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Open-Pit Mine Safety Monitoring Based on Binocular Vision

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Abstract: *This paper presents a real-time video monitoring technology based on binocular stereo vision technology, using multiple sets of binocular camera to the image acquisition, analysis, processing for any targets which in the open-pit mine security area. Then we get the physical coordinates of the targets, acting of regional security early warning for staff fixed with the targets, this greatly improved the security of the staff working in the open-pit mine.*

Key words: *open-pit mine, safety monitoring, binocular vision, stereo matching*

1. Introduction

Open-pit mine safety monitoring is much more easily than underground mines in general. As a result, people tend to ignore the open-pit mine safety management [1]. But in recent years, Open-pit mines have happened a large number of casualty accidents in the process of mining blasting, open pit loading and transportation [2]. The two main influencing factors of the open-pit mining security are shown as follow.1).Due to the edge of the surrounding rock stability is bad, or the wind oxidized zone is deep, the edge of shallow slope are prone to cause geological disasters such as collapse and landslide [3].2). The risk of open stope blasting operation is high. These factors seriously threat the safety of the staff working in the open-pit mine [4-5]. The majority of the casualties are caused by workers enter the dangerous area. At present, the main preventive measures are to furnish fully enclosed security fence around the area. But its warning effect is not ideal.

This paper presents a real-time video monitoring technology based on binocular stereo vision technology, using multiple sets of binocular camera to the image acquisition, analysis, processing for any targets which in the open-pit mine security area. Then get the physical coordinates of the targets, acting of regional security early warning for staff with the targets, this greatly improved the security of the staff working in the open-pit mine.

2. Design Proposal

We proposed a real-time video monitoring technology based on binocular stereo vision, to complete the fast matching by red balls fixed on the workers safety helmet. Finally realize the all-round real-time monitoring of the region. Once the workers keep away from here, alarm rang at once. To avoid the targets obscured, multiple sets binocular cameras are placed around the safety area. Details are shown in Figure 1.

The advantage of this method is safety monitoring system can be set up quickly in any area. The safety of staff in the field can be real-time monitoring. Binocular camera has several advantages including operate simply, move easily and keep a small footprint. This unit is suitable for open-pit mine which operational areas and security areas are not fixed.

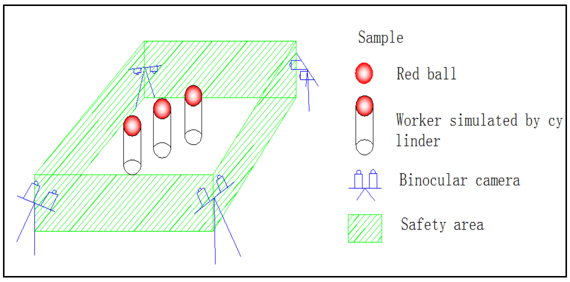

Figure 1. *Design proposal in the open-pit mine*

3. Targets Coordinates Calculation

3.1. Basic Concept of Binocular Vision

Assume that a 3D point is denoted by $M=[X,Y,Z]^T$, the homogeneous coordinate is represented by $\tilde{M}=[X,Y,Z,1]^T$, a 2D point is denoted by $m=[u,v]^T$, ~ as homogeneous coordinate(similarly hereinafter), the relationship between M and m:

$$s\tilde{m} = K[R,t]\tilde{M}\mathrm{K} = \begin{bmatrix} \alpha & \gamma & \mu \\ 0 & \beta & v \\ 0 & 0 & 1 \end{bmatrix} \quad (1)$$

Where s is a scale factor, $P=K[R,t]$ is camera matrix, K as intrinsic matrix, R as rotation matrix, t as translation vector which relates the world coordinate system to the camera coordinate system, α,β are scale factors, $[\mu,v]$as the main point of the camera, γ as inclination factor. Camera calibration is to calculate the camera matrix P. Usually we set the world coordinate system coincides with the left camera coordinate system. We obtain the following equation:

$$\begin{cases} \widetilde{m_1} = s_1 K_1 [I,0] \widetilde{M_1} \\ \widetilde{m_2} = s_2 K_2 [R,t] \widetilde{M_2} \end{cases} \quad (2)$$

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Binocular stereo vision is based on the principle of parallax. By measuring the two camera projection image point coordinate of one point, then the space coordinate of this point can be obtained[6].Details shown in Figure 2. The formula for the parallax of binocular stereo vision:

$$\frac{d-f}{d} = \frac{a}{a+l_b} \tag{3}$$

$$\frac{d-f}{d} = \frac{b-l_a+l_b+a}{b+l_b+a} \tag{4}$$

By submitting Eq.(3)into Eq. (4), we have: $d = f\frac{a+l_b}{l_b} = \frac{bf}{l_a-l_b}$ (5)

Where b as reference line, f as focal length, P as object point, P_l, P_r as stereo image point, d as the depth of field.

