Extraction of Convex Hulls of Metal Microstructure Objects from Metallographic Images

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Introduction

The key problem in the production and operation of low-carbon steel products is to control the compliance of these products with the required characteristics (mechanical properties, residual life, the possibility of use in certain conditions, etc.). One of the effective approaches to estimating the microstructural characteristics of steels is the method of analyzing metallographic images of the microplate of the material (which was presented at previous conferences). In the works of domestic and foreign researchers (Kabaldin, Kokorin, Pekin, Kurganova), it is shown that the long-term operation of pipelines leads to changes in the microstructure of the pipeline, including at the nanoscale, which leads to regular changes in their mechanical characteristics.

Earlier, the authors showed that, based on the analysis of the microplate of pipe steels, it is possible to obtain estimates of such parameters as the grain size of the perlite component of the metal and the overall ratio of ferrite to perlite. The shape of perlite grains is very diverse, which makes it difficult to find their parameters. One of the approaches to solving this problem is the use of convex hulls (CH) of grains. The research of this article is aimed at a comparative analysis and choice of algorithms most suitable for the separation of CH of steel particles in time and determining the parameters of their orientation.

Selection of perlite grain contours

To find the parameters of steel, it is necessary to determine the geometric dimensions of the perlite grains, their directional angle, as well as the general directional vector. To solve this problem, based on the results of the pearlite particle segmentation procedure, for each grain of perlite, it is necessary to construct its contour, along which to find CH of segmented grains.

To highlight grain contours, sequential tracking algorithms, scanning algorithms, and algorithms based on the use of morphological properties of images can be used. For the analysis of perlite particles, sequential tracking algorithms have become the most acceptable, from the point of view of the extraction result (but not from the point of view of speed), since they do not isolate the internal contours of perlite particles. In addition, algorithms of this class make it possible to identify individual "ferritic inclusions" that must be taken into account when analyzing the degree of granularity of pearlite particles.

Construction of perlite grain convex shells

When constructing a CH, only points lying on the boundary of the object whose shell is being built are used to increase the performance of algorithms. There are many algorithms for the allocation of CH, in particular, the algorithms of Chan, Kirkpatrick, Melkman, but in practice, the most common algorithms are those based on the procedures of Graham, Jarvis and the so-called "fast convex hull" (FCH) algorithm. Their comparative efficiency in the construction of perlite grains based on binary metallographic images of micro-grinding steels is considered.

The Graham algorithm

The main algorithm operators are:

1°. Determining the point $c_{\min}$ on the object with the minimum value of y-axis coordinate (if there are several of them, it is necessary to choose the one with the smallest value on the x-axis).

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.

An example illustrating the principle of Graham algorithm is shown in Fig. 1, where c_i is the potential point; c_t is the current point being tested for the "right" (positive) angle; $c_{t\text{-}1}$ is the point consisting of a stack in front of the point being tested; c_{qh_i} is the *i*-the point of CH of the studied object. As can be seen from the figure, the vertice (c_4, c_6, c_7) that have not passed the test for the "right" corner, i.e. "negative angles", are not the vertices of CH.

