Research on Highway Slope Disaster Automated Monitoring Method Based on Video Image Processing

Zhuomin Zhang1,*, Song He2, Chaonan He3, Yi Chen4 and Haobo Shi1
1 Research Institute of Highway, Ministry of Transport, Beijing, China
2 Yingyun Highway Administration Bureau of Guizhou Province, Guizhou, China

*Corresponding author email: zzm@itsc.cn

Abstract. With the rapid development of China highway transportation network, a lot of highways have risen in the mountainous areas. And the risk of geological disasters is also increasing. Due to the instability of the geological structure and geological changes, slope landslides and collapses frequently occur. However, there is a lack of effective means and tools in the field of highway slope disaster monitoring. For large and important slopes, various information-based monitoring methods are used, but the effects and practicability are not satisfactory. This paper proposes a highway slope disaster automated monitoring research method based on multi-camera video image processing to solve the previous engineering problems of slope video monitoring. It can quickly identify slope disaster events with centimeter-level monitoring accuracy, which can meet the application requirements of highway engineering. Correspondingly, the disaster emergency response capabilities of highway operators can also be supported and improved.

Keywords: Automated monitoring; Highway slope disaster; Video image processing.

1. Introduction
The time, location, scale and intensity of slope disasters are difficult to predict. For slope disasters, therefore, the focus is on slope monitoring and prediction. Slope disaster monitoring indicators include geological macroscopic trace, ground displacement, deep displacement, chemical field and other monitoring indicators. Deformation is the most significant parameter when the slope state changes, and it can best reflect the change status and development trend of the slope. Therefore, displacement monitoring occupies an important position in the entire slope displacement monitoring system. Displacement parameters are not only easy to measure, but also have a good reflection on the deformation characteristics of the slope. Not only that, combined with the rock and soil creep theory as the theoretical basis, it can also detect the degree of slope deformation, and then determine the stability of the slidable body. In addition, time forecast, sliding speed, sliding displacement and the magnitude of the disaster can also be estimated. So further study on detection methods based on surface displacement is of great significance to slope monitoring.

2. Technology Status

2.1. Current Status of Slope Monitoring Technology
The previous highway roadbed slope disaster monitoring technology in our country has always been a weak link in highway construction. Although there are some monitoring methods and methods, they lack comprehensive consideration. The realization of slope disaster monitoring by detecting slope displacement applies the principle that the appearance of abnormal phenomena will inevitably lead to
changes in some characteristics of the surface among monitored object, which contains structure, area and spatial location. There have been many monitoring methods, mainly as follows: (1) Manual field observation method; (2) Embedded sensor monitoring method; (3) High-precision positioning monitoring method; (4) Image recognition detection method.

2.2. Current Status of Slope Image Processing and Monitoring Technology
So far, the research on slope image processing and monitoring technology at home and abroad generally takes pictures of the slope to be measured first, then establishes the spatial coordinates of the target array, and recognizes the target object to obtain the plane projection coordinate parameters of the observed object. And last, the three-dimensional reconstruction method and spatial calculation parameters are used to obtain the observation target space data, and the change of target space coordinates will be analyzed by the computers to monitor the slope disaster event. In recent years, with the development of image processing and camera technology, more and more researchers have begun to apply image processing technology to the field of slope engineering. Good results have been achieved at home and abroad. However, there are two main challenges in the current research. One is that the width of the highway slope is large and the terrain environment of the highway is limited. It is necessary to set up multiple cameras to construct the video monitoring array so as to cover the entire area of the highway slope vision. This method requires the deployment of multiple monitoring poles, which inevitably leads to a substantial increase in cost and aggravates the difficulty of outdoor maintaining equipment. Another is that the existing research can only complete the video monitoring of slope disasters under the conditions of good visual environment during the day, and the monitoring accuracy is poor under the environmental conditions at night. Therefore, it is of great significance to propose a new image processing method applied to highway engineering slope disaster monitoring.

3. Slope Disaster Video Monitoring Program Suitable for Highway Engineering
To achieve highway slope disaster monitoring through image processing technology, the key issues to be solved include two aspects. One is the research on the deployment of slope video monitoring cameras. The other is the research on the slope image processing algorithm. The main technical route is shown in Figure 1 below.
Highway slope disaster monitoring based on video image processing first needs to study the construction deployment plan in the engineering application. By selecting the appropriate camera equipment and constructing the right amount of monitoring poles along the highway, the video coverage of the slope can be fully tested. Then, it is necessary to break through the existing slope disaster monitoring image recognition algorithm to reduce false alarms and omissions in order to improve engineering availability.

4. Highway Engineering Video Equipment Deployment Scheme
To study the engineering application deployment plan of highway slope disaster monitoring, the first step is to clarify the surface of the slope to be tested and the key structural points that need to be monitored. In highway engineering, according to the height classification, the soil slope with a cut slope of 20 meters or a rock slope with a cut height of more than 30 meters is generally called a high cutting slope, and a height of more than 50 meters is called super high slope. According to the length classification, the slopes with a length of less than 100 meters are short slopes, those with a length from 100 to 300 meters are medium-long slopes, and those with a length greater than 300m are long slopes. If the classification standard is the slope medium material, it can be divided into soil slope, rock slope and rock-soil mixed slope.