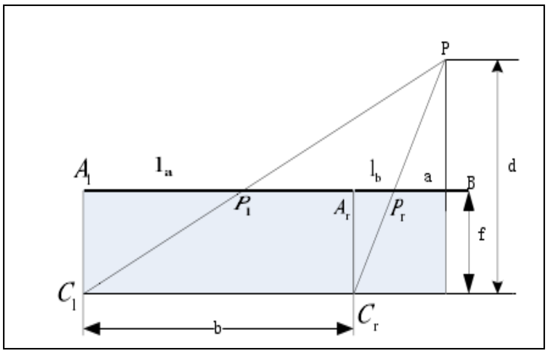


Figure 2. *The parallax theory of binocular camera*

3.2. Stereo Matching

Stereo matching effect directly affects accuracy of deep information of the image. This is confronted with dire challenges for precise localization of workers in the huge and complex open-pit mine. In this paper, the workers safety helmet with a diameter of 7 cm ball red balls. In the process of image recognition obtained by binocular camera, we only need to stereo matching of the markers, and then calculate the markers' coordinates. On this basis, markers' coordinates simulate a cylinder to represent the workers. Finally we can greatly simplify the complex stereo matching problem [7-8].

The detailed steps are as follows:

1) Image Acquisition: In view of the target (red ball) has a clear color contrast, this paper proposed using (R-G) combination operator for color image segmentation [9-10]. First we extract the red channel (R) and the green channel (G) from the color image (RGB), and then do the margin calculation for this two single channel image. The red ball's (R) channel and (G) channel pixel vary greatly compared with the difference in background, so as to achieve image segmentation effect. Finally complete background noise by setting the threshold value. Algorithm shows as follows:

img1=img(:,:,1);
img2=img(:,:,2);
img3=abs(img1-img2);
T=RGayThreshold （img3）
If img3>T then
Optional Objects
Else
Background
End if

Where *img* as original image, *img1* as red channel image(R), *img2* as green channel image(G), *img3* as (R-G) difference image, *T* as threshold value.

2) Edge Detection: Binary image edge detection based on Sobel, Roberts, Prewitt, Laplacian of Gaussian, Canny operators, Canny operator achieves the best effect, but this method need to set the high and low two threshold, that makes results interference by human factors. This paper proposes a adaptive Canny operator, which get the threshold value of traditional Canny operator respectively from the double threshold calculated by the *OTSU* algorithm and Minimum Within-Cluster Variance algorithm. The image grayscale range as $G=[0,L-1]$, the probability of grayscale as p_i. According to the different pixel grayscale image can be divided into 3 groups: $c_0, c_1, c_2 \cdot c_0$ as non-edge pixels, c_2 as edge pixels, c_1 as the probable edge pixels. The probability of these three groups:

$$\begin{cases} w_0(k) = \sum_{i=0}^{k} p_i \\ w_1(k,m) = \sum_{k+1}^{m} p_i \\ w_2(m) = \sum_{m+1}^{L-1} p_i \end{cases} \tag{6}$$

The average gray level of these three groups:

$$\begin{cases} u_0(k) = \dfrac{\sum_{i=0}^{k} ip_i}{w_0} \\ u_1(k,m) = \dfrac{\sum_{k+1}^{m} ip_i}{w_1} \\ u_2(m) = \dfrac{\sum_{m+1}^{L-1} ip_i}{w_2} \end{cases} \tag{7}$$

The average gray level of the whole image:

$$u = \sum_{i=0}^{L-1} ip_i \tag{8}$$

The variance of these three groups:

$$\begin{cases} \sigma_0^2 = \dfrac{\sum_{i=0}^{k}(i-u_0)^2 p_i}{w_0} \\ \sigma_1^2 = \dfrac{\sum_{k+1}^{m}(i-u_1)^2 p_i}{w_1} \\ \sigma_2^2 = \dfrac{\sum_{m+1}^{L-1}(i-u_2)^2 p_i}{w_2} \end{cases} \quad (9)$$

The double threshold calculated by the *OTSU* algorithm and Minimum Within-Cluster Variance algorithm:

$$\begin{cases} \eta^2(t,m) = Arg\max[w_0(u_0-u)^2 \\ \quad + w_1(u_1-u)^2 + w_2(u_2-u)^2] \\ \theta^2(t,m) = Arg\min[w_0\sigma_0^2 + w_1\sigma_1^2 + w_2\sigma_2^2] \end{cases} \quad (10)$$

According to the above constraints, *t*, *m* value represent the high threshold and low threshold in traditional Canny operator.

