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Features Extraction of Flotation Froth Based on Equivalent Binocular Stereo vision*

Lin Zhao, Tao Peng*, Yongheng Zhao, Peng Xia, Yongfang Xie

School of Information Science and Engineering, Central South University, Changsha, China (e-mail: pandtao@163.com).

Abstract: It is widely known that the froth features are closely related to the flotation performances. However, the conventional froth features extracted by two-dimensional image processing methods lose the depth information, so it is difficult for these features to reflect the actual stereo perception of froth appearance as human eyes. In this work, a features extraction method based on the equivalent binocular stereo vision with a single camera is proposed for the flotation froth images. At first, the differences between two adjacent frames by a single camera, caused by the flowing of froth, are used to emulating the binocular parallax in the imaging process. Then, the depth of each bubble center from a froth image is obtained by calculating the equivalent baseline based on macro-block matching. At last, the froth features with depth information are extracted. Experimental results show that the froth features extracted by proposed method have better stability and separability than the conventional features.

Keywords: Froth stereo feature, Feature extraction, Equivalent binocular stereo vision, Stereo matching, Flotation.

1. INTRODUCTION

It is widely known that the froth features are closely related to the flotation performances, such as mineral concentrations, etc. Accurate froth features extraction is the basis of accurate working conditions recognition of flotation processes (Marais and Aldrich, 2011; Gui et al., 2013; Zhu et al., 2014; Cao et al., 2013; Peng et al, 2016). In recent years, the color, size and other descriptions of froth appearance characteristics are widely used in the working conditions recognition, control and optimization of flotation processes (Bartolacci et al., 2006; Kaartinen et al., 2006; Liu et al., 2005; Zhao et al., 2015). But these features are extracted based on the two-dimensional image processing methods. Because the depth information of the shot objective are lost while the conventional 2D image is generated by the camera projection from 3D scene to 2D, it is difficult for these features to reflect actual stereo perception of froth appearance by the naked eye.

The binocular stereo vision is a primary approach to restore 3D scene of a shot objective (Scharstein D and Szeliski R, 2002). Two images of the shot objective are acquired simultaneously by two cameras in different spots. The parallax of two images is obtained through stereo matching and depth estimating by triangulation. But this approach needs additional hardware. The structure from motion (SFM) based on factorization (Tomashi et al. 1992) is a significant method to restore 3D scene from monocular image sequences. It has been widely used in 3D face modeling and obstacle detection, etc. This method is more suitable for static screen or rigid objects. Bonifazi et al. (2000, 2002) proposed a features extraction method using an image based on 3D reconstruction of bubble surface. This method cannot obtain the actual bubble depth in the world coordination. However, extraction of froth features with depth information in the world coordinates, based on restoring the depths of bubble centers from two 2D images generated by flowing froth, has been few reported yet.

In this paper, a features extraction method based on the equivalent binocular stereo vision with a single camera is proposed for the flotation froth images. This paper is organized as following. Section 2, the depth of each bubble center from a froth image is obtained. Section 3, the froth features with depth information are extracted. Section 4, experimental results are presented.

2. FROTH DEPTH ACQUISITION BASED ON EQUIVALENT BINOCULAR STEREO IMAGING

2.1 Binocular Stereo Vision

The schematic diagram of binocular stereo imaging is illustrated in Fig. 1. Two different images of the photographic subject on the same scene can be collected by the left and right cameras that are separated by a short distance, and are mounted parallel to one another. The depth information of the photographic subject can be derived by the disparity between the left and right images. As shown in Fig. 1(a), (x_l, y_l) is the projection of the world point $P(X_c, Y_c, Z_c)$ in an image acquired by the left camera, (x_r, y_r) is the projection of the same world point

