An Improved Vibe Algorithm to Detect Personnel Underground in Coal Mines

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Abstract. Coal mine safety has always been the most important prerequisite for underground coal mine work. Mine personnel inspection is an effective means to ensure underground safety production. Therefore, the quality of inspection will play a decisive role in safety production. At present, due to the influence of the complex environment in coal mines, ghost images are prone to appear in the process of personnel detection, which has a certain impact on the accuracy of detection. Aiming at this phenomenon, a Vibe method for secondary detection based on ghost images is proposed. In the process of underground coal mine personnel detection, the minimum bounding rectangle of the personnel area is delineated, and each pixel of the personnel area and all the areas outside the rectangle are calculated separately. The process of judging whether it is a ghost image and eliminating the ghost image by the number of pixels whose similarity reaches the threshold. Through subjective and objective verification, the proposed improved algorithm has been effectively improved compared to the traditional Vibe algorithm and the Vibe+ algorithm, which is prone to ghosting problems. In terms of the accuracy, recall rate, F1 value and other objective evaluation indicators of the algorithm model, it is proposed Compared with the two algorithms, the improved Vibe algorithm improves by 2.71%, 4.79%, and 3.73% respectively. Experimental data shows that the improved Vibe algorithm effectively suppresses the appearance of ghosts in the process of underground coal mine personnel detection, improves the accuracy of foreground and background separation, enhances the ability to detect moving targets in coal mines, and provides technical support for safe production in coal mines.

Keywords. Coal mine safety; personnel detection; Vibe algorithm; ghosting elimination.

1. Introduction

With the increasing attention to coal mine safety and the increasing control means, in recent years, coal mine safety work has achieved remarkable results, but it has not completely eliminated the occurrence of safety accidents, and there are still some blind spots and weak links in safety management [1]. In particular, the safety production accidents caused by personnel’s poor identification of underground hazards and their own dangerous behaviors occur from time to time [2-3]. Therefore, the behavior analysis and abnormal condition detection of underground personnel are important means to ensure the safety of underground personnel.

Vibe (Visual Background Extractor) The behavior analysis and abnormal condition detection and recognition of coal mine personnel is the understanding and recognition of human movement semantic level after visual semantic detection and analysis. The premise of behavior analysis and anomaly detection of personnel is to correctly identify the personnel and separate the moving target from the
complex scene, which is also called remote target detection [4], that is, to separate the moving target from the static target in the complex video, that is, to separate the foreground and background [5-7]. This separation process is the most basic step of human behavior analysis, and its effect will affect the effect of subsequent analysis. Therefore, an efficient and accurate foreground moving target detection method is the most important of human behavior analysis. At present, optical flow algorithm, background subtraction algorithm, inter frame subtraction algorithm and Vibe (visual background extractor) algorithm are relatively mature in the application of foreground moving target detection [8-9].

Among them, the Vibe background modeling method proposed by Olivier of Montefiori Institute of Liege University in Belgium is widely used in various scenes because of its easy to understand, simple implementation and low computational complexity. After that, many scholars at home and abroad improved Vibe algorithm, for example, Vibe+ algorithm [10] and reference [11] proposed a flame recognition method combining deep learning and improved Vibe algorithm. Although Vibe+ algorithm improves the accuracy of foreground separation by modifying the update factor, there are still some common shortcomings of Vibe algorithm, such as ghost phenomenon. Reference [12] uses seven frame method to remove ghost, Due to the large disturbance of the flame target, there is a problem of slightly higher computational complexity, and it is not suitable for the underground low illumination environment. In this paper, aiming at the problem that ghost area phenomenon is easy to appear in the detection of personnel in the complex environment of coal mine, which leads to the low detection accuracy, the Vibe algorithm is improved by using the method of second judgment ghost to detect the abnormal situation of personnel in coal mine.

2. The Process of Vibe Method Based on Ghost Image
Aiming at the problem of ghost region in background modeling of Vibe algorithm in coal mine, this paper proposes a secondary region judgment method to eliminate ghost.