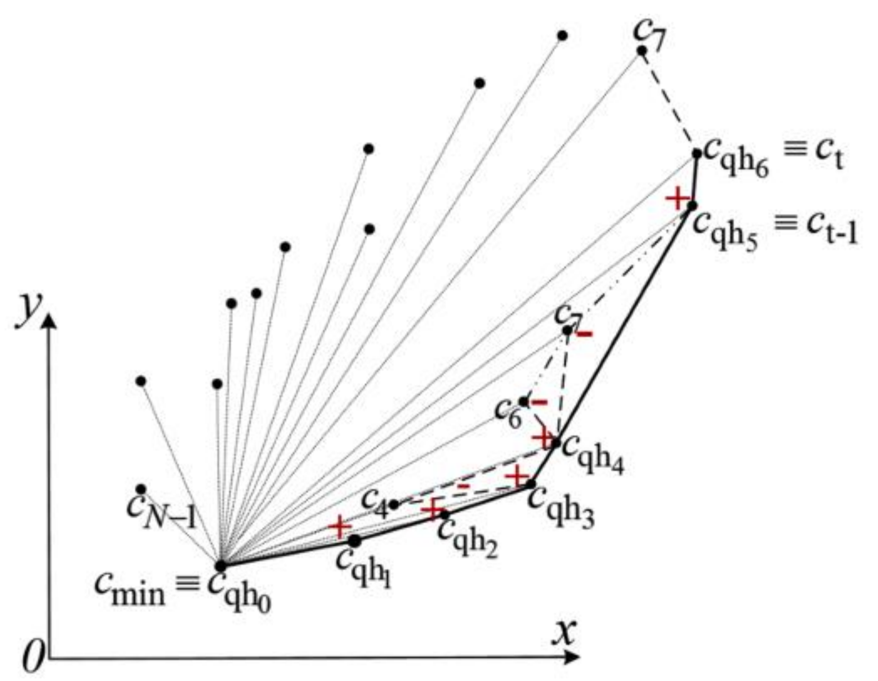


Fig. 1. An example explaining the operation of the Graham algorithm

The Jarvis algorithm

This algorithm is simpler than previous algorithm. In another way it is also called the "gift wrapping" algorithm. It includes of the following steps:

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

2°. Jarvis bypass, highlighting the points of the CH.

3°. Connecting the found points with a hull.

The Jarvis algorithm is presented in Fig. 2. Here c_i are the boundary points of the spot under study; c_t is the current point; the next point c_{t+1} is determined so that the angle between the vectors ($c_{t\text{-}1}, c_t$) and (c_t , c_{t+1}) is minimal.

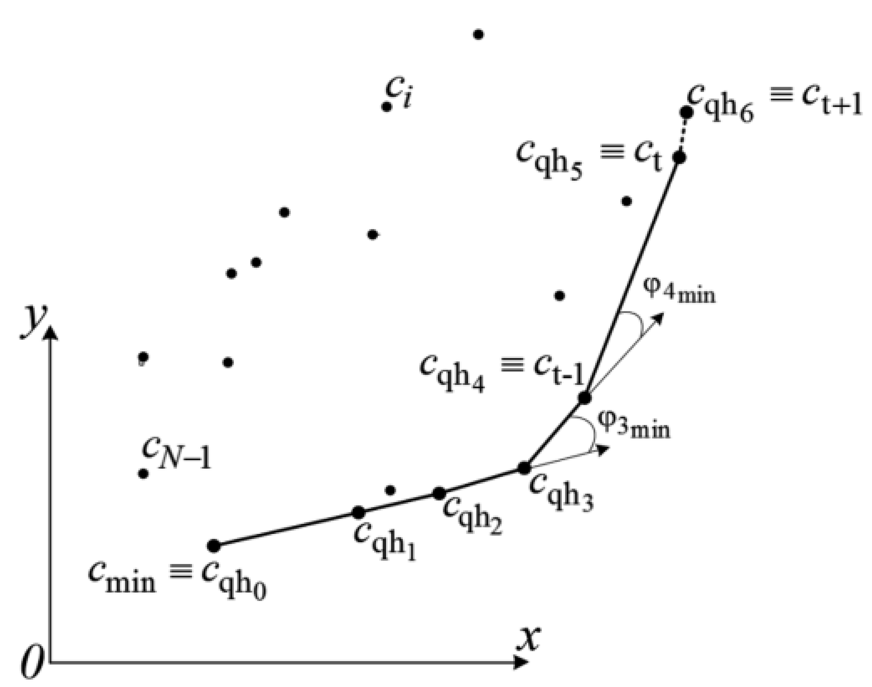


Fig. 2. An example explaining the Jarvis operation

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_{left} and right c_{right}, 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_{left} and c_{right}, and dividing the set of all points into two subsets: located above and below the line $c_{\text{left}}c_{\text{right}}$, respectively.

3°. Consideration of a subset of points located above the straight line $c_{\text{left}}c_{\text{right}}$. Selection of the point c_{qh_1} that is the furthest from the straight line (if there are several, then the one with the largest angle is selected). Such a point is recognized as a vertex of CH.

