A Test System of Dynamic Angle of Tank Turret using Fuzzy Data Fusion

Feng Han¹ ², Wanhai Yang¹, Lei Zhu³, Xuesong Liu⁴

1 Xidian University
Xi’an, Shanxi, China
2 School of Optoelectronics Engineering
Xi’an Technological University
Xi’an, Shanxi, China
3 Xi’an Institute of Applied Optics
Xi’an, Shanxi, China
4 Inner Mongolia North Heavy Industry Group Co., Ltd.
Inner Mongolia, China

Abstract — The measurement accuracy of a tank turret rotation angle relative to the chassis absolutely determines the accuracy and stability of the aiming system and the inertial navigation system. A loaded turret of most battle tanks has a low rotation angle measurement accuracy relative to the chassis, there is a need to solve the problem of steering the tank body only. This paper proposes a high-precision testing system which works on the multi-channel dynamic condition based on Fuzzy set theory and data fusion of the tank turret rotation angle. We introduce the working principle and process first, then make calibration and error analysis on the device. Results of the joint commissioning on the battle tank proved the testing system has met the actual specification.

Keywords - fuzzy theory; tank turret; data fusion; rotation angle

I. INTRODUCTION

The measurement accuracy of dynamic angle [1] directly affect land vehicle weapons, aviation and other fields in the tracking and positioning to combat, the guidance accuracy. At present, all of the country's main battle tank is equipped with a turret relative to the chassis of the angle measuring device can only be a rough measurement of gun relative to the chassis rotation angle, which adopts the mechanical dial display, do not have signal output function. Tank chassis with the angle measuring device is only the tank body to solve the problem, and the measurement accuracy of the angle measuring device is low. Domestic main battle tanks are equipped with high precision gyro, only to realize line of tank cannon and pointing angle measurement of the line, not to be able to achieve a turret relative to the chassis of the angle measurement. Therefore, tank turret relative chassis of dynamic angle measurement with high precision is stabilized sighting system and inertial navigation system on the tank should be used need to solve the bottleneck of technology.

Tank turret huge volume, internal space narrow and complex, and measuring device to work in harsh impact vibration and dust pollution [2], harsh environment, the tank turret and the chassis of serious random radial traverse, resulting in precise angle is very difficult. For tank structure of such a complex and harsh environmental conditions, traditional angle measurement techniques (such as circular magnetic grating angle measuring method, synchronous sensor angle measurement method, circular grating angle measuring method, CCD scanning method, multi tooth indexing plate method and rolling wheel method, etc.) cannot meet the tank turret and the chassis of dynamic angle measurement with integrity, accuracy, stability, reliability, objectivity and other technical requirements. At present there is no domestic a method can achieve tank turret relative to the chassis is high precision of dynamic angle measurement, and it can realize the zero memory and power failure protection function.

This paper proposes a based on fuzzy data fusion of multi channel dynamic conditions under the angle of tank turret high precision testing system [3-5]. The device using photoelectric detection, image measurement and data fusion technology, overcome the turret ring gear machining error, axial channeling move, bearing ring gap, turret overall translation, gear null is passed back to the factors that lead to the error for precision strike tanks and stabilized sighting system and inertial navigation system to provide reliable technical support.

II. SYSTEM COMPOSITION AND WORKING PRINCIPLE

A. System Composition

Dynamic angle of tank turret high precision measuring device by image method for measuring components, resolver measurement component, non contact mechanical sensor measurement assembly and integrated data processing box components is composed of four parts. As shown in Figure 1. The components of the measurement and verification device are as follows:

(1) image measurement component by a cooperative target, CCD camera, CCD camera bracket and lighting light source and supporting power of five modules.

(2) resolver measurement component is composed of two parts, angular position measurement system and the
photovoltaic positioning system, angular position measurement system mainly realizes turret angle measurement, optical positioning system is mainly to achieve the zero memory function, after the power system working again data continuation functions, instantaneous electrical position recognition function;

(3) Non contact mechanics sensor measurement assembly by the mechanical sensor turret, turret data acquisition module, chassis mechanical sensor, data acquisition module chassis and supporting power five modules.

(4) Integrated data processing box component by the system power supply board, image processing unit and a data communication unit circuit board, angular position measurement system and data communication unit circuit board, data fusion module and data communication unit circuit board composition. The core data fusion module and data communication unit circuit board, the board based on the ARM9 Embedded microprocessor as the core and by homogeneous and heterogeneous sensor data processing software and hardware composition.

B. System Working Principle

Using multi-channel measurement technology to achieve turret rotation angle dynamic high precision measurement. The design using rotating transformer angle measurement and image measurement technique measurement of double channel of turret rotation the same physical quantity measurement can be realized, and the multi channel measurement of multi sensor data fusion technology to solve the single sensor cannot be stable and reliable turret angle measurement problems.

