A Review on Measurement of Gun Barrel Pointing

DUAN Xiusheng[1, a], HUANG Yi[2,b*] and ZHU Yaoxuan[3,c]

[1,2]Department of Electronic and Optical Engineering, Ordnance Engineering College, Shijiazhuang, 050003, China

[3]Department of Astronautics, Electronic Engineering Institute, Hefei, 230031, China

[a]email sjzdxsh@163.com, [b]email dd_huangyi@163.com, [c]email zhuyaoxuan1989@126.com

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Abstract. The measurement of the gun barrel pointing is an important part of artillery performance test. In this paper, the existing methods are classified and their principles, advantages, disadvantages and application situations are introduced. Besides, we discussed the prospects and trends on the measurement methods from different aspects.

1.Introduction

The measurement of elevation angle and azimuth angle of gun is an important index of artillery servo system performance test. It's also the basic to ensure the first hit for live firing training or combat and realize the closed-loop correction. Under the modern war, to achieve precision hit, precision correction and rapid response, the high precision measurement of gun barrel pointing becomes a problem to be solved.

The measurement methods can be generally grouped into two categories: direct and indirect [1].

2.Methods based on the direct measurement

This kind method is to measure the rotation of gun barrel to a stable reference object directly, but usually it fails to take factors such as the vibration of gun barrel into account [1].

Domestic research starts in 2001 with the first set of instrument outfitting factory [2], and has developed several methods, as shown as follows:

2.1 Based on high precision theodolite.

The method based on high precision theodolite is the mainstream approach.

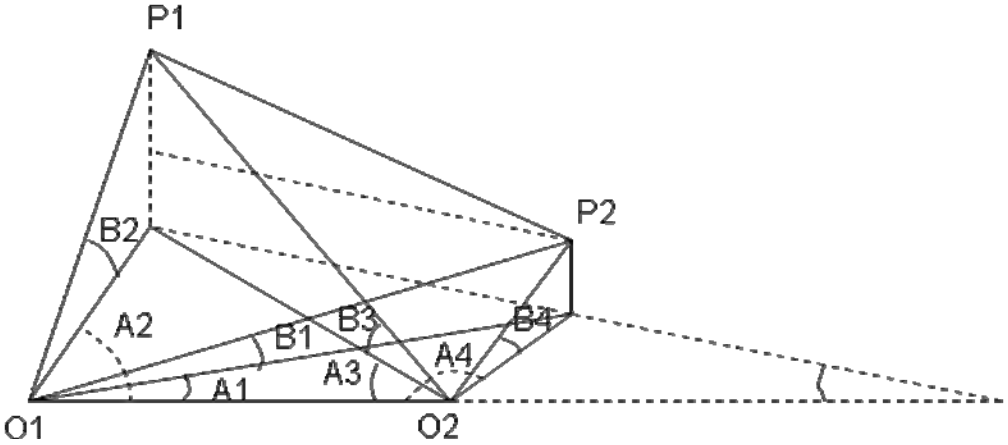

Fig. 1. Testing system diagram based on high precision theodolite.

As illustrated in Fig. 1, firstly, set two electronic theodolites O1, O2 at one side of the artillery, zero the azimuth after collimating each other; then paste two tags P1, P2 on the axis of the gun barrel and leave two theodolites aim at P1, and then P2 to obtain four azimuth angle A1, A2, A3, A4 and

four elevation angle B1, B2, B3, B4. According to the relationship between the angle measured and the gun barrel pointing, it's easy to figure out the azimuth and elevation angle of gun barrel.

In 2001, Tao Huacheng designed test system of gun barrel pointing to suppressing weapons, the static measurement precision of which reached o.2 mil [2], but it's expensive and not cost-efficient for large distribution. Dong Qi-shun et al. studied the influence of theodolite disposition on measurement precision, and given the optimal disposition. SUN Ze-lin et al. investigated the measurement error and given the method to control and reduce error.