In highway engineering, the most common type of slope is a high rock cutting slope with a length from 100 to 300 meters. Due to the limited terrain environment of the highway, the straight-line distance between the slope to be measured and the video monitoring rod is usually not more than 40 meters when monitoring a rocky cutting high slope of this length. In a limited geographical environment,
conventional road cameras have a limited range of sight. If the existing video image monitoring method is used to complete the video full coverage monitoring of the slope to be tested, it is necessary to deploy multiple camera poles and cameras. By constructing a camera video monitoring matrix, the coordinate displacement monitoring of the target array is realized. This experimental approach will bring about a substantial increase in construction costs, and the multi-camera video matrix calibration and operation and maintenance are difficult to solve. Therefore, it is effective to use cameras with a wide-angle lens that can achieve a wide range of viewing distance for highway slope monitoring. At the same time, a camera that supports low illumination and infrared light should be selected in order to achieve night video monitoring. In this way, the video image coverage of the wide angle of view of the slope under the limited terrain of the highway is realized, and the construction scale of video monitoring poles is reduced. The layout of the camera and its pole is shown in Figure 2.

![Figure 2. The layout plan of the slope monitoring camera.](image)

The performance requirements of parameters such as panoramic ultra-wide angle, horizontal field of view, and vertical field of view are applied to solve the problem of small viewing angles. The resolution parameter performance requirement is used to solve the problem of monitoring accuracy. Supporting infrared supplementary light and low illumination is to solve the problem of night monitoring.

5. **Slope Disaster Monitoring Image Processing Scheme**

The image analysis process is usually divided into three steps: image segmentation, target expression and parameter measurement. This method has high measurement accuracy, but the calculation of the three-dimensional coordinate system is complicated, and the demand for computing resources is relatively larger. Therefore, this paper studies the use of multi-camera imaging calculation principles to analyze the differential results of different images of the slope over a period of time and evaluate the slope disaster situation.

This paper takes binocular visual monitoring and analysis as an example, which is similar to four-eye and multi-eye. Image recognition and monitoring based on binocular vision is a kind of stereo perception monitoring technology that has received widespread attention at present. It has the advantages of compact structure, low energy consumption, rich information, and high recognition accuracy. The main analysis steps are as follows:

1) Determine the relative geometric position and internal parameters of the camera, which means the calibration of the camera.

2) Extract common features or matching primitives from the left and right images.

3) Find the corresponding relationship between the relevant features in the left and right images, that is, perform feature matching.

4) Obtain three-dimensional information of the target according to the parallax and geometric relationship.
This paper uses binocular cameras to realize the image recognition and monitoring of slope disasters with binocular vision. First, establish a binocular vision model to complete the camera coordinate calibration. Secondly, complete the extraction of common features or matching primitives in the left and right images of the binocular camera. Then set the time threshold, and compare and analyze the feature changes based on the time threshold. Finally, the three-dimensional coordinate change information is output according to the data analysis results. In the three-dimensional coordinate value calculation method, the projection points of the spatial point $P_w$ on the two images acquired under the two lenses of the binocular camera are $P_{d_1}$ and $P_{d_2}$. Assume that the projection transformation matrix when shooting two images has been given by calibration, which can be written as

$$M^{(1)} = \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \end{bmatrix}$$

(1)

$$M^{(2)} = \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \end{bmatrix}$$

(2)

According to the linear theory of camera image imaging:

$$\begin{bmatrix} l_{x_d}^{(1)} \\ l_{y_d}^{(1)} \\ 1 \end{bmatrix} = \begin{bmatrix} a_{u}^{(1)} & 0 & u_{0}^{(1)} \\ 0 & a_{v}^{(1)} & v_{0}^{(1)} \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} c_{R}^{(1)} & c_{T}^{(1)} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} w_{X_w} \\ w_{Y_w} \\ w_{Z_w} \end{bmatrix} = A^{(1)} M^{(1)} R^{(1)} T^{(1)} \begin{bmatrix} w_{X_w} \\ w_{Y_w} \\ w_{Z_w} \end{bmatrix} = M^{(1)}$$

(3)

$$\begin{bmatrix} l_{x_d}^{(2)} \\ l_{y_d}^{(2)} \\ 1 \end{bmatrix} = \begin{bmatrix} a_{u}^{(2)} & 0 & u_{0}^{(2)} \\ 0 & a_{v}^{(2)} & v_{0}^{(2)} \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} c_{R}^{(2)} & c_{T}^{(2)} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} w_{X_w} \\ w_{Y_w} \\ w_{Z_w} \end{bmatrix} = A^{(2)} M^{(2)} R^{(2)} T^{(2)} \begin{bmatrix} w_{X_w} \\ w_{Y_w} \\ w_{Z_w} \end{bmatrix} = M^{(2)}$$

(4)

Where $(l_{x_d}^{(1)}, l_{y_d}^{(1)}, 1)$ and $(l_{x_d}^{(2)}, l_{y_d}^{(2)}, 1)$ are the homogeneous coordinates of $P_{d_1}$ and $P_{d_2}$ in their respective image coordinate systems, and $(w_{X_w}, w_{Y_w}, w_{Z_w}, 1)$ is the second coordinate of the space point $P_w$ in the world coordinate system.

