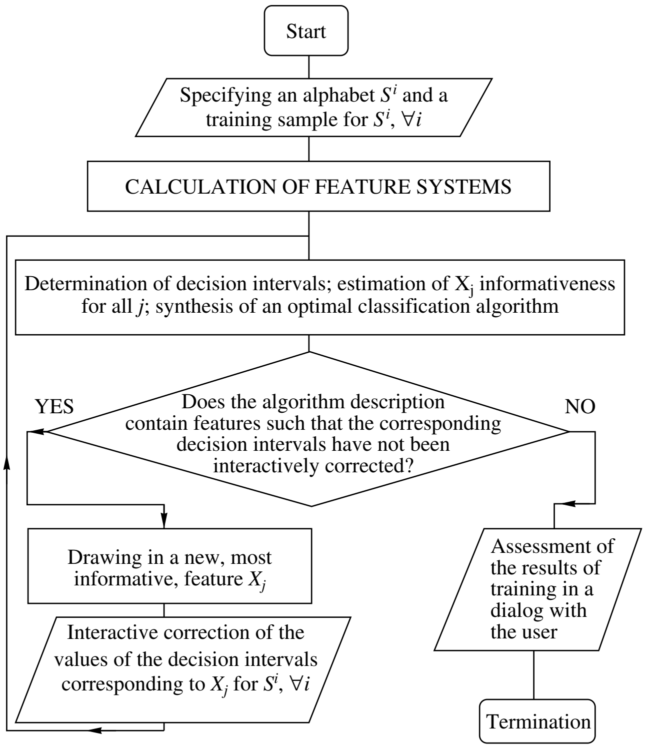

Block diagram of the interactive method.

the properties of classes over features. The source of information is samples of classes supplied by the end user. In applying this approach to the subject field being analyzed, we need to define several hundred regions, which is hardly acceptable in a user-oriented system. The method described in this work uses the fact that all features mentioned above can be interpreted by the end user. Therefore, it is possible to draw the end user into testing and correction the decisions that are made by the system on the basis of incomplete data about the features.

The scheme of the method is as follows (see figure).

(1) At the first stage, the user specifies the name of a new subclass of images. The name must include the alloy type and can contain additional information specifying the structural aspect to be examined and the imaging procedure.

(2) The user specifies N names of the objects S^i (phases and structural components) present on the image and puts each of them in correspondence with a set of structural characteristics.

(3) For each object S^i, $i = \overline{1, N}$, the user specifies a training sample by selecting several regions identified at the stage of low-level image segmentation with the help of a graphical marker.

(4) A feature space is calculated.

(5) Based on the available information, the system makes a guess about the arrangement of decision intervals corresponding to separate S^i and fills the table characterizing the probabilities that the classification according to the features X_j is complete or incomplete.

(6) The system synthesizes an optimal classification algorithm. The probability of classification incompleteness is estimated.

(7) The most informative feature X_k is selected from among those features that are used in the algorithm and the arrangement of whose decision intervals has not been refined during a dialog with the user.

(8) If such a feature is absent, then the following is performed.

(8.1) If the probability of incompleteness of the classification obtained by the selected algorithm is nonzero, then the system displays a warning. On receiving the warning, the user can

(a) classify the results of training as unsatisfactory and repeat the training with new experimental material in a new dialog session;

(b) accept the results as satisfactory but realize the necessity of more active participation in segmentation: the user should manually (with the use of interactive facilities) mark the regions on the image that have not been recognized by the system.

(8.2) EXIT

(9) For the X_k feature the arrangement of decision intervals is refined in a dialog. The user has the following tools for decision making:

(a) graphic dialog facilities for augmenting the set of training samples;

(b) a graphic tool for moving the boundaries of the decision intervals;

(c) alphanumeric dialog facilities for directly specifying the boundaries of a decision interval.

(10) GO TO 5.

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