3) Feature Extraction: Due to the target is spherical, we set the aspect ratio, circular degree and Gaussian filter variance to complete denoising. Experiments showed that set aspect ratio as 0.5, the circular degree as 0.6, Gaussian filter variance as 0.4 are the optimum effect.

4) Stereo Matching: In many cases, there are 2-3 workers at the same time into the area. Due to the target of each workers are the same (the same color and size ball), Stereo matching is easy to cause confusion. This paper proposes a matching method according to the relative position between multiple targets unchanged. We number the targets from top to bottom respectively, the corresponding number matching, which improved the matching accuracy. Assuming there are three targets (workers) appeared in the scene, number the feature points projected on the each camera. Details show in Figure 3.

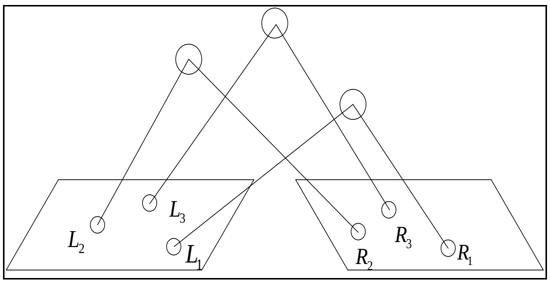


Figure 3. *Number the feature points based on relative position*

Feature points of each camera sorted by pixel coordinates in y-axis (smallest to largest) respectively. $L_1 < L_2 < L_3 < ... < L_n$ as pixel coordinates of the left camera, similarly $R_1 < R_2 < R_3 < ... < R_n$ as pixel coordinates of the right camera. Feature points pixel coordinates of each camera size order should be consistent, if not, these points must be matching error. This paper proposes an algorithm to find out the points matching by mistake.

$$T_i = \left| \begin{matrix} (L_n - L_{n-1})/(L_n - L_{n-2}) \\ -(R_{m+1} - R_{m-1})/(L_{m+1} - L_{m-2}) \end{matrix} \right| \quad (11)$$

$$T_{i+1} = \left| \begin{matrix} (L_{n+1} - L_{n-1})/(L_{n+1} - L_{n-2}) \\ -(R_m - R_{m-1})/(L_m - L_{m-2}) \end{matrix} \right| \quad (12)$$

If $T_i > T_{i+1}$, the point corresponding to L_n is matching error, if not, the point corresponding to L_{n+1} is matching error.

3.3. Targets Coordinates Fusion of Multiple Sets of Binocular Camera

In most cases, a group of binocular camera is unable to complete the monitoring of the regional security. In order to view full cover of safety area, usually need multiple sets of binocular camera in different locations. The world coordinate system usually overlaps with the left camera coordinate system, so N groups of binocular cameras match with N groups of different world coordinate system. We can complete the coordinate transformation by multiple rotation matrix *R* and translation matrix *T* in Eq.1. The N groups of camera coordinate system are calibrated into one scene coordinate system. Due to the influence of the angle and error factors, different camera to get the coordinates of the same target location will appear deviation. Details show in Figure 4.

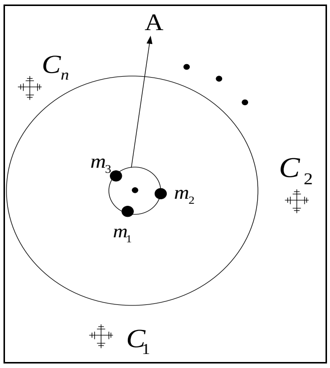


Figure 4. *N groups of camera to get the coordinates of the same target location*

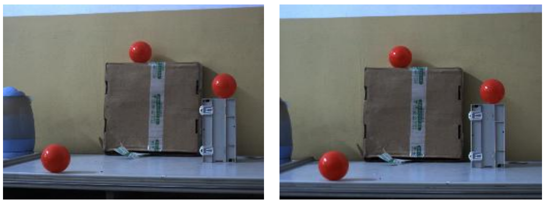
m_1, m_2, m_n as N group of different coordinates of the same target, we take the mean of N group of different coordinates as the final point coordinate. The point coordinate satisfied:

$$\begin{cases} X = (X_1 + X_2 + ... + X_n)/n \\ Y = (Y_1 + Y_2 + ... + Y_n)/n \\ Z = (Z_1 + Z_2 + ... + Z_n)/n \end{cases} \quad (13)$$

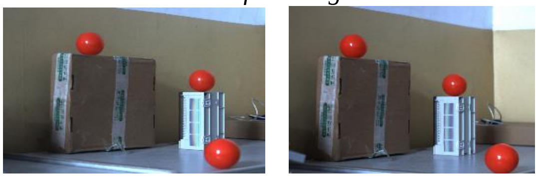
4. Experiment Results

This experiment adopts *Microvision* company CCD binocular camera, model for MV-VS220, resolution of 1280x960.