Using rotating transformer angle measurement and image measurement technique land with high precision measurement of vehicle equipment turret rotation angle to achieve, photovoltaic coding and image coding technology to achieve zero memory, power-off protection, power-off during rotation, electric instant recognition as the performance index, using non contact mechanics sensor measurement verification apparatus verifies dynamic measurement accuracy (tank movement).

Multi channel measurement of multi-sensor data fusion is measured in different positions of a plurality of similar or dissimilar sensor data to be integrated to eliminate that may exist among sensor redundant and conflicting data, reduce the uncertainty and improve the measuring accuracy and measuring stability and repeatability[6].

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III. DATA FUSION ALGORITHM BASED ON FUZZY THEORY

In the data fusion, the degree for multi sensor data fusion algorithm based on Fuzzy clinging. First of all, the measured and estimated values are fuzzified, and then calculated to measure value and fuzzy value between the fuzzy degree of nearness, according to fuzzy closestness degree to describe the sensor in the measurement of weight, this method can objectively reflect the reliability degree of each sensor and data fusion without prior information of the data, strong versatility, income of fusion results are reliable and high precision.

A. Data Preprocessing

The idea of using the 3σ rule, only one residual error is removed at a time, and the maximum value falls within 3 ± σ. Read all the data, there are m data, calculate the average value of M data, \( \bar{x} \) representation. As well as the difference between the average value of the data and the extraction of the maximum value of these CO. Compare \( |C| \) with \( 3 \pm \sigma \), if \( |C| \geq 3 \pm \sigma \), then eliminate \( |C| \), else if \( |C| \leq 3 \pm \sigma \), retention data \( |C| \). All with the completion of the gross error data is removed. Is not to eliminate all measured values, does not contain gross errors, as a fusion algorithm of effective data.

In the measurement process, affected by various factors, the sensor measurement value and the real value of error, the true value just in the vicinity of all valid data. The assumption that the measured value contains only random errors, in order to facilitate the engineering application, choose triangle membership function[7].

B. Fuzzy Data Processing

In the measurement process, affected by various factors, the sensor measurement value and the real value of error, the true value just in the vicinity of all valid data. The assumption that the measured value contains only random errors, in order to facilitate the engineering application, choose triangle membership function.

The definition of a fuzzy number \( \mu \) is a normal convex fuzzy set defined on the real number field \( R \), and satisfies the following conditions[8]: (1) There is only one point \( s \in R \), degree of membership \( \mu(s) = 1 \); (2) The membership function is left and right continuous.

\[
\mu(x) = \begin{cases} 
L(x), & \text{if } s \leq x \leq m \\
R(x), & \text{if } m \leq x \leq r 
\end{cases}
\]
In Formula (1), \( L(x) \) is an increasing function, and the right continuous, and \( 0 \leq L(x) \leq 1 \). \( R(x) \) is a reduced function, and the left continuous, and \( 0 \leq R(x) \leq 1 \). If \( L(x) \) and \( R(x) \) are linear functions, then \( N \) is called triangular fuzzy number.

As shown in Figure 2, the center of the triangle is the measured value of the sensor, and the width is 4 times the variance of the measurement data. In the practical work, the application of \( N \) sensors, the first \( I \) of the real value of \( A \) sensor for \( K \) times measurement, measured value are \( x_{i1}, x_{i2}, \ldots, x_{in} \), their average value is \( \bar{x}_i \) and standard deviation is \( \sigma_i \). The fuzzy quantity of the measured value is expressed as:

\[
A_i = (a_{i1}, a_{i2}, a_{i3}) = (\bar{x}_i - 2\sigma_i, \bar{x}_i, \bar{x}_i + 2\sigma_i)
\] (2)

Measurement data a total of \( m \) data, a fuzzy method for measuring the value of a target for all measured values is similar to the method of measuring the value of the measured value. The estimated value is expressed by \( x_0 \), the estimated variance is expressed by \( \sigma_0 \).

\[
\sigma_i = \frac{1}{m} \sum_{n=1}^{m} (x_n - x_0)^2
\] (3)

\[
\bar{x}_0 = \frac{1}{m} \sum_{n=1}^{m} x_n
\] (4)