As shown in figure 1, the overall idea of the algorithm is to construct the background model from the first frame of the initial video image in the coal mine, and then compare the next frame of the image with the background model to judge the foreground background, and update the background at the same time. On the basis of the traditional algorithm, this paper adds the second judgment of the ghost region, by minimizing the bounding rectangle of the foreground object the specific Vibe algorithm and ghost elimination process will be described later.

3. Vibe Algorithm Model
Vibe algorithm is a moving object foreground detection method based on background update. The algorithm sets an initial background model from the first frame, and then separates the foreground and background by comparing with the pixels of the previous frame, and updates the background model in real time based on the current frame [13]. Generally speaking, the essence of Vibe algorithm is to set the initial background model and update the background model Background modeling is a process.

3.1. Background Modeling Process
Firstly, the background model is constructed for each pixel in the image as figure 2. Assuming that the first frame of the video in the coal mine is taken, a certain pixel in the image is extracted, and N pixels in the neighborhood of the pixel are selected as the sample values. Generally, the construction method of eight neighborhood is adopted to complete the initialization of the background model:

\[ B(x) = \{q_1(1), q_1(2), q_1(3), \ldots, q_1(N)\} \] (1)
Background initialization

Foreground and background judgment

Last image

end

Figure 1. The overall process of Vibe algorithm.

Figure 2. The background model of a certain pixel in the first frame.

3.2. Foreground and Background Judgment

When the background model is initialized, the foreground background is judged according to the initialized background model from the second frame. By calculating the similarity between each pixel in the frame image and the initial background model, it is judged whether the pixel is a background [14], as shown in figure 3:

Take a pixel in the current frame $q(x)$ as the center of the circle, $R$ as the radius to delimit a circular area, use Euclidean distance to calculate the similarity of two pixels, $u$ represents the
similarity function, and the formula is as follows:

\[ U(x) = \{ \text{dist}(q(x), B(x)) \leq R \} \] (2)

Among them, \( C_R(q(x)) \) represents a circular area with the center of circle \( q(x) \) and radius \( R \). \( B(x) \) represents \( N \) sample points of the background model. At the same time, the number of background sample points in the circular area is calculated. If it is greater than or equal to the threshold \( T \), the pixel in the current frame image is judged as the background point, otherwise it is the front scenic spot. The specific formula is as follows:

\[ q_j(x) = \begin{cases} \text{background} & \text{count}(U \geq T) \\ \text{foreground} & \text{otherwise} \end{cases} \] (3)

where \( q_j(x) \) is the pixel value of \( x \) point in the image of frame \( j \), and \( \text{count}(U \geq T) \) is the number of elements greater than \( R \) in the similarity function \( U \).

3.3. Background Update

Background update is to re judge the foreground background points of the previous frame or frames. In the video image, if the pixel positions of the front scenic spot and the background point are kept unchanged, a moving object may be recognized as the background all the time. However, if the background model of each frame is detected and updated in the process of updating, it will undoubtedly increase the workload and complexity of the operation. In the Vibe algorithm, the random strategy is used to update the background model. When a pixel is defined as a front attraction \( n \) times in succession, the pixel is redefined as a background point, and a sample value in the background model is updated by the probability of \( \frac{1}{\phi} \). After time \( t \), the probability of retaining a sample in the background sample set of the point is [15]:

\[ P(t, t + dt) = e^{-\ln\left(\frac{N}{N-1}\right)dt} \] (4)

4. Improvement of Ghost Problem in Vibe Model

As one of the most widely used moving target detection methods, Vibe algorithm has been applied to the detection of personnel targets in coal mines. Due to the requirements of safety standard and explosion-proof, the performance of algorithm server in coal mines is more limited, and the data communication rate is lower than that on the ground. Vibe algorithm has the advantages of simple modeling, high modeling speed and detection efficiency, and has achieved good results in personnel detection. It's a good effect. However, since Vibe algorithm usually uses the first frame of the video to initialize the background model, if there is a moving object in the first frame of the video, it will be identified as the background model, and there are certain delays and errors in the background update process of the next \( N \) frames, that is, the real background area of the current frame is determined as a moving object, which is called ghost phenomenon [16], as shown in figure 4.

