Error Tracking and Compensation Method Obtained by High-speed TV Measurement System

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Abstract: Because the high-speed TV measurement instrument used to track and measure the vertical take-off section of the carrier rocket sometimes can’t provide the systematic error in the spaceflight test range, a systematic error compensation method is established succinctly and skillfully through spatial analytic geometric relationship by making full use of the rocket outline size, launch aiming direction and site parameters of each measuring station. An analysis on calculation results of actual task data shows that this error compensation method not only realizes the error correction purpose of tracking measurement instrument accurately, but also improves the flight trajectory and attitude calculation results of the carrier rocket at the same time, expanding the technology for systematic error correction method through optical measurement.

1. Introduction
In the spaceflight test range, the high-speed TV measurement instrument used to track and measure the lateral drift in the vertical take-off section of the rocket adopts the optical structure of short focal length and large vision. This structure feature makes the instrument cause obvious measurement error response even though there is only a tiny error. When the instrument systematic error can’t be measured (for example, ineffective shooting of azimuth mark used to calibrate the systematic error, or the calibration instrument can’t be installed due to insufficient installation condition, or the tracking coded disc can’t be linked), the measurement data can’t reflect the trajectory and attitude of rocket flight accurately. Therefore, without the support of systematic error parameters, the data measured by high-speed TV measurement system is no longer significant. However, for spaceflight measurement task, it is a waste of resource and data processing regret if the measured data is abandoned only for this reason. Based on making full use of the existing rocket outline size and site parameters of each station, this paper establishes a systematic error compensation method succinctly and skillfully through spatial analytic geometric relationship to determine the flight state of the rocket accurately.

2. Method introduction
Generally, three high-speed TV measurement instruments are used to track and measure the vertical take-off section of the rocket in the spaceflight range test. Due to the scientific and reasonable design, there is only orientation error and zero error in general. Therefore, this paper researches and determines based on the two systematic errors so as to compensate the systematic errors and determine the flight state of vertical take-off section of the rocket accurately.

2.1 Measuring method
The orientation error is that the zero position of azimuth coded disc of optical measurement unit...
deviates from the angle value of geodetic north or astronomic north. The zero error is that the zero position of high and low coded disc of optical measurement device deviates from the angle value of the horizontal direction\cite{1-5}. Based on this concept, the position of different measuring stations in the launching coordinate system, design data of corresponding measuring points of carrier rocket and launching aiming direction are used to obtain the amount of orientation error and zero error of devices in different measuring stations.

Fig. 1 is the relationship diagram of carrier rocket, launching coordinate system and aiming direction, where O-XYZ is the launching coordinate system; N is the launching aiming direction; O-O is the launching standard horizontal plane.

Measuring method: Firstly, select a feature point position of the carrier rocket from the video image tracked and measured by the high-speed TV measurement instrument in the measuring station, as shown in point A in Fig. 2, read the feature points in the video image of the rocket on static state to obtain the measured data of 20 points. Then after the dimension restoration and position correction (correct to the rocket axis), the azimuth angle and mean pitch angle of this point in the coordinate system of measuring station are obtained, namely Ac and Ec.

Fig. 1 Relationship diagram of carrier rocket, launching coordinate system and aiming direction

Fig. 2: Outline drawing of rocket

2.2 Calculation method

2.2.1 Determination of orientation error

According to the position of each measuring station in different quadrants, Ai, the theoretical azimuth angle of a certain feature point in the coordinate system of measuring station can be obtained. Fig. 3 is the station distribution of measuring station O_i in the launching coordinate system. According to the position of each measuring station in different quadrants, Ai, the theoretical azimuth angle of a certain feature point in the coordinate system of measuring station can be obtained.
① The first kind of station distribution

② The second kind of station distribution

③ The third kind of station distribution

④ The fourth kind of station distribution

Fig. 3: Diagram of measuring station distribution (horizontal direction)

Suppose the site coordinates of measuring station in the launching coordinate system are \( x, y \) and \( z \), establish the calculation model based on the different station distributions in Fig. 3:

\[
A_i = \begin{cases} 
A_0 + \frac{\pi}{2} + \arctan \left( \frac{x}{-z} \right) & \text{The first kind of station distribution} \\
A_0 + \arctan \left( \frac{z}{x} \right) & \text{The second kind of station distribution} \\
A_0 - \arctan \left( \frac{z}{-x} \right) & \text{The third kind of station distribution} \\
A_0 - \frac{\pi}{2} - \arctan \left( \frac{x}{z} \right) & \text{The fourth kind of station distribution}
\end{cases}
\] (1)

