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A geometric-based method for recognizing overlapping polygonal-shaped and semi-transparent particles in gray tone images

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A B S T R A C T

A geometric-based method is proposed to recognize the overlapping particles of different polygonal shapes such as rectangular, regular and/or irregular prismatic particles in a gray tone image. The first step consists in extracting the salient corners, identified by their locations and orientations, of the overlapping particles. Although there are certain difficulties like the perspective geometric projection, out of focus, transparency and superposition of the studied particles. Then, a new clustering technique is applied to detect the shape by grouping its correspondent salient corners according to the geometric properties of each shape. A simulation process is carried out for evaluating the performance of the proposed method. Then, it is particularly applied on a real application of batch cooling crystallization of the ammonium oxalate in pure water. The experimental results show that the method is efficient to recognize the overlapping particles of different shapes and sizes.

1. Introduction

The detection of overlapping particles of polygonal shapes has attracted the attention of many researchers in various applications in chemical engineering, biology, computer vision, pattern recognition and many others. Its importance comes from the need to get accurate particle's characterization, measurement or localization. Thus, several approaches have been developed to detect overlapping particles in 2D gray tone images. Some of them are based on line detection algorithms (Jang and Hong, 2002; Illingworth and Kittler, 1988; Burns et al., 1986; Liu et al., 2007, etc.) which extract line segments from an edge image. Then, these line segments are used as essential features for the proposed clustering system such as Larsen et al. (2006, 2007) and Liu et al. (2007). However, the accuracy of detecting lines and grouping segments highly decreases in the case of agglomeration or overlap, and with the out of focus problem. Besides the line segment detection, Yu and Bajaj (2004) proposed a method based on shape matching between the object boundaries and a template of the desired shape. The method is developed to detect objects of pre-determined shape and sizes. Thus, it is not sufficient to extract overlapping objects of varied size and different shapes. A neural-network-based method has been developed by Su and Hung (2007) to detect rectangular overlapping objects using edges as data inputs to the neural network. It shows efficiency in detecting different cases of overlapping rectangles, but it is sensitive to the initialization process of the neural network and to the number of the data points brought from the edges, and it is also limited to detect rectangles with perspective distortion. Wan et al. (2008) have presented a method to detect the L-glutamic acid particles in gray tone images with high overlapping particles, which is based on analyzing the convexity of the particle's boundaries obtained from a multi-scale segmentation (Anda et al., 2005). Then, the concave points are defined as markers for the marker-controlled watershed algorithm (Beucher, 1991), which identifies each marked particle as an individual one. Its results illustrate high efficiency to separate the attached particles of different sizes. However the concave points are not sufficient as markers to give an accurate detection of the particles for such difficult cases of overlap that are presented in the current study.

The goal of the present paper is to introduce a novel geometric method based on image analysis for recognizing overlapping particles of different polygonal shapes and sizes, even in high overlap cases. The problem becomes more critical if the real particles have different sizes and orientations in 3D space. So, the projection onto an image plane will change the geometric properties of the shape, and the perspective geometric projection will lead to a large variety of 2D anisotropic shapes. Several specific characteristics of the studied particles such as the heterogeneity, transparency and anisotropy strongly affect the recognition problem. In Fig. 1, these difficulties are clearly illustrated in a real example of ammonium oxalate crystals image which is obtained during batch cooling crystallization process in pure water.

The proposed geometric-based method first detects the salient corners from overlapping particles, of rectangular and regular/irregular prismatic shapes, using both gray tone and edge analysis. Thereafter, the correspondent salient corners that belong to the

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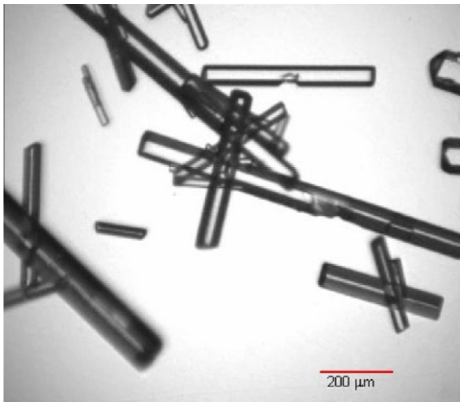

Fig. 1. A gray tone image of ammonium oxalate crystals in pure water (size 640×480 pixels), showing illumination heterogeneity, perspective geometric projection, out of focus imaging, transparency and overlapping of particles.

same particle are clustered according to the geometric properties of the particle's shape.

The present paper is organized as follows. The detection of salient corners is introduced in Section 2. The clustering technique of the correspondent salient corners is presented in Section 3. In Section 4. the results are illustrated on both artificial and real overlapping particles, and a quantitative comparison with the manual detection is also presented. Finally, a conclusion and some perspectives are discussed in Section 5.

