The Study on Real-time Repetition Measurement of Subway Shield and Duct Piece Based on Close-range Photogrammetry

Yang Song[1], Wu kun[2, 3]

[1]Civil and Construction Engineering Institute, Southwest Petroleum University, Chengdu, Sichuan Province 610500;

[2]Civil and Construction Engineering Institute, Southwest Petroleum University, Chengdu, Sichuan Province 610500;

[3] Sichuan Jiuzhou Beidou Navigation and Location Services Corporation, Chengdu, Sichuan Province 610041, China

Abstract

Shield method is more and more widely used in urban subway construction. However, for the shield posture and duct piece repetition measurement, the traditional method of measurement is time-consuming, inefficient and affects construction schedule. Close-range photogrammetry saves a lot of human and material resources, and has high accuracy.

Keywords

Close-range photogrammetry; shield posture; duct piece; repetition measurement.

1. Introduction

In the recent thirty years, China has gained tremendous achievement in economic construction. Urban construction has made steady progress. Many cities have vigorously built subways to alleviate the increasing traffic pressure. Subway has become a more and more important mean of transportation in large cities, and has been an important standard to measure the development and construction of a city.

Shield construction method has been more and more widely used in subway construction[1]. The attitude parameter and location of shield tunneling machine need to be obtained at any time to make it work following the designed circuit. The direction of subway tunnel and installment of duct piece in the tunnel are under the influence of the digging process of shield tunnel machine. If the machine doesn’t dig in accordance with the design, the tunnel may be sigmoid and has an excursion, which may cause heavy loss to project in severe cases.

In using shield method to construct subway, the repetition measurement of duct piece posture (installment of duct piece forms central coordinates of pipe ring and design deviation) is the correct guidance of shield and the last defense to realize tunnel holing-through, which is extremely important. In June of 2014, at about 100 meters from starting drilling in a section of a metro line which is under construction, elevation deviates the design for nearly 2 meters. For this reason, shield construction is changed into underground excavation, directly causing the loss of tens of millions yuan and inestimable indirect damage. The primary reason is the error data input into shied guidance. Without timely man-made repetition measurement, making the last defense lose efficiency, is another reason. In February of 2011, elevation deviates the design for about 1.2 meters when the shield is from the through plane for just 150 meters in a subway construction. Therefore, a transition curve is ponderously added to make the line smooth enough to go through, which causes irretrievable loss. One of the important reason for this is without timely repetition measurement for duct piece posture. Thus, it is of practical significance to study a fast, low-cost and efficient repetition measurement for duct piece posture in subway shield construction.

In recent years, close-range photogrammetry is developing rapidly, which is used in many fields such as deformation of rock mass[2], hydraulic model studies[3], archeology[4] and deformation monitoring[5]. But in subway shield construction, traditional method is still applied in the repetition measurement of shield posture and duct piece. This paper mainly discusses the appliance of close-range photogrammetry in the repetition measurement of duct piece posture of subway shield.

2. The repetition measurement of subway shield posture

2.1 The subway shield posture

The repetition measurement of shield posture includes lateral and vertical deviation and slope of shield axes. The center’s actual 3D coordinates of the plane of shield’s head and tail need to be confirmed to calculate shield posture. Shield’s shape can be regarded as a horizontal cylinder. When shield is working, the center’s 3D coordinate figures of the planes of shield’s head and tail can’t be obtained by general method, which could be deduced through indirect way instead.