4°. Construction of vectors $c_{qh_1}c_{\text{left}}$ and $c_{\text{right}}c_{qh_1}$, as well as exclusion from further consideration of points located to the right of Them (internal points of the triangle $c_{qh_1}c_{\text{left}}c_{\text{right}}$).

5°. Consideration of a subset of points located to the left of the straight line (similar to paragraph 3).

6°. For all subsequent subsets formed, operations similar to steps 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 $c_{\text{left}}c_{\text{right}}$ is considered.

An example demonstrating the operation of the FCH algorithm is shown in Fig. 3.

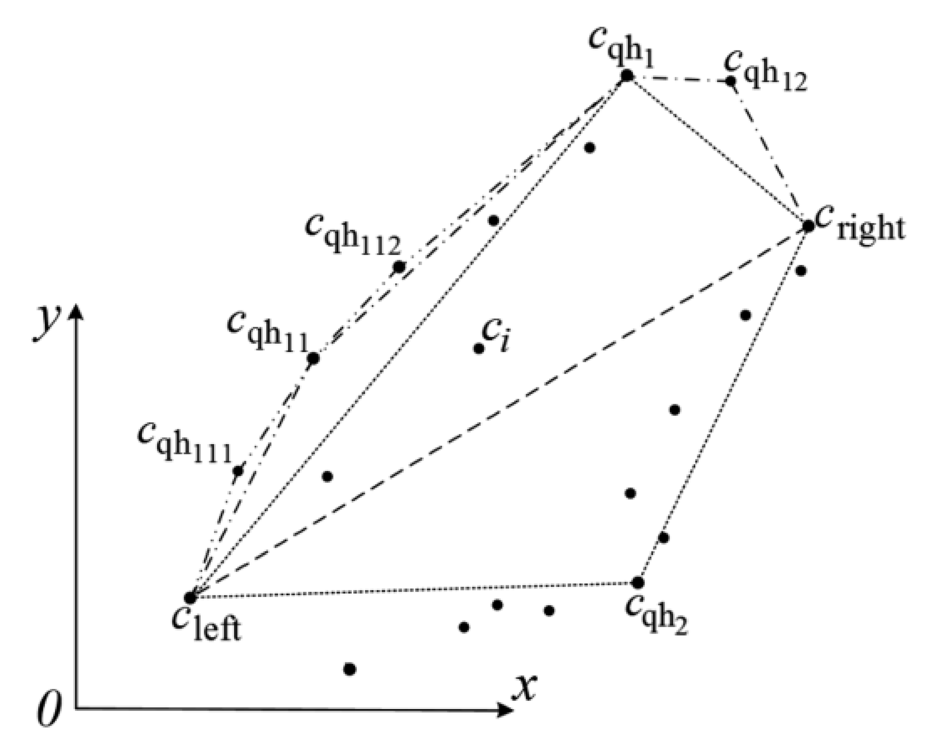
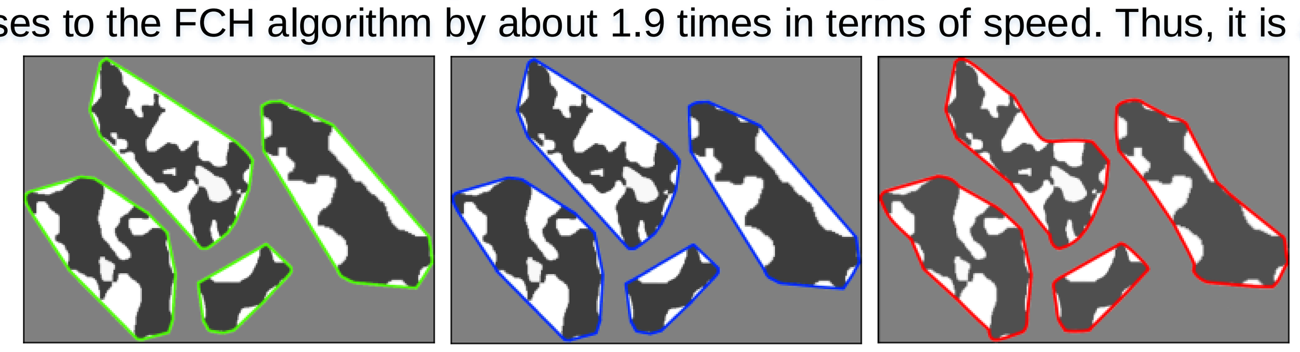