2.2 Based on the total station.

Generally, Test system based on high precision theodolite needs two theodolites, and measures eight angles. In comparison with theodolite, Single total station can not only measure angle but also distance to the gun barrel. In fact, only two distance values and four angle values is enough for calculating the azimuth and elevation angle of gun barrel, as shown in Fig. 2. The mathematical model is as follows:

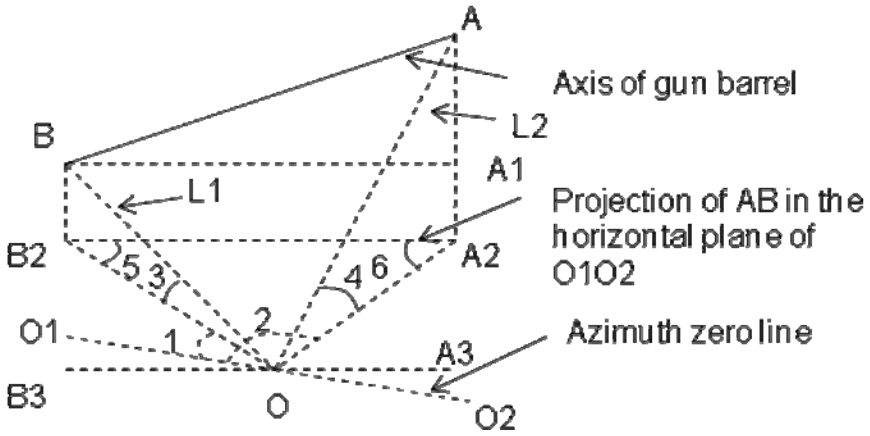

Fig. 2. Testing system diagram based on the total station.

In 2013, ZENG Kan improved the approach based on two theodolites by introducing total station and designed a system to measure gun rotated accuracy [3]. In 2014, WANG Jian-guo et al. presented a method to complete the detection of gun aiming accuracy using a total station. This method developed the traditional method based on double theodolites, to some extent, reduced the cost and simplified the calculation.

2.3 Based on the gyroscope.

Gyroscope is a detection device sensitive to the change of angle.

FOG (fiber optic gyro) and laser gyro are both modern gyroscope based on the SAGNAC effect in optics. In fiber optic circuit, two light propagates from the opposite direction, and when the circuit rotates, optical path length will change. By detecting the change of the optical path length, we can obtain the angular velocity accurately, then get the rotation angle through the integral of it.

In 2003, Zhang Bo et al. proposed a method based on rate gyroscope, and obtained the rotation angle by the integral of the angular rate [4]. In 2010, Zhou Lihui et al. put forward an approach to use FOG as a sensor to angular velocity and angular acceleration. In 2011, Yan Debin presented a method to use three laser gyro installed mutually perpendicular to get the changes of three directions and two accelerometer installed mutually perpendicular to measure carrier's initial horizontal posture. This method is of high precision, hardly affected by the test environment, and the operation is relatively simple, while its test precision mainly depends on the precision of the gyroscope and its price is high. In addition, for rate gyroscope, the integral of angular rate will lead to error accumulation due to the interference and noise added to angular rate, and result in a decline in its precision.

2.4 Based on machine vision.

Through camera, the point in the real world is imaged on the CCD as an image point. There is a certain corresponding relationship between the image point and point in the real world. By calculating the relationship, we can match any image point with the point in the real world. This is the calibration of the camera. The ordinary method of calibration is to set a reference object such as chessboard in the real world, and extract its image to get the internal and external parameters, which represents the certain corresponding relationship. By processing the image recorded according to the conversion between the image and real world, , we can get the gun barrel pointing easily.

In 2012, Duan Xiu-sheng and Zhu Yao-xuan proposed a method based on machine vision [5]. They fixed a chessboard on the gun barrel, and get gun barrel pointing through addressing image of it. This method is inexpensive, simple to operate and of high precision relatively, but easy to be affected by the light.