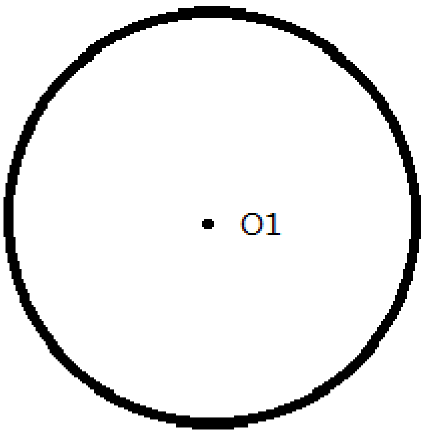


Fig 1. plan sketch of shield’s head

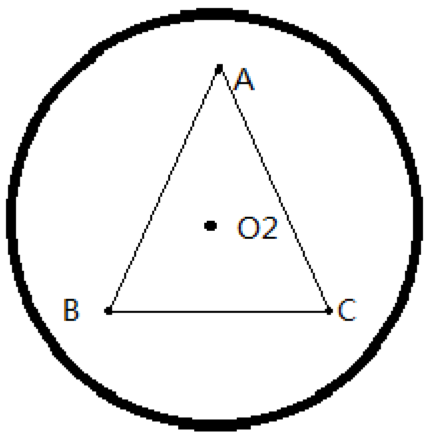


Fig t 2. plan sketch of shield’s tail

As is shown above, point O1 is plane’s center of shield’s head, and point O2 is plane’s center of shield’s tail. Point A, point B, and point C are measurement points in the plane of shield’s tail, whose distance to the center point O2 is equal. The central axis of shield can be obtained by linking point O1 and point O2 (whose length is known and set as L). Based on close-range photogrammetry, the 3D coordinate figures of point A, point B, and point C can be calculated, which are（XA YA, ZA）,（XB, YB, ZB）,（XC, YC, ZC）. Therefore, point A, point B, and point C confirm the plane of shield’s tail, whose normal vector is $\vec{n} = \overrightarrow{AB} \times \overrightarrow{AC}$. According to the 3D coordinate figures of point A, point B, and point C, the 3D coordinate figures of point O1（X1, Y1, Z1）and point O2（X2, Y2, Z2）can be obtained. Based on geometrical relationship, the following equation is listed:

$$\left.\begin{array}{c}
(X_1 - X_A)^2 + (Y_1 - Y_A)^2 + (Z_1 - X_A)^2 = (X_1 - X_B)^2 + (Y_1 - Y_B)^2 + (Z_1 - X_B)^2 \\
(X_1 - X_A)^2 + (Y_1 - Y_A)^2 + (Z_1 - X_A)^2 = (X_1 - X_C)^2 + (Y_1 - Y_C)^2 + (Z_1 - X_C)^2 \\
(X_2 - X_A)^2 + (Y_2 - Y_A)^2 + (Z_2 - X_A)^2 = (X_2 - X_B)^2 + (Y_2 - Y_B)^2 + (Z_2 - X_B)^2 \\
(X_2 - X_A)^2 + (Y_2 - Y_A)^2 + (Z_2 - X_A)^2 = (X_2 - X_C)^2 + (Y_2 - Y_C)^2 + (Z_2 - X_C)^2 \\
(X_2 - X_1)^2 + (Y_2 - Y_1)^2 + (Z_2 - Z_1)^2 = L^2 \\
\vec{n} \cdot \overrightarrow{OA} = 0
\end{array}\right\}$$

According to the above equation set, unknown 3D coordinate figures（X1, Y1, Z1）and（X2, Y2, Z2）of point O1 and point O2 can be calculated. In a certain range, the designed 3D coordinate figures of plane’s centers of shield’s head and tail are known. Therefore, there are equations ΔX=Xreal—XAssume, ΔY=Yreal—YAssume, ΔZ =Zreal—ZAssume., deducing plane deviation value（$\sqrt{\Delta X^2 + \Delta Y^2}$）between shield’s axis and designed axis, elevation deviation value（ΔZ）, and shield’s longitudinal grade（(Z2-Z1）/L）, which are shield machine’s posture parameters.

2.2 The steps of repetition measurement of shield posture based on close-range photogrammetry

The steps are as follows:

(1) The set of object space coordinate system and baseline of photogrammetry is in accordance with shape and location of shield machine, and specific conditions in construction, which can be completed by general measurement method (total station). In setting the baseline of photogrammetry, the appropriateness of baseline's length should be considered;

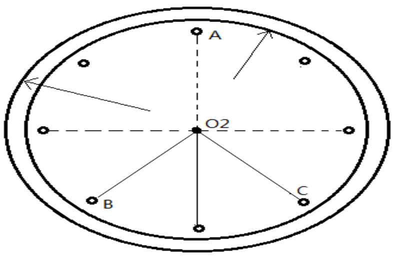
(2) Put digital camera at correct camera station. Then, adjust focal length, shoot and get the photo. Later, measure the picpointed coordinate of control points in the photo;

(3) Calculate exterior and interior parameters of the photo and 3D coordinate figures of point A, point B, and point C based on the principle of close-range photogrammetry;

(4) Calculate 3D coordinate figures of point 01 and point O2 based on point A, point B, and point C;

(5) Calculate horizontal deviation, vertical deviation and horizontal slope of plane centers of shield' s head and tail to realize the purpose of testing shield posture.