As shown in figure 4, a moving object appears in the first frame of the image, so ghost appears in the process of using Vibe algorithm, as shown in figure 4d. Aiming at the ghost problem, this paper uses the secondary detection method based on ghost phenomenon to eliminate the ghost area. The main implementation process is as follows:

Step 1: the essence of the second detection based on ghost phenomenon is to detect the moving object when it appears in the process of personnel detection using Vibe algorithm, and judge whether it is ghost.

Taking figure 5 as an example, in the gray-scale image of Vibe detection process, when a moving target appears in the image, the minimum bounding rectangle of the target is used to delimit the range, as shown in the following figure 5.
Step 2: according to figure 5, determine the area based on the minimum circumscribed rectangle of the moving target, as shown in the red border in figure 5b, define all the areas in the red frame as S, and the blue area outside the moving target in the S area as SG, as shown area B in figure 5b, and define the moving target area as SF, as shown area A in figure 5b.

Step 3: The second detection method based on ghost image is to calibrate the minimum circumscribed rectangle of all moving objects when moving objects appear in the video image, and calculate the similarity between each pixel in the moving area SF in the current scene and all pixels in the area SG out of the moving object in the S area respectively. The similarity between the two points is expressed by Euclidean distance. If the similarity between all pixels in the SG area and each point in the SF area is less than a set value and greater than a threshold, these points in the SF area are recognized as ghost points, and the ghost area can be eliminated. The formula is as follows:

\[ U(x) = |M_{SG} - M(S_F(x))| \quad (x = 1 \sim N) \]  
\[ V(x) = \text{count}(U(x) < R) \]  

In equation (5), U is the absolute value of the difference of the pixels in the two regions, \( M_{SG} \) is the matrix of all the pixels in the \( S_G \) region, and \( M(S_F(x)) \) is the matrix of all the pixels in the moving target region. \( V(x) \) is the number of all elements in the similarity matrix that are less than the set value \( R \).
\begin{equation}
\begin{cases}
V(x) > T & \text{ghost} \\
\text{otherwise} & \text{sport goal}
\end{cases}
\end{equation}

In equation (7), when the number \(V(x)\) of similarity between all pixels in \(S_G\) region and each point in \(S_F\) region is less than a certain set value and greater than the threshold \(T\), the point is a ghost point.

The whole implementation steps of the improved Vibe algorithm are as follows:

1. Background modeling, using equation (1) for eight neighborhood background modeling;
2. In Section 2.2, Euclidean distance is used to calculate the similarity between two pixels, and then the foreground and background of the image are classified;
3. When the moving object appears in the image, the second detection method based on ghost phenomenon is used to judge the ghost phenomenon in the image. If the ghost appears, the ghost is eliminated.
4. To update the background, the foreground and background of the ghost removed image are rejudged, and the random update strategy such as equation (4) is used to update the background.

5. Experimental Analysis

In order to verify the effectiveness of the proposed Vibe method based on ghost image, the experiment was carried out in the underground track Lane of coal mine. The experimental hardware equipment was mine flameproof server, the main technical parameters were CPU i7, graphics card rtx2060, memory 16g, operating system windows10, programming language environment was Python 3.8, and the numpy and opencv modules were used for the experiment.

In the experiment, part of the video of the track Lane area in the coal mine is selected for analysis, and the situation of people in the video is taken as the initial frame to simulate the conditions of ghost in the Vibe algorithm. The proposed improved Vibe algorithm is used to deal with the ghost, and the effect of ghost elimination is judged subjectively. Finally, the original Vibe algorithm, Vibe+ algorithm and the proposed improved Vibe algorithm are used Part of the video of coal transportation area in coal mine is processed, and the detection effect of video image is evaluated from subjective and objective aspects.

5.1. Subjective Verification Experiment of Ghost Elimination

The video image is 24 frames per second, and the 0th, 77th and 128th frames of the video are selected as the processing images respectively. The Vibe algorithm, Vibe+ algorithm and the proposed improved Vibe algorithm are selected to process the three images respectively to judge the processing effect.