Abroad starts the research in the 70 s to 80 s and has a relatively mature development. In recent years, few literatures can be found in this research area abroad. Only in a research paper of Li Zhiqiang in 1999 [1], it shown there were mainly two methods. One is with the shaft encoder of high precision; the other is using flexible gyro to get gun barrel pointing.

3.Methods based on the indirect measurement

This method is to detect and calculate the position that gun barrel aims at on target board, so you can put all the factors affect the aiming accuracy taken into account [1].

The domestic mainly formed the following methods:

3.1 CCD + target board.

This method is basically the same with the gun stability precision test method in military standard. The procedure is to install CCD on the muzzle, set the target board out of the radius of the gun barrel, as shown in Fig. 3; Then do calibration for CCD, for the purpose of determining the corresponding angle value to each pixel of each frame picture, as shown as follows:

$$Ka = \frac{a}{H} \times 16.6667 . \tag{1}$$

$$Kb = \frac{b}{V} \times 16.6667 . \tag{2}$$

where a, b is horizontal and vertical field angle and H, V is corresponding pixel number of image.

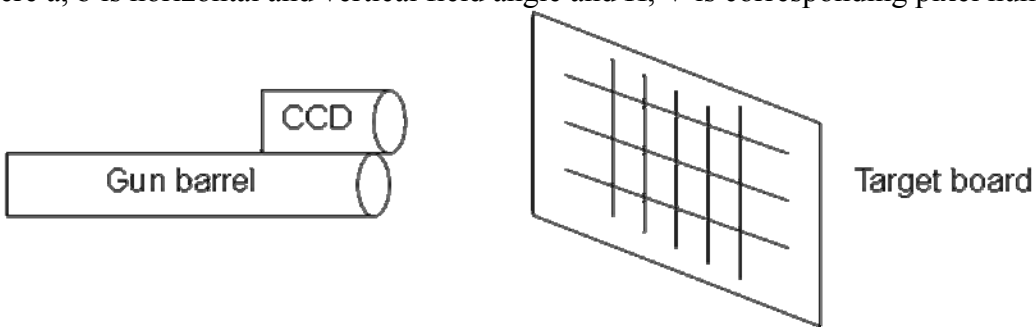

Fig. 3. Testing system diagram based on CCD + target board.

By addressing the information recorded by CCD, it's easy to get the target position in the picture, and obtain the rotation angle according to the formula above.

In addition, on the choice of the target board, to get image data of high precision, you can make some marks easy to identify on the target board, like cross, grid. On the processing of data, in order to

reduce random error, recording the video data of the target and fitting these addressed results of each frame picture can make sense.

In 2011, WANG Chunyan et al. developed multi-optical system, and realized the high accuracy measurement of muzzle axis, the axis of the bore and line of sight. By adding the optical system between CCD and target, the CCD imaging accuracy is greatly improved. In 2012, SUN Zelin et al. established an artillery stability precision test system using CCD and target board, and studied the detail algorithm of imaging preprocessing, fuzzy matching and positioning the cross center on the target board [6]. In 2012, DUAN Changlin et al. applied angle sensor to detect zero-line and zero-spot, and realized the detection in the environment of all-weather.

3.2 Laser + PSD board.

PSD (Position Sensitive Detector) is a new type semiconductor device sensitive to position and also with high resolution and rapid response. In this method, we set the PSD target out of the radius of gun barrel, install the laser on the muzzle, and pulse laser at a certain frequency. The PSD can accurately capture the laser spot location. By comparing with the former location, the rotation angle can be figured out.

Because the light area of PSD board is only 10*10 mm, in order to extend the test range, an optical lens could be placed between the PSD board and laser, to ensure laser received in a wider range, as shown in Fig. 4.