2.3 Instance analysis of repetition measurement of shield posture based on close-range photogrammetry



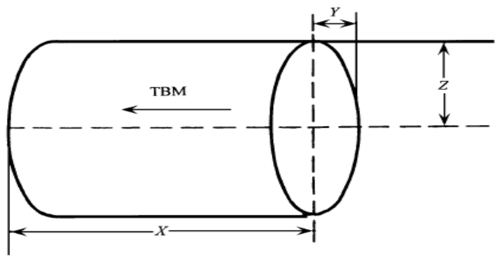


Fig 3. distribution sketch of measuring point of the plane of shield's tail Fig 4. the sketch of part of shield axis

Based on close-range photogrammetry, 3D coordinate figures of point A, point B, and point C are as follows:

Table 1. 3D coordinate figures of gauge points on the shield machine

	X(m)	Y(m)	Z(m)
Point A	4770.404	2632.052	6.636
Point B	4772.294	2627.748	1.655
Point C	4771.472	2634.099	-0.919

3D coordinate figures of point O1 and point O2 can be deduced from point A, point B, and point C and L=4.24m, which are presented in Table 2:

Table 2. Actual figures of 3D coordinates of point O1 and point O2

	X(m)	Y(m)	Z(m)
Point O_1	4767.114	2630.852	1.715
Point O_2	4771.284	2631.727	2.542

The designed 3D coordinate figures of point O1 and point O2 in this range are presented in Table 3:

Table 3. The designed 3D coordinate figures of point O1 and point O2

	X_{Assume} (m)	Y_{Assume} (m)	Z_{Assume} (m)
Point O_1	4767.110	2630.855	1.710
Point O_2	4771.280	2631.731	2.545

Therefore, the parameters of the measurement of shied posture in this range are presented in Table 4

Table 4. The parameters of shied posture

	ΔX (mm)	ΔY (mm)	Lateral deviation(mm)	Vertical deviation(mm)	slope (‰)
Center of shield's head	4	-3	5	5	19.5
Center of shield's tail	4	-4	6	-3	19.5

Table 5 compares the result of repetition measurement of shield posture based on close-range photogrammetry and traditional repetition measurement by manpower.

Table 5. The parameter list of shield posture measured by above two ways in this range

Measuring method	Lateral deviation(mm)		Vertical deviation(mm)		slope (‰)
	Center of shield's head	Center of shield's tail	Center of shield's head	Center of shield's tail	
Number obtained by close-range photogrammetry	5	6	5	-3	19.5
Number obtained by manpower	7	5	5	4	17.7

Close-range photogrammetry is more accurate and appropriate by comparing the two different results. Therefore, it is necessary to apply the close-range photogrammetry to the repetition measurement of shield posture.

3. The repetition measurement of duct piece posture

The measurement of duct piece includes testing segment ring's center deviation, ovality and posture. More than 3 to 5 rings' front face of duct piece will be tested per measurement. In measuring adjacent ring, 2 to 3 rings should be tested in overlap. Allowable misalignment is ±15mm in testing ring plane and height measurement[6] . The operation scheme of close-range photogrammetry's appliance into shield duct piece posture is as follows:

3.1 The choose and layout of mark points

Set solid marks before measuring, which could be used as control points or points to be tested. If the marks are used as control points, there are two requirements for the shapes of marks: first, to choose appropriate size; second, mark points are clear enough to be recognized. There are many shapes of marks. Some marks that are commonly used are as follows:

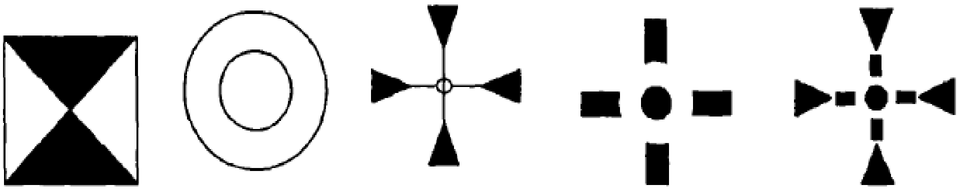


Fig 5. Several marks that are commonly used

The size of marks is related to photographic scale. Generally, the size of marks' image formation is a little bigger than marks. However, this is not the only standard. The size of marks varies in different geographical conditions, which should be designed according to the actual demand.