2. Detection of the salient corners

Before detecting the salient corners of the particles, a pre-processing step is needed to remove the heterogeneity of the background illumination as seen in Fig. 1, and to increase the contrast between the particle's corners and the background. The background image is acquired at the beginning of the video acquisition before the particles formation, and then it is subtracted from the studied image of particles (see Fig. 3(c)). From now, the initial image I which will be mentioned in the following of this paper is the gray tone image after the background removing.

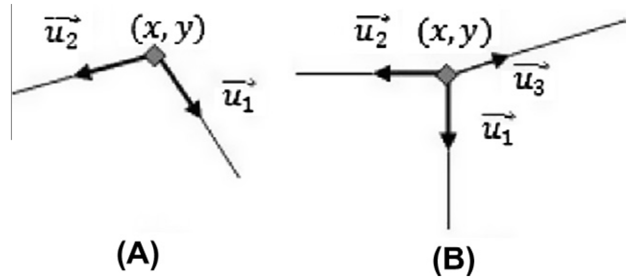

Fig. 2. A salient corner (vertex) is illustrated in (A), and a non-salient corner (junction) is illustrated in (B).

2.1. Definition of a salient corner

Let D be the image spatial support defined by a set of pixels $\{P = (x,y) \in D\}$. Let $\{\overrightarrow{u_i}\}_{i \geqslant 1}$ be a set of normalized vectors that define the orientations of all possible intersected edges (lines) at each pixel P in D, such that $\forall P_i \in D$, $\overrightarrow{u_i} = \frac{\overrightarrow{PP_i}}{\left\|\overrightarrow{PP_i}\right\|_2}$ where the vector $\overrightarrow{PP_i}$ is related with the existence of an edge between P and P_i. Then, the pixel P defines a salient corner, denoted C_s, if and only if exists two intersected lines of directions $\overrightarrow{u_1}, \overrightarrow{u_2}$ at P such that:

$$C_s = \{(x, y, \overrightarrow{u_1}, \overrightarrow{u_2}) : (x, y) \in D,\ \|\overrightarrow{u_1}\|^2 = 1, \|\overrightarrow{u_2}\|^2 = 1\} \tag{1}$$

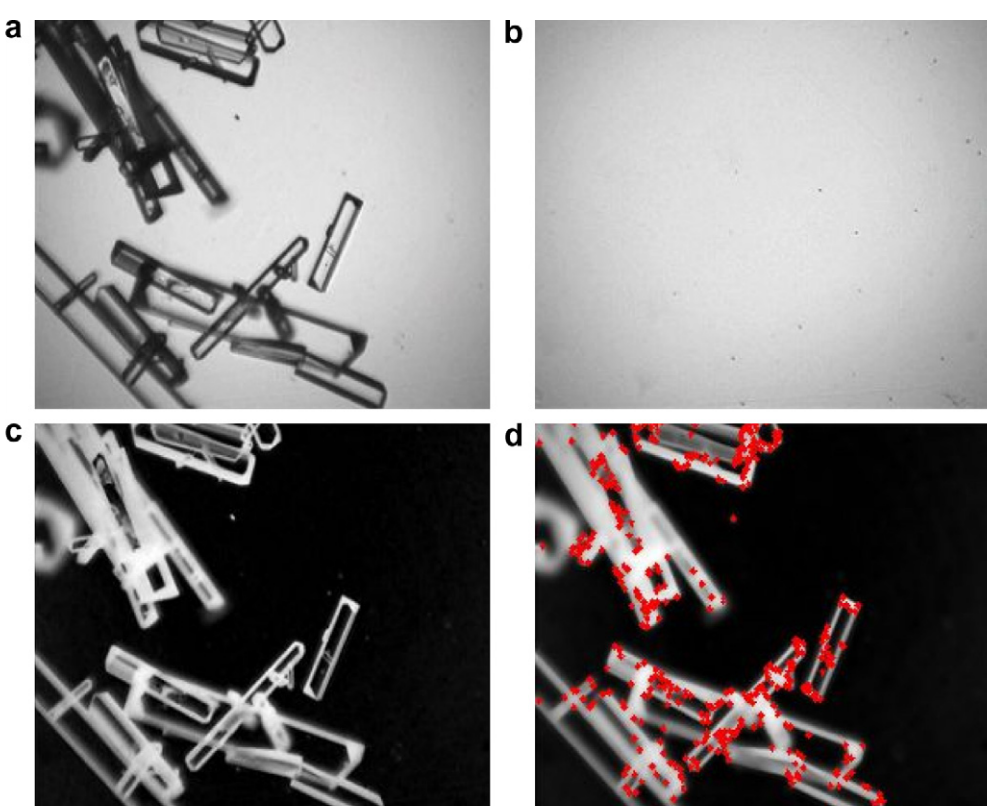

Fig. 3. Example of the detection of candidate corners applied on an image of ammonium oxalate crystals. (a) Original image. (b) Background image. (c) Removing background from (a). (d) Image with candidate corners in overlay.