Research on dynamic deformation monitoring of viaduct based on digital camera

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Abstract. In order to realize dynamic deformation monitoring of viaduct and provide data support for safe operation of viaduct, this paper studies the application of digital camera in dynamic deformation monitoring of viaduct. Firstly, the digital camera is corrected to eliminate the aberration, then the corrected digital camera is used to collect data, and then the time baseline parallax method is used to calculate the data, and finally the operation status of the viaduct is obtained through the analysis of the data. The experiment shows that the viaduct is in good operation and use digital camera as monitoring equipment, the dynamic deformation monitoring of viaduct is realized, which is of great significance to the safe operation of viaduct.

1. Introduction

With the acceleration of urbanization, the viaduct plays an important role in easing traffic pressure, improving transportation efficiency and saving land funds. But at the moment of viaduct collapsed accidents emerge in endlessly, especially when the elevated bridges using a certain fixed number of year, after a long-term accumulation of structural fatigue and damage will directly affect the safe usage of elevated bridge, which brought great losses to the economy, even life safety threat people therefore need to deformation monitoring of the viaduct.

The deformation of viaduct can be divided into two types: one is long-term deformation, such as foundation settlement; The other is a short-term deformation, which includes static and dynamic deformation. Static deformation refers to the slow change caused by continuous wind force and other factors. Dynamic deformation is due to the vibration of the bridge structure under the excitation of environmental factors such as wind and traffic load. The long-term deformation and static deformation of the viaduct are easy to be observed, but there are still many shortcomings in the conventional monitoring methods for dynamic deformation of viaduct. It is difficult to complete dynamic deformation monitoring of viaduct due to the limitation of sampling frequency, automation and monitoring cost.

Therefore, to realize dynamic deformation monitoring of viaduct, it is necessary to explore new technical methods. With the rise of digital camera, the problems existing in conventional instrument
monitoring have been solved. The digital camera can continuously capture the instantaneous deformation information of various points of deformities, and is convenient to carry, simple to operate and low in price. At present, some achievements have been made in the deformation monitoring of tunnel, masonry, sluice and other engineering structures.\cite{6,7} Therefore, this paper takes digital camera as the monitoring equipment to study its imaging principle and error as well as the calculation method of the data acquired by digital camera and the dynamic deformation monitoring of viaduct is carried out with an example to verify the scientificity of the research method.

2. Principle of data solution

2.1. Error analysis of digital cameras and correction of optical errors

The error of digital camera includes optical error, mechanical error and electrical error. Among them, optical errors have the greatest impact. Therefore, we mainly study the effects of optical errors on digital camera imaging. Optical error mainly refers to optical distortion, which includes radial distortion and centrifugal distortion. The radial distortion makes the image point deviate from its exact position along the radial direction, which is usually caused by the shape defect of the lens. It is only related to the distance between the image point and the main point, and can be divided into bucket distortion and pillow distortion. The centrifugal distortion is caused by the inconsistency of optical center and geometric center of the lens, which makes the image point deviate from its correct position both along the radial direction and perpendicular to the radial direction.

Digital camera is non-measuring camera, which usually has optical errors. Therefore, inspection and calibration of digital cameras is required.\cite{8}

\[
\begin{align*}
\Delta x &= (x - x_0)r^2K_1 \\
\Delta z &= (z - z_0)r^2K_1
\end{align*}
\]

\(\Delta x, \Delta z\) represents the distortion correction term of optical errors; \(x, z\) is the image point coordinates; \(x_0, z_0\) is the coordinate of principal point of photograph; \(K_1\) is the undetermined coefficient of distortion of symmetry objective lens; \(r\) is radius vector.

2.2. Time-baseline parallax method

Time-baseline parallax method is a method to calculate the relative change value of two-dimensional coordinates of moving objects by measuring the parallax change value of photographs to determine the plane displacement deformation of the object.\cite{9,10}

The plane-time baseline parallax model is shown below:
\[ \Delta X = \frac{Y}{f} \Delta P_x = \lambda \Delta P_x \]
\[ \Delta Z = \frac{Y}{f} \Delta P_z = \lambda \Delta P_z \]  

\( \Delta X, \Delta Z \) represent the horizontal displacement and vertical displacement on the plane of the object; \( \Delta P_x, \Delta P_z \) are the horizontal displacement and vertical displacement of the monitored point on the image plane. \( f \) is the focal length of the camera, \( Y \) is the distance from the center of the objective lens to the object plane \( s \) the photographic scale.