To measure shield duct piece posture, it is necessary to know what it is. Being the permanent lining structure of shield tunnel, shield duct pieces are composed of several matched duct pieces, as is shown in Fig 6:

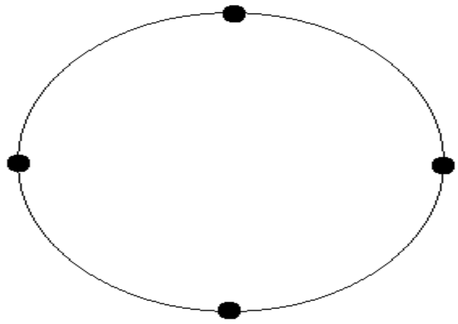


Fig 6. Chart of tunnel duct pieces Fig 7. Diagrammatic sketch of measuring points on segment ring

To finish the measurement of duct piece posture, four joints on the left , right, top and bottom of segment ring are regarded as layout location of mark points, as is shown in Fig 7. On the tunnel duct pieces, set a group of measuring points per 5 rings. Measuring points are painted on reflecting marks, which is fixed on expansion bolt. Later, someone installs them on the tunnel duct pieces.

3.2 Data acquisition and processing

After setting control points in the tunnel, choose two appropriate sites, and then take digital image of tunnel duct pieces with digital camera after calibration. The image should contain control points which are set in the respect of tunnel's forward direction. After calculating the unknown control points, the result is used in the second calculation, which is the recursive method following regular sequence. Besides, in taking the image of duct pieces, three rules need to be obeyed to improve image's quality. First, choose appropriate camera angle; second, the camera should be placed on tripod to avoid imaging errors caused by the shaking of hands; third, two images should contain all measuring points when shoot by convergent method. Choose appropriate, high-quality image from several images, which is used as measuring image.

As for collecting 3D coordinates of control points, all need to do is to collect 3D coordinates of the first set of data acquired by total station. Meanwhile, inquire coordinate system in the tunnel from construction material, the data obtained from which is brought into the same coordinate system of the construction, bringing convenience for the later calculation and project.

Process the unclear image to eliminate the influence of uneven brightness and noise on image, which improves image's quality. Then measure the plane coordinates of measuring points' image and transform it into image's plane coordinates, which is done by calibrating procedure of camera coordinate. Based on resection and intersection, object's spatial coordinate is calculated, which can deduce 3D coordinates of segment rings' mark points.

4. Conclusion

Along with the advancing of section construction in large-scale tunnel and underground space, the traditional contact measurement is time-consuming and strenuous, the use of which make measurement and construction interfere with each other and human factor have a great influence on the accuracy of measurement. Because of the above disadvantages, the original measuring line may be given up, causing the disruption of measuring data and the loss of large measurement information. Therefore, the traditional contact measurement can't meet the demand for modern tunnel shield construction. Total station coordinate method can realize non-contacting observation and can obtain 3D information of points' change. However, total station requires much of field environmental condition and it takes a long time to achieve actual observation, which sometimes contradicts the construction. Moreover, the number of deformation points to be measured is limited. Compared with other methods, especially with contacting ones, close-range photogrammetry is a non-contacting measurement without interfering analyte's natural state, whose large physical information and geometric information can be obtained in an instant. It is convenient to gain, store and process data with close-range photogrammetry. However, aspects including the acquisition and processing of data, the improvement of accuracy, communication and delivery, software implementation, early warning beyond limits need further strengthened to realize the need for real-time repetition measurement.

Acknowledgements

Sichuan province science and technology innovation talent project (2016096).

References

[1] Chen Kui, Hong Kai-Rong, Wu Xue-Song. Shield Construction Technique [M]. 2009.
[2] GB 50446-2008, Code for Construction and Acceptance of Shield Tunneling Method[S].
[3] Lane S N, Chandler J H, Porfiri K. Monitoring river channel and flume surfaces with digital photogrammetry [J]. Journal of Hydraulic Engineering, 2001， 127(10): 871-877.
[4] Liu Zhi-Ming, Fang Yong, Zhang Jian-Hui, etc. The Application of Non-metric Digital Camera in Segment Deformation Measurement[[J]. Bulletin of Surveying and Mapping, 2001(6):40-41.
[5] Ohdake T, Chikatsu H. 3D modeling of high relief sculpture using image-based integrated measurement system[J]. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2005, 36(5/W I 7): 6.
[6] McGinnis M J, Pessiki S, Turker H. Application of three-dimensional digital image correlation to the core-drilling method[J]. Experimental Mechanics, 2005, 45(4): 359-367.