According to figure 6, when the underground moving target appears in the initial image of frame 0, Vibe and Vibe+ algorithm mistakenly recognize the moving target as the background. Therefore, at the position of frame 77 of the video, Vibe algorithm as shown in figure 6e and Vibe+ algorithm as shown in figure 6h respectively appear ghost phenomenon composed of different density pixel distribution, while the improved Vibe algorithm is used for underground moving target recognition, At frame 77 of the video, as shown in figure 6k, only a few pixels in the original ghost area of the image are identified as the front scenic spots, and no large area of front scenic spots appear. At frame 128 of the video, it can be seen that although the number of ghost pixels in Vibe algorithm, such as figure 6f and Vibe+ algorithm, as shown in figure 6i, decreases, some of them are still identified as the front scenic spots in the current frame image processed by the improved Vibe algorithm, as shown in figure 6l, there is no ghost region, so the improved Vibe algorithm has a certain role in eliminating ghost phenomenon in the process of moving target detection.
5.2. Verification Experiment of Moving Target Detection Index

(1) Background point extraction and verification

Vibe algorithm, Vibe+ algorithm and the proposed improved Vibe algorithm are used for moving target detection of underground video. Vibe algorithm, Vibe+ algorithm and the proposed improved Vibe algorithm are used for moving target detection of underground video through receiver operation. The moving target detection ability of the three algorithms is evaluated by receiver operation characteristic curve, accuracy, recall rate and running time estimate.

Receiver operating characteristic curve (ROC) is an intuitive curve to evaluate the quality of the model. The true positive rate (TPR) and false positive rate (FPR) are calculated by four indicators composed of correlation, positive category, irrelevant category and negative category. The calculation formula is as follows [17-18]:

\[
TPR = \frac{N_{TP}}{N_{TP} + N_{FN}} \quad (8)
\]

\[
FPR = \frac{N_{FP}}{N_{TN} + N_{FP}} \quad (9)
\]

In equation (8), \(N_{TP}\) represents the number of pixels of correctly judging the front scenic spot, \(N_{FN}\) represents the number of background points of correctly judging the front scenic spot, in equation (9), \(N_{FP}\) represents the number of background points of correctly judging the front scenic spot, and \(N_{TN}\) represents the number of correctly judging the background points. By calculating the
false positive rate and true positive rate of each frame of the underground image, the curve is fitted in the coordinates, and the picture is as follows:

In the ROC curve, the ordinate represents the true positive rate of the algorithm, and the value range is 0-1. The higher the index is, the better the processing effect of the model is. The closer the curve is to the vertical axis of the upper left corner, the better the classification effect of the model is. As can be seen from figure 7, the improved Vibe algorithm is closer to the upper left corner of the vertical axis in trend and position than Vibe and Vibe+ algorithm, and the true positive rate of the improved Vibe algorithm is higher. The value range is 0.55-0.96, while the value range of true positive rate of Vibe algorithm and Vibe+ algorithm is 0.37-0.76 and 0.41-0.79, respectively, which shows that the improved Vibe algorithm is more accurate and accurate in the separation and judgment of scenic spot background points in front of video image.

Figure 7. ROC curve diagram of three algorithms.

According to table 1, compared with the traditional Vibe algorithm, the accuracy rate, recall rate and F1 value of the improved Vibe algorithm are increased by 5.42%, 6.18% and 5.82% respectively under the complex conditions of underground coal mine; compared with the Vibe+ algorithm, they are increased by 2.71%, 4.79% and 3.73% respectively. Compared with Vibe algorithm and Vibe+ algorithm, the average processing time of the improved Vibe algorithm is higher, but it has no effect on the whole detection process.

