A deep-sea drilling rig MEMS gyroscope random drift error correction method

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Abstract—**The deep-sea drilling rigs usually work in a complex waters and magnetic field environment and their attitude detection systems generally use a gyroscope to determine the output of the yaw angle. Deepwater rigs in seawater attitude detection and analysis of the characteristics of the MEMS gyroscope random drift come to a result that reducing the MEMS gyroscope random drift error is an important method to improve the precision of gyroscopeand and it establishes a MEMS gyroscope random drift error model for MEMS gyroscope initial measurement data pre-processing and gives the random drift fitting valuation and compensation method to improve the accuracy of the gyroscope within a certain time.With OpenGL 3D controlling corrected detection ,we can clearly see the effectiveness of the method after calibration.**

Keywords-deep-sea;drilling;rig;gyroscope;Yaw;angle;error; OpenGL;

I. INTRODUCTION

In recent years, with the support of the country marine high-tech 863 plan , China's offshore drilling sampling has a rapid technological development .A number of important scientific deep-sea expedition equipment ,such as TV grab, deep-sea shallow drilling, integrated drag body, TV multi-tube sampling put into use in succession[1] and the deep hole sampling rigs in the deep-sea provide a strong basis for the exploration of marine resources, which is one of the basic equipment of "Ocean One" scientific expedition ship.

In the field of marine technology, the use of autonomous inertial navigation system, real-time measurement of the current 3D pose of the carrier, is the main direction of the present study. The core component of the autonomous SINS is gyro. Generally for underwater robots, drag-and-drop detection system, fiber optic gyroscope is preferred; however, for magnetometer, seismograph, altimeter and other deep-sea equipment, the MEMS gyroscope is an affordable selection target. For a core MEMS gyroscope attitude measurement system, a method is completely independent of the sensor built-in system, which is the use of high-precision high-speed processing chip as the correction of the gyro output data solver unit and then the final attitude data is sent to the sensor ; with the constraint of deepwater rigs in the main control board in the size, power consumption and cost constraints, we need a shared processor, which is a built-in gyroscope inside the deepwater rigs in the main control board ,and share an MCU processing chip. In this case, the commonly used Kalman filter [2], high-order Runge - Kutta algorithm [3] once applied to the limited computing power sensor ,MCU can easily affect the real-time sensor data acquisition.

This paper provides a deep-sea drilling rig gyro random drift error-correction method in the initial measurement of the MEMS gyroscope data , which is based on pre-treatment, non-linear curve fitting estimates and the attitude instrument in the deepwater rigs in a cycle within the random drift control in the affordable range and attitude transmitted back to the host computer through the optical fiber with OpenGL real-time display [4], in order to achieve the attitude measurement requirements of deep-sea drilling rig in the decentralization process.

II. GYRO RANDOM DRIFT ERROR MODEL

The core part of strapdown attitude detection system is the three-axis gyroscope, whose output vector value of the three components of the angular velocity and the angular velocity of the points available to the angle after the attitude updating algorithm,you can get real-time attitude information [5].Strapdown attitude algorithm is an important part of strapdown algorithm, both in respect to real-time spacecraft attitude solver and related to the mathematical platform - real-time correction of the attitude matrix.The pros and cons of the strapdown attitude algorithm performance will directly affect strapdown system accuracy.

Generally methods for determining the attitude of the Euler angle method are calculation of the carrier coordinate system with the reference coordinate system associated with the direction cosine matrix, or using a numerical integration method calculates the equivalent of four elements.

Commonly used in engineering rotating representation of the four elements, Euler angles, to save storage space and convenience interpolation advantages compared to the matrix. Define alpha, beta, gamma, respectively around the X axis, Y axis, Z axis rotation angles, such as vector $\vec{n} = \sin\frac{\theta}{2}\cos\alpha i + \sin\frac{\theta}{2}\cos\beta j + \sin\frac{\theta}{2}\cos\gamma k$ axis turned to the right-hand rule after changes to the vector . Use the following formula represents the rotation:

$$\overline{R'} = Q\vec{R}Q^{-1} \qquad (1)$$

$$Q = \cos\frac{\theta}{2} + \sin\frac{\theta}{2}\cos\alpha i + \sin\frac{\theta}{2}\cos\beta j + \sin\frac{\theta}{2}\cos\gamma k \qquad (2)$$

"Q" is the rotation quaternion.