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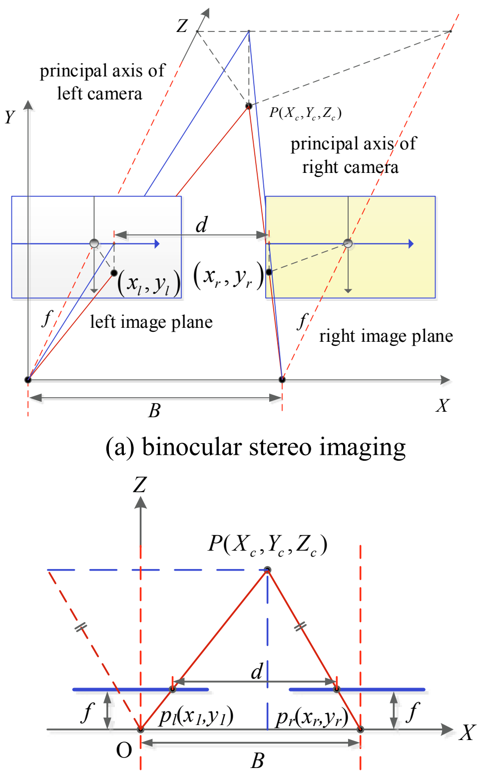
$P(X_c, Y_c, Z_c)$ in an image acquired by the right camera. The disparity between (x_l, y_l) and (x_r, y_r) is denoted by $d = x_l - x_r$.



(a) binocular stereo imaging

(b) simplified binocular stereo imaging

Fig. 1. Schematic diagram of binocular stereo imaging

As shown in Fig. 1(b), using similar triangles the equations are given by

$$\begin{cases} \dfrac{x_l}{X_c} = \dfrac{f}{Z_c} \\ \dfrac{x_l - x_r}{B} = \dfrac{f}{Z_c} \end{cases} \tag{1}$$

where f is focal length, and B is the baseline.

Then the depth of $P(X_c, Y_c, Z_c)$ can be written as

$$Z_c = \frac{Bf}{d} \tag{2}$$

and the corresponding X_c and Y_c are given by

$$\begin{cases} X_c = \dfrac{x_l Z_c}{f} \\ Y_c = \dfrac{y_l Z_c}{f} \end{cases} \tag{3}$$

Thus, the world point $P(X_c, Y_c, Z_c)$ can be obtained from the images points (x_l, y_l) of the left camera and (x_r, y_r) of the right camera.

2.2 Equivalent Binocular Stereo Vision Based on a Single Camera

The froth flow in the flotation processes satisfies the following assumptions:

(1) The flow is incompressible due to the fact that the volume of liquid in the froth is low compared to the gas and hence there is a relatively small pressure change between the top and bottom surface of the froth (Neethling and Cilliers, 1998). Let us denote the velocity by $\vec{u}$, then the condition for incompressible is given by

$$\nabla \bullet \vec{u} = 0 \tag{5}$$

where $\nabla \bullet$ is the divergence operator.

(2) The flow is irrotational, namely that there should be no inertial effects and constant viscosity, and the condition for irrotational is given by

$$\nabla \times \vec{u} = 0 \tag{6}$$

where $\nabla \times$ is the rotation operator.

(3) The shapes and structures of the froth remain fixed during the interval τ between two adjacent frames.

The froth flowing at two consecutive time frames can be regarded as the movement of a rigid body under the above assumptions.

According to the principle of relativity, the camera is fixed and the froth is flowing, in this case the froth is static and the camera is moving in the opposite direction. As the interval τ between adjacent frames is very short, the two adjacent frames shot by a camera at different times can be naturally regarded as two images shot simultaneously by two cameras at different positions, just as shown in Fig. 2. Here u_x is velocity in the x direction, and $B' = u_x \tau$ is equivalent baseline.

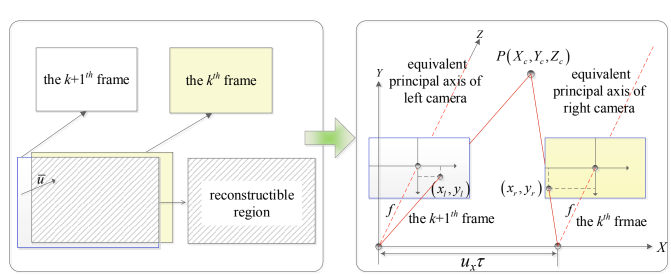


Fig. 2. Schematic diagram of the equivalent binocular stereo imaging

Using the two frames shot by a camera, namely the two images shot simultaneously by two equivalent cameras, the