\( A_0 \) in the formula is the launching aiming azimuth angle of the carrier rocket. Then the orientation error is obtained:

\[2.2.2 \text{ Determination of zero error}\]

According to the different position of measuring station in the launching coordinate system, especially the high and low position of measuring station, \( E_i \), the theoretical pitch angle of a feature point in the coordinate system of measuring station can be obtained, as shown in Fig. 4.
The first kind of station site

The second kind of station site

The third kind of station site

Fig. 4: Diagram of measuring station distribution (vertical direction)

Suppose the site coordinates of measuring station in the launching coordinate system are \(x, y\) and \(z\), establish the calculation model based on the different station distributions in Fig. 4: \(h\) in the formula is the vertical distance from a certain measuring point on the rocket to the origin of launching coordinate system.

\[
E_i = \begin{cases} 
- \arctan \frac{h-|y|}{\sqrt{x^2 + z^2}} & \text{The first kind of station site} \\
- \arctan \frac{h+|y|}{\sqrt{x^2 + z^2}} & \text{The second kind of station site} \\
\arctan \frac{|y|-h}{\sqrt{x^2 + z^2}} & \text{The third kind of station site}
\end{cases} 
\]  

(2)

And the zero error is obtained:

\[
\Delta E = E_i - E_c 
\]  

(3)

3. Application analysis

The external trajectory data before and after error compensation are calculated and compared with the simulation data. Fig. 5 to Fig. 7 is the data comparison of coordinate position in direction \(x\). Fig. 8 to Fig. 10 is the data comparison of coordinate position in direction \(y\). Fig. 11 to Fig. 13 is the data comparison of coordinate position in direction \(z\).
We can see from Fig. 5 to Fig. 7 that the position parameter in direction X is closer to the actual take-off situation at the moment “0” after error compensation correction. After take-off, especially during the program turning a corner, the data of uncompensated position is 2 meters lower and develops into an obvious rapid decline trend as the time goes on.
We can see from Fig. 8 to Fig. 10 that the position parameter in direction Y is closer to the actual take-off situation at the moment “0” after error compensation correction. After take-off, especially during the program turning a corner, the data of uncompensated position is nearly 15 meters lower and then develops into a rapid increase trend.

We can see from Fig. 11 to Fig. 13 that the position parameter in the uncompensated direction Z is nearly 10 meters lower and totally deviates from the actual flight situation, while the data after compensation is closer to the actual take-off situation. After take-off, especially during the program turning a corner, the data of uncompensated position shows an obvious increase trend.

4. Conclusion
The high-speed TV measuring instrument system is an important optical measuring device used to track and measure the vertical take-off of carrier rocket, and the measured data can be used as an
important reference for the carrier’s flight performance, improving the rocket structure, perfecting measuring and launching systematic performance and improving the safety of launching process. The error compensation method of tracking measurement proposed in this paper can effectively compensate the systematic error in high-speed TV measuring instrument, provide reliable technical support for reflecting the flight situation of carrier rocket accurately and continue to play an important role in the subsequent spaceflight test tasks.

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References
[1] Liu Lisheng. Post processing of external measurement data [M]. National Defence Industry Press.2000.02.
[2] Liu Bingshen,Liu Chunkui,Du Haitao. Accuracy identification of range measuring equipment in shooting range [M]. National Defence Industry Press.2008.03.
[3] Luo Haiyin. Technology Dictionary of missile TT & C Communication [M]. National Defence Industry Press.2001.09.
[4] He Zhaocai. Optical measurement[M]. National Defence Industry Press.2002.10.
[5] Cui Shuhua, Hu Shaolin. Processing of optical tracking measuring data[M]. National Defence Industry Press.2014.09.
[6] Xiong Zhihui. Application of High-Speed Pickup In Measurement System for Shooting Range [82-84]. CHINA MEASUREMENT & TEST.2012.01.
[7] Zhang Junfeng Zhang Shanxi Yang. Zhigang Information Transmission Design of Distributed Cinetheodolite Instrumentation System [78-82]. Journal of Spacecraft TT&C Technology.2005.04.
[8] Chen Zhijian Yang Xiaojun Li Zhe. Study on the Methods of Control and Calibrated Focal Length in High-speed TV Measurement Instrument[3145-3148].Science Technology and Engineering.2007.07.
[9] Xiong Zhihui. Design and Realization of Main Monitoring Software About High Speed Videograph [92-95].JISUANJI YU XIANDAIHUA.2011.02.