Fig. 3. An example explaining the operation of the FCH

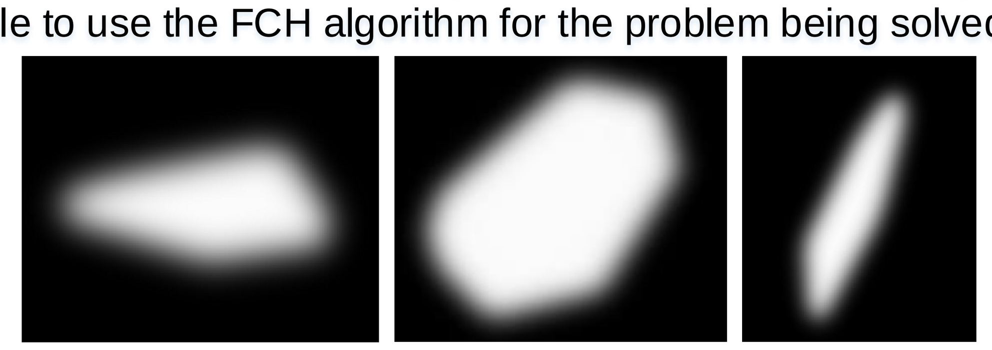
Examples of determining convex hulls

The algorithms of Graham, Jarvis and FCH algorithm for finding CH were investigated on metallographic images of pearlite spots and binary images of simple shapes (from a collection of test binary images). 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 of different service life, Jarvis algorithm and FCH algorithm were adequately isolated from perlite spots. An example of the results is shown in Fig. 4a and fig. 4b, respectively. At the same time, Graham's algorithm was characterized by CH allocation errors, which is explained by the complex, sometimes chaotic structure of pearlite spots. A typical example of such erroneous allocation is shown in Fig. 4c. As for computational costs, the average operating time of the Graham algorithm was 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 for the problem being solved.



(a) (b) (c)

Fig. 4. An example of identification of pearlitic spot convex hulls.



(a) (b) (c)

Fig. 5. An example of Gaussian filtering of convex shapes.

Convex hulls usage

After the selection of CH and the construction of convex shapes on their basis, the geometric characteristics of pearlite grains are found, which are used in assessing the microstructural parameters of pearlite-class steels. These are the area of the perlite spot, the area of the convex figure, the length of the perimeter of the spot, the length of the perimeter of the CH and a number of others. For automated detection of pearlite spots and determination of their geometric parameters, the method of adaptive stochastic gradient identification of objects on binary images is used, based on the use of an object reference with various deformation parameters in a given range. Strain values are used as initial approximations of parameter estimates during identification. The peculiarity of the method is that the template parameters are adaptive and adapt to the parameters of the CH. The scale factor, ellipticity coefficient, parallel shift, angle of deviation of the longitudinal axis of the grain from the axis of the template are used as deformation parameters. The conducted studies have shown that using an ellipse is sufficient as a template for finding the parameters of pearlite grains. At the same time, finding microstructural characteristics for a large number of perlite grains gives the desired level of accuracy. To increase the operating range of the stochastic gradient identification method, adaptive templates and the resulting convex shapes are pre-subjected to low-frequency Gaussian filtering with a filter mask of 15% of the linear size of the object. Examples of filtered convex shapes are shown in Fig. 5.

Conclusion

When finding the microstructural characteristics of perlite-grade steels from metallographic images of micro-grinds, the initial information is the parameters of the HE grains of perlite, which determines the important role of the quality of CH separation. A comparative study of the most used algorithms for the allocation of CH: Graham, Jarvis and the FCH algorithm on micro-grinds of steels of different service life has shown that for this task, the most adequate CH is allocated by Jarvis and FCH algorithms. Graham's algorithm requires the least computational costs, however, with a complex configuration of spots, it makes errors in the allocation of time. In terms of speed, the Jarvis algorithm is about 1.7 times inferior to the FCH algorithm, which makes the latter preferable when solving the problem of separating perlite grains from metallographic images of perlite-grade steels.

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