Combine $M^{(1)}$ and $M^{(2)}$ into equation (3) and (4), then we can get

$$\begin{bmatrix} m_{11} w_{X_w} + m_{12} w_{Y_w} + m_{13} w_{Z_w} + m_{14} & l_{x_d}^{(1)} \\ m_{21} w_{X_w} + m_{22} w_{Y_w} + m_{23} w_{Z_w} + m_{24} & l_{x_d}^{(1)} \\ m_{31} w_{X_w} + m_{32} w_{Y_w} + m_{33} w_{Z_w} + m_{34} & l_{x_d}^{(1)} \end{bmatrix} = \begin{bmatrix} w_{X_w} \\ w_{Y_w} \\ w_{Z_w} \end{bmatrix}$$

(5)

$$\begin{bmatrix} m_{11} w_{X_w} + m_{12} w_{Y_w} + m_{13} w_{Z_w} + m_{14} & l_{x_d}^{(2)} \\ m_{21} w_{X_w} + m_{22} w_{Y_w} + m_{23} w_{Z_w} + m_{24} & l_{x_d}^{(2)} \\ m_{31} w_{X_w} + m_{32} w_{Y_w} + m_{33} w_{Z_w} + m_{34} & l_{x_d}^{(2)} \end{bmatrix} = \begin{bmatrix} w_{X_w} \\ w_{Y_w} \\ w_{Z_w} \end{bmatrix}$$

(6)

It is known from analytic geometry that the plane equation of three-dimensional space is a linear equation, and the combination of two plane equations is a space linear equation. The geometric meaning of equation (5) or (6) is a straight line passing $O_{c_1} P_{d_1}$ or $O_{c_1} P_{d_2}$. Since the space point $P_w$ is the intersection of the straight lines, the three-dimensional coordinates $(w_{X_w}, w_{Y_w}, w_{Z_w})$ of the point $P_w$ can be obtained by combining equations (5) and (6). In fact, three equations are capable to find the three-dimensional coordinates of a point in space. Therefore, the equations using equations (5)
and (6) must have solutions, and the solution is unique. In this way, the three-dimensional information of the scene can be reconstructed through two images.

In this paper, the binocular camera is used to construct the coordinate system. Since the relative position of the camera does not change after calibration, the system can be calibrated by the offline calibration method using the least square method. The projection transformation matrices $M^{(1)}$ and $M^{(2)}$ of the binocular camera can be obtained. First, separate the target from the background to get the target area. Then, according to the corner points or edge points detected on the first image, the epipolar line constraint method is used on the second image to roughly determine the matching area to be searched. And similarity measurement and continuity assumptions are used to accurately locate the corresponding matching points in the matching area. On the condition that the corresponding coordinates of any point in the space in the two images and the parameter matrix of the two cameras are obtained, the reconstruction of space point can be carried out. By formulas (5) and (6), four linear equations with the world coordinates of the point as unknowns are established, and the world coordinates of the point can be solved by the least square method. Since the coordinates of the spatial point in the camera coordinate system are not clear, the distance information of the target object from the current system cannot be determined. Therefore, the calculated space point coordinates must be converted to the camera coordinate system to obtain the coordinates. Then compare with the set time threshold and analyze the image data so as to detect the slope disaster situation.

6. Experimental Verification

According to the method above, a video monitoring system for slope disasters is established, as shown in Figure 3. The system should be calibrated first. Then the slope image is collected and the image data is analyzed and processed to obtain the projection transformation matrix $M^{(1)}$ and $M^{(2)}$ of the system, and the projection matrix is decomposed to obtain the external parameter matrix and translation matrix of the camera. After obtaining the information above, disaster simulation experiments and conduct image monitoring tests on the slope can be conducted.

![Figure 3. Highway slope disaster video monitoring system.](image-url)
Figure 4. Schematic diagram of image analysis of the slope to be tested.

After the experimental test, the image coordinate changes before and after using the binocular camera are analyzed and compared, as shown in Figure 4. When the camera resolution is 8 million (4096*1800) pixels, it can detect the image coordinate changes within 5 cm, and the error is not more than 1 cm.

7. Conclusion and Discussion

This paper makes full use of the advantages of binocular or multi-eye ultra-wide-angle cameras, and proposes a slope disaster video monitoring method suitable for the application environment of highway engineering. This method solves the slope disaster monitoring problems of great difficulty, high cost, and low practicability. Taking the binocular camera as an example, the calibration of the multi-camera video measurement coordinate system and the image recognition algorithm of slope disaster monitoring are studied. It is verified by experiments that it has centimeter-level monitoring accuracy, which can meet the application requirements of highway engineering.

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