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Flotation bubble image segmentation based on seed region boundary growing

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ABSTRACT

Segmenting blurred and conglutinated bubbles in a flotation image is done using a new segmentation method based on Seed Region and Boundary Growing (SRBG). Bright pixels located on bubble tops were extracted as the seed regions. Seed boundaries are divided into four curves: left-top, right-top, right-bottom, and left-bottom. Bubbles are segmented from the seed boundary by moving these curves to the bubble boundaries along the corresponding directions. The SRBG method can remove noisy areas and it avoids over- and under-segmentation problems. Each bubble is segmented separately rather than segmenting the entire flotation image. The segmentation results from the SRBG method are more accurate than those from the Watershed algorithm.

1. Introduction

A method of correctly segmenting bubble images is important to the flotation industry. Image segmentation helps obtain the size, and size distribution, of bubbles formed during the flotation of non-ferrous and ferrous metals. This can improve automation of flotation. An image of the flotation surface is full of moving bubbles and shadows. Some bubbles conglutinate so that bubble boundaries blur and become irregular. Small bubbles attach to big bubbles and create image noise. Bubble segmentation is full of challenges created by these problems.

The edge-based method, the multi-threshold method, and the region-based method are three image segmentation techniques that are currently available [1–4]. Zeng Rong proposed edge detection for segmenting a bubble image but that work was confined to images with distinct bubble boundaries [5]. For a fuzzy mass flotation bubble image edge detection technology fails to properly divide the image sometimes. Watershed has been used to segment flotation images having clear boundaries but it will not distinguish bubbles where there are noisy areas [6,7]. Gu Yingying et al. have proposed a segmentation method used on coal slime [8]. This was a combination of a Watershed transformation and a corroding and swelling method. Only approximate segmentation results were obtained when the bubble borders had a jagged shape or consisted of irregular polygons. Wang Weixing et al., who specializes in bubble segmentation, designed a valley-edge detection segmentation algorithm [9–13]. This required classifying bubble images first and then choosing the segmentation algorithm and tracking the bubble boundaries on the basis of this classification. Hence, this method was confined to images that could be reasonably classified. Blurred bubble boundaries, especially noisy areas, could not be segmented properly.

A new segmentation algorithm is proposed herein that combines seed region growing and is based upon seed boundary growing. The tops of the bubbles have a higher brightness level and are chosen as the seed region. The seed areas are extracted by a gray threshold method and each seed boundary is divided into four consecutive curves in the left-top (LT), right-top (RT), right-bottom (RB), and left-bottom (LB) directions [14,15]. Each curve then grows outward until the bubble boundary conditions are satisfied. The Seed Region and Boundary Growing (SRBG) method segments each bubble separately rather than operating on the whole image. It can remove noisy areas and solve the over- and under-segmentation problems. Segmentation results from the SRBG method are more accurate than those from the Watershed algorithm.

2. Seed region extraction

Bubble tops, and some adjacent areas, in the flotation image take on higher brightness levels while other adjacent areas, and shadow regions, are darker. A region composed of linked pixels with gray values above some threshold is marked as a seed region.

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For each pixel within a seed region, the minimum and maximum x coordinates are named $x_{\min}$ and $x_{\max}$, and the minimum and maximum y coordinates are named $y_{\min}$ and $y_{\max}$. If set V represents a seed region as defined in Eq. (1), where $G(p(x,y))$ is the gray value of any pixel $p(x,y)$, then the set V_0 contains all the boundary pixels of V and is composed of four curves that are LT, RT, RB and LB: $V_0 = \{V_1,V_2,V_3,V_4\}$.

$$V = \{p(x,y) | G(p(x,y)) > H \& x_{\min} \le x \le x_{\max} \& y_{\min} \le y \le y_{\max}\} \quad (1)$$

Definition 1. Set V_1 includes pixels of the LT curve: s_1 is the starting pixel and e_1 is the ending pixel.

$$\begin{aligned} V_1 &= \left\{ p(x,y) \middle| \begin{matrix} x=\underset{x}{\operatorname{argmin}}(p(x,y_{\min}-1)), y=y_{\min}-1 \\ x=x_{\min}, y=\underset{y}{\operatorname{argmin}}(p(x_{\min},y)) \end{matrix} \right\} \\ s_1 &= \{(x,y)|x = x_{\min} \& \max(y)\} \\ e_1 &= \{(x,y)|(y = y_{\min} - 1) \& \max(x)\} \end{aligned} \quad (2)$$

Definition 2. Set V_2 includes pixels of the RT curve: s_2 is the starting pixel and e_2 is the ending pixel.

$$\begin{aligned} V_2 &= \left\{ p(x,y) \middle| \begin{matrix} x=x_{\max}-1, y=\underset{y}{\operatorname{argmax}}(p(x_{\max}-1,y)) \\ x=\underset{x}{\operatorname{argmin}}(p(x,y_{\min})), y=y_{\min} \end{matrix} \right\} \\ s_2 &= \{(x,y)|y = y_{\min} \& \min(x)\} \\ e_2 &= \{(x,y)|(x = x_{\max} - 1) \& \max(y)\} \end{aligned} \quad (3)$$

Definition 3. Set V_3 includes pixels of the RB curve: s_3 is the starting pixel and e_3 is the ending pixel.