If the deformation value is to be solved by equation (2), it must be satisfied that the interior orientation element and exterior orientation elements remain unchanged when different photos are taken. But in the actual operation, digital camera cannot meet this condition, so it is necessary to correct the parallax measured. Since the parallax of the reference point should be 0, theoretically the coefficient of the reference point can be calculated first, and then the coordinate of the deformation point can be substituted into it to get the change value of the parallax of the deformation point:

\[
\begin{align*}
P_x &= a_x x + b_x z + c \\
P_z &= a_z x + b_z z + d
\end{align*}
\]

In the formula: \((P_x, P_z)\) is the change value of parallax in the \( X \) direction and \( Z \) direction of the image plane, \((a_x, b_x) (a_z, b_z)\) are the parallax coefficients in the \( x \) direction and \( z \) direction respectively, \((x, y)\) is the coordinate of the reference point in the average image plane coordinate system, \((c, d)\) are the fixed parallax coefficients in the \( X \) and \( Z \) directions respectively.

Then the actual deformation value of the deformation point can be obtained:

\[
\begin{align*}
X_s &= m \cdot \Delta P_x \\
Z_s &= m \cdot \Delta P_z
\end{align*}
\]

In the formula, \( m \) is the proportionality coefficient. The proportionality coefficient is usually taken as the distance between two reference points divided by the number of pixels.

The time-base parallax method has some limitations when the direction of image plane and object plane are not parallel. For this purpose, a reference plane parallel to the image plane can be established, allowing the camera to photograph from any direction.

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First, the proportional coefficient \( m_1 \) of the reference plane is obtained. Then, the rangefinder is used to measure the distance \( l_1 \) from the center \( S \) to the deformation point and \( l_2 \) from \( S \) to the corresponding point.
in the reference plane, Therefore, the proportional coefficient \( m_2 \) of the deformation point is:

\[
m_2 = m_1 \frac{l_2}{l_1} \quad (5)
\]

3. Experimental process

(1) The camera is put in the right place, select the deformation point and reference point. This experiment mainly monitored the bridge span and pier. The layout of each point is shown in the figure:

![Fig 3. schematic diagram of point location](image)

(2) The total station is used to measure the position coordinates of the camera and each point. The measurement results are shown in the following table:

| Point | X     | Y     |
|-------|-------|-------|
| Camera| 2000.233 | 2000.151 |
| C0    | 1998.932 | 2014.050 |
| C1    | 1996.720 | 2014.152 |
| C2    | 1998.932 | 2014.050 |
| C3    | 1996.720 | 2014.152 |
| U1    | 1991.437 | 2034.129 |
| U2    | 1997.466 | 2033.732 |
| U3    | 2003.492 | 2033.203 |
| U4    | 2009.572 | 2032.242 |
| U5    | 2014.954 | 2035.815 |
| U6    | 1985.265 | 2037.185 |

(3) When there is no train passing over the viaduct, it can be considered that the viaduct has not been impacted by external load and has no deformation. At this time, a picture is taken, which is called a zero picture.

(4) In the process of the train passing the viaduct, a sudden force will be applied to the viaduct, and the external load will do work to the bridge. After the viaduct is subjected to the impact load, it produces instantaneous deformation. At this time, the continuous shooting function of digital camera is used to shoot the picture, which is called the follow-up picture.

4. Data processing and analysis

4.1. Establishment of reference plane

It is considered that when the reference point is too close to the bridge, vibration deformation will occur and affect the experimental results Therefore, a reference plane parallel to the bridge is laid at a place.
far away from the bridge. Because the reference point and the deformation point are not in the same plane, the proportionality coefficient is different, so the proportionality coefficient must be carried out.

The distance between the two reference points in the reference plane can be input to calculate the distance between the two deformation points, and the field measurement of the distance between the two deformation points.

Table 2. Proportionality coefficient conversion table

| Position     | distance | Solve length/m | Actual length/m | Solve/actual length |
|--------------|----------|----------------|-----------------|---------------------|
| Bridge span  | U1-U4    | 7.388          | 18.197          | 0.408               |
| Pier         | U5-U6    | 10.942         | 29.720          | 0.368               |

Therefore, the distance between the two reference points is divided by the number of pixels between the images of the two reference points. This value should also be divided by 0.408 (deformation point at bridge) or 0.368 (deformation point at bridge pier), which should be used as the corrected proportional coefficient into formula (4).

4.2. Deformation diagram

By calculating the data, the deformation value of each deformation point can be obtained, and the deformation curve is made according to the deformation value, as shown in the figure.

5. Conclusion

Using digital camera to monitor dynamic deformation of bridges in this test is an important direction of future deformation monitoring development. Through the study of the above methods, we can draw the following conclusions:

(1) The deformation diagram above clearly reflects the deformation process at each point when the train passes. All the points on the viaduct can be quickly restored to their positions after deformation, which fully conforms to the elastic deformation principle.

(2) U5 and U6 are located on the bridge pier, and their deformation range is very small. U1, U2, U3 and U4 are located on the bridge span structure of viaduct, and their deformation interval is larger than that of the bridge pier is larger than bridge pier. This also conforms to the deformation law of the viaduct.

(3) Digital camera is used for deformation monitoring of deformation points, which reduces the monitoring cost and has the advantages of high cost performance ratio, easy operation and convenient
promotion.

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