Extraction of convex hulls of metal microstructure objects from metallographic images

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***Abstract*—A comparative analysis of the effectiveness of algorithms for convex hull identification of perlite spots on binary metallographic images is carried out. The adequacy and computational complexity of the Graham, Jarvis algorithms and the "fast convex hull" algorithm on images of micro-grinds of metal pipelines with various lifespan are investigated.**

***Keywords*— metallographic image, convex hull, algorithm, perlite spot, microstructural characteristics, steel.**

1. Introduction

One of the most important problem in the production and operation of low-carbon steel products is the control of compliance of these products with the required characteristics (mechanical properties, residual life, the possibility of usage in certain conditions, etc.), which is primarily provided by the characteristics of the steel itself [1]. One of the effective approaches to estimate the steel microstructural characteristics is a technique based on the analysis of metallographic images of material microplate [2, 3]. In turn, an important component of this technique is the construction of convex hulls (CH) of detected perlite grains, according to the parameters of which the microstructural characteristics of perlite steels, which are the main products of ferrous metallurgy, are determined. The effectiveness of identification of objects (for the considered problem – perlite spots) on binary images is considered, for example, in the paper [4].

When constructing CH, only the points lying on the boundary of the object whose hull is being detected are used to increase the algorithm performance. Many convex hull identification algorithms are known, in particular, the algorithms of Chan, Kirkpatrick, Melkman [5], but in practice, the algorithms based on the procedures of Graham [6], Jarvis [7] and the so-called "fast convex hull" algorithm (FCH) [8] have received the greatest prevalence. The paper investigates their comparative effectiveness in the construction of CH of perlite grains (also called perlite spots) from binary metallographic images of steel micro-grinds.

2. A Brief Description of the Algorithms

A. The Graham algorithm

The main algorithm operators are:

1°. Determining the point $c_{\min}$ on the object with the minimum coordinate on the ordinate axis (if there are several, then the one with the smallest value on the abscissa axis is selected).

2°. Ranking of points from the object boundaries in ascending order of the polar angle counterclockwise relative to the point $c_{\min}$ (if the polar angles for several points coincide, the furthest from $c_{\min}$ is selected).

3°. Graham bypass, which is based on the concepts of «left» and «right» corners. As a result, the points that match with vertices of CH are highlighted. At the same time, vertices that have not passed the «right» corner test are not vertices of CH.

4°. Connecting the found vertices with a hull.

Б. The Jarvis algorithm

The Jarvis algorithm, also known as the «gift wrapping» algorithm, is slightly simpler than the Graham algorithm and consists of the following basic operators:

1°. Determining the minimum point of the object (as in the Graham algorithm).

2°. Jarvis bypass, highlighting the points of the convex hull.

3°. Connecting the found points with a hull.

В. The "fast convex hull" algorithm

The "fast convex hull" algorithm consists of the following main steps:

1°. The choice of two extreme points of the spot having the largest and smallest values along the abscissa axis: the left c_l and right c_r, which are the vertices of the CH (if there are several points with the same values, any of them is selected).

2°. Constructing a straight line passing through the points c_l and c_r, and dividing the set of all points into two subsets: located above and below the line $c_l c_r$, respectively.

3°. Consideration of a subset of points located above the straight line $c_l c_r$. Selection of the point c_1^{ch} that is the furthest from the straight line (if there are several, then the one with the largest angle $\angle c_1^{\text{ch}} c_l c_r$ is selected). Such a point is recognized as a vertex of CH.

4°. Construction of vectors $\overrightarrow{c_l c_1^{\text{ch}}}$ and $\overrightarrow{c_r c_1^{\text{ch}}}$ and exclusion from further consideration of points located to the right of them (internal points of the triangle $c_1^{\text{ch}} c_l c_r$).

5°. Consideration of a subset of points located to the left of the line $c_l c_1^{\text{ch}}$, for which there is a point c_2^{ch} furthest from the line $c_l c_1^{\text{ch}}$ (similar to paragraph 3), which is recognized as a vertex of CH.

6°. For all subsequent formed subsets operations similar to paragraphs 4 and 5 are performed until there is not a single non-empty subset left.

7°. Similarly to operators 3-6, a subset of points located below the straight line $c_l c_r$ is considered.

3. Computational Complexity of Algorithms

The computational complexity of Graham algorithm does not depend on the number of detected vertices and is proportional to L_P:

$$W = L_\text{P} \log(L_\text{P}),$$

where L_P is the number of external points of the object perimeter.

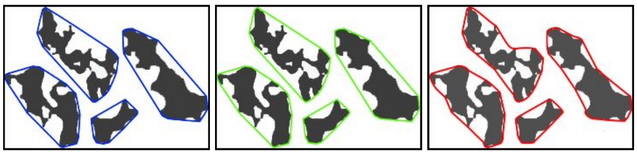
The computer operating capacity for the Jarvis algorithm, unlike the Graham algorithm, depends on the number of the polygon vertices (on the shape of the perlite grain) and is proportional to $L_\text{P} L_\text{CH}$, where L_CH is the number of common points of the grain and its convex hull, which in the worst case is equal to $(L_\text{P})^2$.

The computational complexity of the "fast convex hull" algorithm is determined by the complexity of constructing all subsets. In the best case, the problem is divided into two equally powerful sub-problems, then the complexity of the algorithm is from $2L_\text{P}$ to $(L_\text{P})^2$. The advantage of the "fast convex hull" algorithm is also the possibility of parallel calculations for all subsets of points.

4. Research Results

The algorithms of Graham, Jarvis and FCH algorithm for CH identification were investigated on metallographic images of pearlite spots and binary images of simple shapes (from the collection of test binary images, from the Internet portal [9]). On test binary images of simple shapes, all algorithms showed adequate results, differing mainly in speed. On binary images of real objects – pearlite spots, obtained from images of microstructures of metal pipelines with different lifespan, the Jarvis algorithm and the FCH algorithm adequately detected perlite spots. An example of the results is shown in Fig. 1a and Fig. 1b respectively. At the same time, errors of CH identification are characterized for the Graham algorithm. It is explained by the complex, sometimes chaotic structure of pearlite spots. A typical example of such an erroneous identification is shown in Fig. 1c. As for computational costs, the average operating time of the Graham algorithm is about 1.1 times less than that of the FCH algorithm. In turn, the Jarvis algorithm loses to the FCH algorithm by about 1.9 times in terms of speed. Thus, it is advisable to use the FCH algorithm to solve the problem.

After the convex hulls are detected, the geometric characteristics associated with them are calculated: the perlite spot area, the CH area, the length of the spot perimeter, the length of the CH perimeter, and others, which are then used to evaluate the microstructural parameters of perlite-grade steels.



(a) (b) (c)

Fig. 1. An example of identification of convex hulls of pearlitic spots

5. Conclusion

When finding the microstructural characteristics of perlite-grade steels from metallographic images of micro-grinds, the initial information are the parameters of the CH perlite grains, which determine the important role of the quality of CH detection. A comparative study of the most used algorithms of Graham, Jarvis and the FCH algorithm on micro-grinds of steels with various lifespan has shown that for this problem CH are detected most adequately by the Jarvis and FCH algorithms. The Graham algorithm requires the least computational costs, however, with a complex configuration of spots, it makes errors in CH identification. The Jarvis algorithm is about 1.7 times inferior to the FCH algorithm, which makes the latter preferable when solving the problem of detecting perlite grains from metallographic images of perlite-grade steels.

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