### C. Weight Value Calculation and Data Fusion Based on Fuzzy

In actual multi-sensor data fusion process, the different measurement value of its reliability is not the same for different measurement value in fusion should be given different weights, better stability, high reliability of data fusion should have greater weights. Theoretically speaking, if a measurement value is more close to the estimated value, you can think the better stability and reliability of the data. Based on the fuzzy set theory, fuzzy closeness degree of measuring values and estimated values were close to that extent, determines the corresponding weight, in order to carry out the integration of data processing. Definition and calculation of fuzzy closeness degree [9]: Set \( \hat{A}_i \) and \( \hat{A}_j \) for two fuzzy quantities, \( S(\hat{A}_i, \hat{A}_j) \) if \( A \) meets the following conditions, ① \( 0 \leq S \leq 1 \); ② if and only if \( \hat{A}_i \cap \hat{A}_j = \Phi \), \( S(\hat{A}_i, \hat{A}_j) = 0 \); ③ if \( \hat{A}_i \subset \hat{A}_j \), then \( S(\hat{A}_i, \hat{A}_j) > S(\hat{A}_j, \hat{A}_i) \). Then \( S \) is called for \( \hat{A}_i \) and \( \hat{A}_j \) close degree, \( \hat{A}_i \) and \( \hat{A}_j \) close to the degree. There are many methods to calculate the closeness degree of fuzzy quantity. In order to realize the reliability and convenience, the method of calculating the closeness degree based on distance measure is defined as follow:

\[
S(\hat{A}_i, \hat{A}_j) = \frac{1}{1+d(A_i, A_j)}
\]

\[
d(\hat{A}_i, \hat{A}_j) = \left| \frac{a_{i1} + a_{i2} + a_{i3} - a_{j1} - a_{j2} - a_{j3}}{6} \right|
\]

The greater the value of \( S = S(\hat{A}_i, \hat{A}_j) \), the more close to the \( \hat{A}_i \) and \( \hat{A}_j \). If \( S(\hat{A}_i, \hat{A}_j) = 0 \), indicates that \( \hat{A}_i \) is completely different from \( \hat{A}_j \).

In this consideration is the close degree of each sensor measurement value \( A_i \) and the target estimate value \( A \), the relative weight of the first \( i \) measurement value is \( r_i \), then the relative weight of each data obtained after the normalization process that is \( w_i \). \( r_i \) and \( w_i \) relations are as below:

\[
w_i = \frac{r_i}{\sum_{i=1}^{n} r_i}
\] (5)

According to the relative weights of the data obtained, the final fusion result \( y \) is as follow:

\[
y = \sum_{i=1}^{n} w_i x_i
\] (6)

The data fusion algorithm based on the fuzzy theory is shown in Figure 3.
Figure 1  A high precision measuring device for the turret of the tank under dynamic condition

Figure 2  Triangular fuzzy function

Figure 3  Data fusion algorithm flow chart
IV. CALIBRATION OF ANGLE MEASUREMENT SYSTEM

The angle measuring system is calibrated by the method of photoelectric self collimation. Photoelectric self collimation calibration system is structured by rotary transformer angle measurement system, turret angle calibration table, consisting of four groups of autocollimator and a plane mirror and standard four prism. The calibration process is divided into the calibration of the turret corner (shown in Figure 4) and the calibration of the angular measurement system (shown in Figure 5). The calibration process using 5W-F550 type autocollimator, it’s precision is 1”.

In the turret angle calibration and calibration. First of all, the standard four prism through a bracket fixed on a plane which is parallel with the turret ring, with 1” autocollimator aiming mirror, regulation 4 groups autocollimator to return the cross like coincide with the preimage and turret angle calibration and calibration.

In angle measuring system calibration. First of all, the plane mirror through a bracket fixed on a plane which is parallel with the turret ring, with the group 1 autocollimator aiming mirror encoder zero, this point is used to measure the starting point, angle measuring system four standard face angle rotation, the measurement process and the measurement data as shown in Table 1 below.

V. TEST EXPERIMENT AND DATA PROCESSING

The test of the angle measuring system is shown in Figure 6, in which the theodolite is placed in the center of rotation of the turret of the tank.

The value of measurement, the theodolite aimed at plumb line AA1 as an initial zero and random rotation angle alpha read resolver values and theodolite, and then rotating theodolite the once again targeting the plumb line AA1 and read at this time the value of the theodolite, theodolite twice the difference is standard tank turret relative to the chassis rotation angle. Repeat the above steps, measurement data as shown in Table 2.

In the actual measurement, the measurement results in the presence of large error data, eliminating gross error after the angular accuracy of 22.3”.

VI. ERROR ANALYSIS BASED ON FUZZY CLOSENESS

The error of the angle measuring system mainly includes the image method angle measurement error, the measuring error of the rotating transformer and the measurement error of the non contact mechanical sensor, respectively as \( \delta_I \), \( \delta_{II} \), \( \delta_{III} \). The specific measurement error is shown in Table 3.