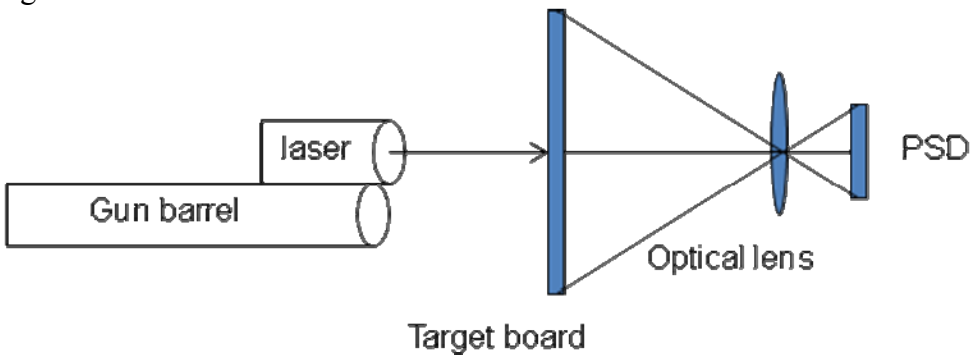

Fig. 4. Testing system diagram based on Laser + PSD.

Both two methods are to measure the displacement reflected on target board or video to get the rotation angle. Its advantage is that it's consistent with the test methods of tank or gun stability precision in the current military standard and contains all factors that affect the precision. Its disadvantage lies in that the error resulted by the calculation formula has to be made up if beyond the range of the target board.

In 2001, TANG Xia-qing et al. applied PSD to the performance test of fire control system and investigated measures to improve test precision [7]. In 2004, HE CH et al. studied several kinds of indirect measurement methods (mainly procedure, advantages and disadvantages) [8]. In 2009, QIN J et al. introduced the stability precision test method applied in range and the procedure of video collection, calculation and analysis.

There is no foreign research literature found in this area, and the two main test method has been mentioned only in a paper published in 1999 by Li Zhiqiang [1]. One is to install the CCD on the muzzle, set a target board with grid out of the gun, and then process the image recorded by CCD to determine the rotation angle of the gun barrel. The other is to replace the target board with transparent board, record the spot on the board produced by laser on the axis of the gun barrel, and then process the data recorded. In addition, using photo sensor array as an alternative of transparent board can easily capture the spot on the target board.

4.Main problems and trends of development

As illustrated above, the basic methods about gun barrel pointing measurement are introduced. Different method suits different condition. In range test, target board + CCD and gyroscope are always used; in laboratory or factory test, it's adaptive for two theodolites, total station, gyroscope, machine vision and laser + PSD etc. Moreover, as to equipment state inspection , performance test after repair or minor repairs and real time closed-loop correction, because of lacking test conditions such as high precision theodolite and total station, methods based on sensor and machine vision should be focused on.

Currently, method based on two theodolites is the mainstream and has a relatively mature development, but the cost is high. From the point of view to reduce cost, the method based on machine vision has a good prospect, because this kind method mainly depends on the precision of CCD and ability of data processing. For example, in the case of ordinary industrial camera, satisfactory accuracy can be obtained through optimizing algorithm. In addition, there is no enough work done on the dynamic measurement of gun barrel pointing. In the view of high precision, direct data, and not so strict with the environment, gyroscope could be a good choice to be applied presently. Methods introduced above mainly are developed for performance test in laboratory or factory, and has a low practicability in range and battle. On this aspect, gyroscope is not so strict with the environment and could be a choice, but cost high. To solve the problem, new method has to be proposed. Moreover, except performance test, another purpose of the measurement of gun barrel pointing is to use the signal as a feedback for the fire control system, to realize the real-time closed-loop control. However, there is no method adaptive to integrate into the gun system, so gyroscope and shaft encoder have a good prospect presently.

5.Conclusion

The measurement of the gun barrel pointing plays an important role in artillery performance test. In this paper, we investigated the existing methods and their principles, advantages, disadvantages and application situations. Finally, from different aspects, we discussed the prospects and trends of measurement methods.

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