$$\begin{aligned} V_3 &= \left\{ p(x,y) \middle| \begin{matrix} x=\underset{x}{\operatorname{argmin}}(p(x,y_{\max}-1)) \\ x=x_{\max}, y=\underset{y}{\operatorname{argmin}}(p(x_{\max},y)) \end{matrix} \right\} \\ s_3 &= \{(x,y)|x = x_{\max} \& \min(y)\} \\ e_3 &= \{(x,y)|(y = y_{\max} - 1) \& \min(x)\} \end{aligned} \quad (4)$$

Definition 4. Set V_4 includes pixels of the LB curve: s_4 is the starting pixel and e_4 is the ending pixel.

$$\begin{aligned} V_4 &= \left\{ p(x,y) \middle| \begin{matrix} x=x_{\min}+1, y=\underset{y}{\operatorname{argmax}}(p(x_{\min}+1,y)) \\ x=\underset{x}{\operatorname{argmin}}(p(x,y_{\max})), y=y_{\max} \end{matrix} \right\} \\ s_4 &= \{(x,y)|y = y_{\max} \& \max(x)\} \\ e_4 &= \{(x,y)|(x = x_{\min} - 1) \& \min(y)\} \end{aligned} \quad (5)$$

3. Growth of boundary region

The LT, RT, RB, and LB curves grow in the upper left, upper right, lower right, and lower left directions respectively as four separate units.

3.1. Growing process

Definition 5. Set V_1^{j-1} and V_1^j contain the pixels of curve LT at the $(j-1)_{\text{th}}$ and j_{th} growth steps. Starting pixel s_1^{j-1} of set V_1^{j-1} grows left and diagonally to the upper left into two pixels. The end pixel e_1^{j-1} of V_1^{j-1} grows up and diagonally to the upper left. A similar situation prevails for the j_{th} step of growing and for the curves RT, LB, and RB.

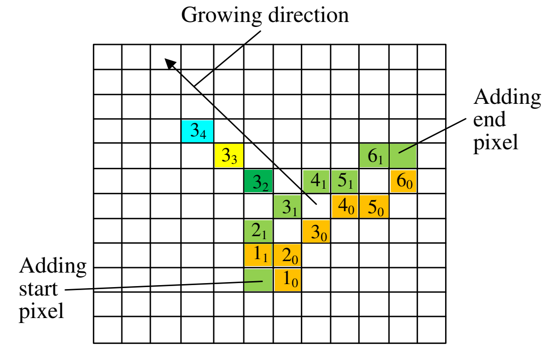

Fig. 1. Boundary growth process.

$$V_1^j = \begin{cases} p(x-1,y-1), p(x,y) \in V_1^{j-1} \\ p(x-1,y), p(x,y) = s_1^{j-1} \\ p(x,y-1), p(x,y) = e_1^{j-1} \end{cases} \quad V_2^j = \begin{cases} p(x+1,y-1), p(x,y) \in V_2^{j-1} \\ p(x,y-1), p(x,y) = s_2^{j-1} \\ p(x+1,y), p(x,y) = e_2^{j-1} \end{cases}$$
$$V_3^j = \begin{cases} p(x+1,y+1), p(x,y) \in V_3^{j-1} \\ p(x+1,y), p(x,y) = s_3^{j-1} \\ p(x,y+1), p(x,y) = e_3^{j-1} \end{cases} \quad V_4^j = \begin{cases} p(x-1,y+1), p(x,y) \in V_4^{j-1} \\ p(x,y+1), p(x,y) = s_4^{j-1} \\ p(x-1,y), p(x,y) = e_4^{j-1} \end{cases} \quad (6)$$

Moving from the $(j-1)_{\text{th}}$ to the j_{th} step the start and end positions of each curve must have new pixels added to maintain continuity of the grown curves. Start pixel s_2^{j-1} of V_2^{j-1} grows toward up and diagonally to the right while end pixel e_2^{j-1} grows right and diagonally to the right and down. Likewise, start pixel s_3^{j-1} of V_3^{j-1} grows right and diagonally to the right and down while end pixel e_3^{j-1} grows right-down and down. And, start pixel s_4^{j-1} of V_4^{j-1} grows down and left-down while end pixel e_4^{j-1} grows left-down and left.

The curve boundary growth is shown in Fig. 1. For example, 3_j is the j_{th} position of the third pixel of curve LT. The symbol 3_3 indicates the third growth position of the pixel.

3.2. Bubble boundary rule set

The gray value of pixel I after the j_{th} step is $G(I\,j)$. The following five rules are the bubble boundary conditions.

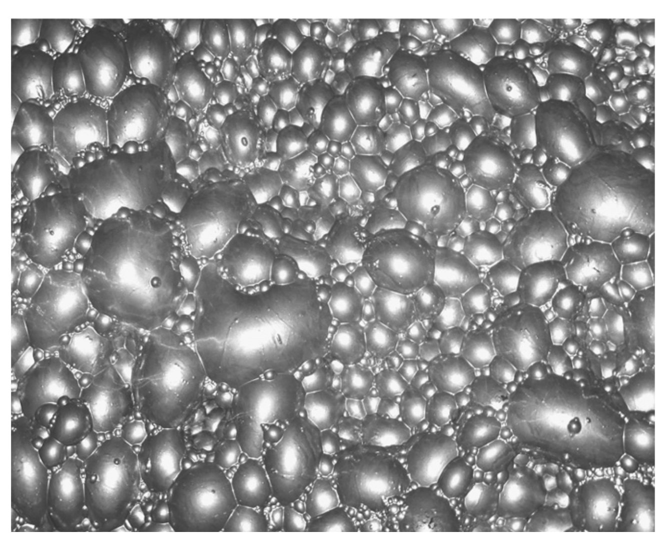

Fig. 2. Original bubble image.