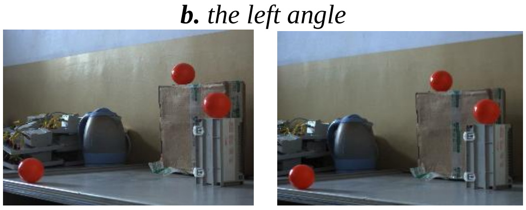
In order to acquire the real data, three red balls with 7 cm diameter which used as targets. We acquire images in three different angles which on the front, the left and the right. Three different locations (height, depth, background) are selected for image acquisition. Details are shown in Figure 5.



***a.** the front angle*



***b.** the left angle*



***c.** the right angle*

***Figure 5.** The same scene graph in three different angles*

Three sets of color images are segmented by (R-G) combination operator. Details are shown in Figure 6. Due to the algorithm is the same, we only taken a set of image with the front angle.

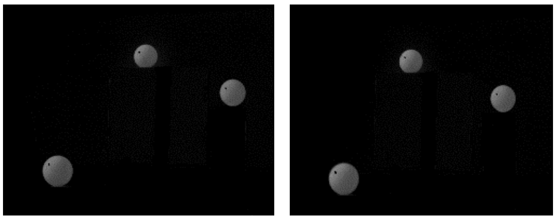
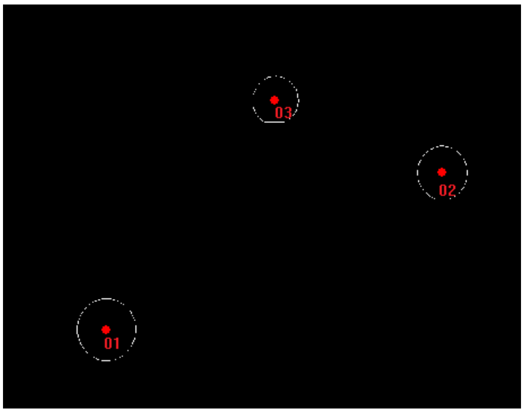


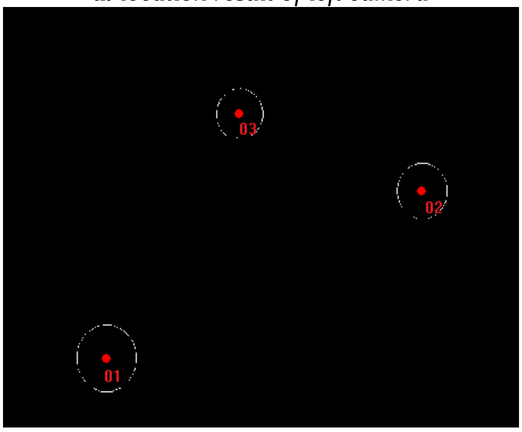
***Figure 6.** The front images segmented by (R-G) combination operator*

We set the aspect ratio; the circular degree and Gaussian filter variance to complete denoising. Experiments showed that set aspect ratio as 0.5, the circular degree as 0.6, Gaussian filter variance as 0.4 are the optimum effect.

Eventually determine the feature points coordinates, complete stereo matching. Details are shown in Figure 7. Due to the algorithm is the same, we only taken one set of image with the front angle.



***a.** location result of left camera*



***b.** location result of right camera*

***Figure 7.** The front image matching results*

Matching the image in three different angles which on the front, the left and the right respectively, calculating the mean of the three coordinates to complete coordinates fusion finally. Details are shown in Table.1.

***Table.1:** the world coordinates of the three red balls*

	left image coordinates		right image coordinates		the world coordinates		
the01point	169.379	223.154	215.368	191.675	-218.25	29.6785	1426.88
the02point	987.696	558.898	1022.65	528.171	151.544	92.1366	1627.55
the03point	699.804	726.145	734.334	694.067	48.3852	135.091	1781.56

Targets' coordinates simulate a cylinder to represent the workers, finally realize the all-round real-time monitoring of the region.

5. Conclusions

This paper proposes a real-time video monitoring technology based on binocular stereo vision technology, using multiple sets of binocular camera to the image acquisition, analysis, processing for any workers which in the open-pit mine safety area. In this paper, the red balls with 7 cm diameter are used in each workers safety helmet as targets. This paper proposed using (R-G) combination operator for color image segmentation, the coordinates of the targets are located by stereo matching according to the relative position between multiple targets unchanged and coordinates fusion. Greatly improve the location accuracy and speed. Extensive experiments validate the proposed methods.

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