(2) Verification of moving target detection rate
The higher the precision, recall and F1 value, the better the model effect [19-20]:

| Algorithm       | Precision | Recall | F1    | Time (ms) |
|-----------------|-----------|--------|-------|-----------|
| Vibe            | 0.837     | 0.881  | 0.858 | 34.12     |
| Vibe+           | 0.861     | 0.894  | 0.877 | 33.91     |
| Improving vibe  | 0.885     | 0.939  | 0.911 | 34.35     |

Through the verification experiment of moving target detection index of underground personnel, it can be seen that in the complex underground environment, the improved Vibe algorithm model proposed, compared with the traditional Vibe algorithm, Vibe+ algorithm has a certain improvement in the accuracy, recall rate, F1 value and other objective evaluation indexes.

6. Conclusion
Aiming at the problem of ghost in the process of moving target detection of underground coal mine personnel, this paper proposes a secondary detection Vibe algorithm based on ghost phenomenon. The algorithm counts the pixel value difference of each point in the minimum rectangular area of the
detected moving target to reach the threshold number in the process of moving target detection in underground coal mine, and then judges whether it is a ghost and eliminates the ghost. The subjective and objective experiments show that the improved Vibe algorithm can effectively limit the appearance of ghost phenomenon, improve the accuracy of foreground background separation, and enhance the ability of moving target detection in coal mine.

The improved Vibe algorithm provides an effective means for moving target detection in coal mine, and provides technical support for safe production in coal mine.

References
[1] State Administration of Work Safety, State Administration of Coal Mine Safety 2011 Coal Mine Safety Regulations (Beijing: Coal Industry Press).
[2] Sun J P 2011 Research on coal-mine safe production conception Journal of China Coal Society 36 (2) 313-316.
[3] Wang G F, Zhao G R and Ren H W 2019 Analysis on key technologies of intelligent coal mine and intelligent mining Journal of China Coal Society 44 (1) 34-41.
[4] Zhang L Y 2017 Mine target monitoring based on feature extraction of moving target Journal of China Coal Society 42 (S2) 603-610.
[5] Sun J P and Jia N 2015 Human target matching and tracking method in coal mine video Journal of China University of Mining and Technology 44 (3) 540-548.
[6] Qiu Z Y 2013 Moving target detection algorithm based on real-time video China Jiliang University.
[7] Zhang L Y 2017 Research on intelligent video analysis and early warning system for mine Industry and Mine Automation 43 (11) 16-20.
[8] Zhang X H and Zhao X H 2016 Research on moving target detection in coal mine intelligent video monitoring Industry and Mine Automation 42 (4) 31-36.
[9] Yang T 2016 Research and Realization of Fire Detection System Based on Video Surveillance DongHua University.
[10] Kumar P D and Sukadev M 2018 A new Wronskian change detection model-based codebook background subtraction for visual surveillance applications Journal of Visual Communication and Image Representation S104732031830186X-.
[11] Chen X 2019 Research on indoor video flame recognition based on improved Vibe algorithm and deep learning Xi’an University of Science and Technology.
[12] Dewan P and Kumar R 2017 Detection of object in motion using improvised background subtraction algorithm International Conference on Trends in Electronics and Informatics (ICEI) pp 651-656.
[13] Yang J F 2009 Research on the analysis and recognition of human actions in video University of Electronic Science and Technology of China.
[14] Guo Z T, Cao X Q, Li C Y, et al. 2018 A moving object detection method based on improved ViBe algorithm Video Engineering 42 (08) 33-35.
[15] Loy C C, Xiang T and Gong S 2012 Salient motion detection in crowded scenes Proc. of the 5th IEEE Int’l Symp. pp 1-4.
[16] Li D D 2017 Research on crow abnormal detection method based on improved Vibe algorithm Xi’an University of Technology.
[17] Xie L, Zhang X H, Guo P Y, et al. 2015 Vibe with adaptive threshold based on energy minimization Applied Mechanics and Materials 782 397-406.
[18] Mao Z C and Shen X S 2018 Improved Vibe algorithm integrated with multiscale transformation Laser & Optoelectronics Progress | Las Optoelect Prog 55:1-8.
[19] Qiu Z Y and Wang X H 2012 A Vibe moving objects detection combined with Grabcut Journal of China University of Metrology 23(3):250-257.
[20] Gui B 2015 Research on moving target detection and shadow elimination method based on Vibe Anhui University.