According to the error theory, the two measurement methods are the same physical quantity measurement, but it is considered as the system error of the analysis of the above analysis, the measurement error is the system error as follow:

\[
\omega_1 = \frac{\delta_I}{\delta_I} = 1
\]

\[
\omega_{II} = \frac{\delta_{II}}{\delta_{II}} = 1.2
\]
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\[ \omega_{III} = \frac{\delta_1}{\delta_{III}} = 1.9 \]  \hspace{1cm} (10)

According to the error calculation formula of group measurement:

\[ \delta = \sqrt{\frac{1}{(n-1)} \sum_{i=1}^{n} \omega_i \delta_i^2} = 0.18 \text{mrad} = 37.1' \]

In the whole measurement process, the error sources can be regarded as uniform distribution, measurement error of data fusion system is as follow:

\[ \delta = \frac{\delta'}{\sqrt{3}} = 0.103 \text{mrad} = 21.4' \]

From the above we can know that after the data fusion algorithm, the system is better than the average variance of two different measurement channels, that is, after the data fusion of multi sensor system, the measurement accuracy of the whole system is significantly improved.

<table>
<thead>
<tr>
<th>Rotation mode</th>
<th>Nominal value</th>
<th>Measuring value of angle measuring device</th>
<th>average value</th>
<th>standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>first time</td>
<td>second time</td>
<td>twice time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0°~90°</td>
<td>90°00'0.0&quot;</td>
<td>90°00'16&quot;</td>
<td>90°00'18&quot;</td>
<td>3.5&quot;</td>
</tr>
<tr>
<td>90°~180°</td>
<td>90°00'0.0&quot;</td>
<td>90°00'15&quot;</td>
<td>90°00'14&quot;</td>
<td>3.7&quot;</td>
</tr>
<tr>
<td>180°~270°</td>
<td>90°00'0.0&quot;</td>
<td>90°00'16&quot;</td>
<td>90°00'17&quot;</td>
<td>3.1&quot;</td>
</tr>
<tr>
<td>270°~360°</td>
<td>90°00'0.0&quot;</td>
<td>90°00'15&quot;</td>
<td>90°00'17&quot;</td>
<td>3.1&quot;</td>
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<tr>
<td>0°~180°</td>
<td>180°00'0.0&quot;</td>
<td>180°00'14&quot;</td>
<td>180°00'15&quot;</td>
<td>2.0&quot;</td>
</tr>
<tr>
<td>180°~360°</td>
<td>180°00'0.0&quot;</td>
<td>180°00'14&quot;</td>
<td>180°00'15&quot;</td>
<td>2.0&quot;</td>
</tr>
<tr>
<td>0°~360°</td>
<td>360°00'0.0&quot;</td>
<td>360°00'17&quot;</td>
<td>360°00'16&quot;</td>
<td>3.5&quot;</td>
</tr>
<tr>
<td>0°~360°</td>
<td>360°00'0.0&quot;</td>
<td>360°00'12&quot;</td>
<td>360°00'16&quot;</td>
<td>3.5&quot;</td>
</tr>
<tr>
<td>0°~180°</td>
<td>180°00'0.0&quot;</td>
<td>180°00'16&quot;</td>
<td>180°00'15&quot;</td>
<td>2.0&quot;</td>
</tr>
<tr>
<td>-180°~360°</td>
<td>180°00'0.0&quot;</td>
<td>180°00'23&quot;</td>
<td>180°00'26&quot;</td>
<td>2.0&quot;</td>
</tr>
<tr>
<td>0°~90°</td>
<td>90°00'0.0&quot;</td>
<td>90°00'18&quot;</td>
<td>90°00'17&quot;</td>
<td>2.3&quot;</td>
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<td>90°00'14&quot;</td>
<td>90°00'18&quot;</td>
<td>2.3&quot;</td>
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</table>

VII. CONCLUSIONS

This paper put forward a based on fuzzy data fusion of multi channel dynamic condition angle of tank turret high precision test method, the multi-channel measurement technology realize the turret rotation angle dynamic high precision measurement. The device using photoelectric detection, image measurement and data fusion technology, overcome the turret ring gear machining error, axial channeling move, bearing ring gap, turret overall translation, gear null is passed back to the factors leading to the error and precision strike tanks and stabilized sighting system and inertial navigation system to provide reliable technical support. The design and use of multi channel multi sensor data fusion technology to solve the problem of single sensor can not be stable and reliable measurement turret rotation. Through data processing and error analysis indicates that, the measurement error of the data fusion of tank turret of dynamic angle measurement system based on fuzzy for 21.4°. Practice has proved that the precision of measuring...
The system can for precision strike tanks to provide reliable technical support, has the very high use value.

REFERENCES