In a unit time interval Δt Those assumed in the cylinder angular velocity $\vec{\omega}$, Then the direction of the axis of

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rotation $\vec{e}$ And turned around the axis angle $\emptyset$ Were as follows:

$\vec{e}=\vec{\omega}/|\vec{\omega}|$, $\emptyset=|\vec{\omega}|\Delta t$ [6]

Quaternion calculated as follows:

$$q=(q_0,q_1,q_2,q_3)^T=\begin{pmatrix}q_0\\ \vec{q}\end{pmatrix}=\begin{pmatrix}\cos(\frac{\emptyset}{2})\\ \vec{e}\sin(\frac{\emptyset}{2})\end{pmatrix} \quad (3)$$

The time t standardization quatemion meets the following conditions:

$$q_1^2(t)+q_2^2(t)+q_3^2(t)+q_4^2(t)=1 \quad (4)$$

The hypercomplex said:

$$q=\cos(\frac{\emptyset}{2})+i\sin(\frac{\emptyset}{2})+j\sin(\frac{\emptyset}{2})+k\sin\left(\frac{\emptyset}{2}\right) \quad (5)$$

Satisfy the constraints:

$i^2=j^2=k^2=-1; ij=-ji=k; \quad jk=-kj=i; ki=-ik=j;$

Using trigonometric formulas:

$$\cos\emptyset=2\cos^2\frac{\emptyset}{2}-1, \sin\emptyset=2\sin\frac{\emptyset}{2}\cos\frac{\emptyset}{2} \quad (6)$$

Quaternion can be transformed into the attitude matrix A =

$$\begin{bmatrix} q_0^2+q_1^2-q_2^2-q_3^2 & 2(q_1q_2+q_0q_3) & 2(q_1q_3-q_0q_2)\\ 2(q_1q_2-q_0q_3) & q_0^2-q_1^2+q_2^2-q_3^2 & 2(q_2q_3+q_0q_1)\\ 2(q_1q_3+q_0q_2) & 2(q_2q_3-q_0q_1) & q_0^2-q_1^2-q_2^2+q_3^2 \end{bmatrix}$$

Final Euler angle attitude can be expressed as:

$$\psi=\arctan(\frac{A(1,2)}{A(1,1)})=\arctan(\frac{2(q_2q_3+q_0q_1)}{q_0^2-q_1^2-q_2^2+q_3^2})$$

$$\theta=\arcsin[A(1,3)]=\arcsin(-2(q_1q_3-q_0q_2))$$

$$\varphi=\arctan(\frac{A(2,3)}{A(3,3)})=\arctan(\frac{2(q_1q_2+q_0q_3)}{q_0^2+q_1^2-q_2^2-q_3^2})$$

" ψ "is Yaw angle,"θ" is the pitch angle, φ is the roll angle.

III. GYROSCOPE RANDOM DRIFT ERROR MODEL

Since the attitude solution algorithm is a recursive algorithm update, every solver error will be accumulated to the next calculation, and thus the error in the raw data of the gyro in the attitude solver results continued to enlarge.

Constant bias and random drift characteristics are the main reasons that affect the accuracy of the gyroscope. The literal bias refers to the average output per unit of time in the boot gyro sensitive axis angular velocity input. Removing the constant bias component from the sequence of some of the original datas point by point, they will have a sequence of random drift of the gyroscope in this orientation.

Gyro random drift modeling has been more research and generally are used autoregressive model (AR), moving average model (MA), autoregressive moving average model (ARMA) modeling. Before making modeling bias are subtracted from the original signal and mean estimation method can be used to remove the bias [1], and its expression is:

$$r_n=\frac{1}{l}\sum_{i=n-l+1}^{n}\overset{*}{r_i} \quad (7)$$

" l " is the length of the window, $\overset{*}{r}_i$ removed for measurement data determined after the residuals, r_n is the time sequence.

Then need to ensure the rest of the time series of stability and normality. First-order autoregressive AR (1) modeling, in the form of:

$$x_n=ax_{n-1}+\varepsilon_n \quad (8)$$

"a" is model parameter and " ε "is white noise. The formula represents the observed value of the n points in time associated with the observed values of the n-1 time only.

Introducing cumulative error ,the gyroscope error into the attitude solver algorithm will be the output of the pitch, roll and yaw angle. Detection system for underwater posture, pitch and roll errors can be compensated by the accelerometer and yaw angle on the one hand due to the complex of underwater magnetic field environment is not suitable for using magnetic sensors to compensate, on the other hand, considering the low-power equipment requirements, ships are not equipped with a high performance central processor, so the need to use a high efficiency, small amount of computation algorithm compensates the drift of the yaw angle.

IV. THE DISTAL END OF GYROSCOPE ORIGINAL DATA COMPENSATION METHOD

First analyse the actual attitude instrument error conditions without a yaw angle compensation case. The deepwater rig controls panel gyro sensor and the PC only connection with the preparation of the OpenGL 3D controling test platform is shown in Figure 1, the PC is shown in Figure2:

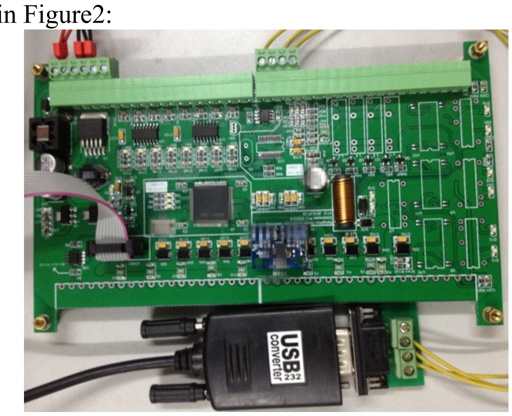

Figure 1 attitude detection experiment platform of next-bit machine

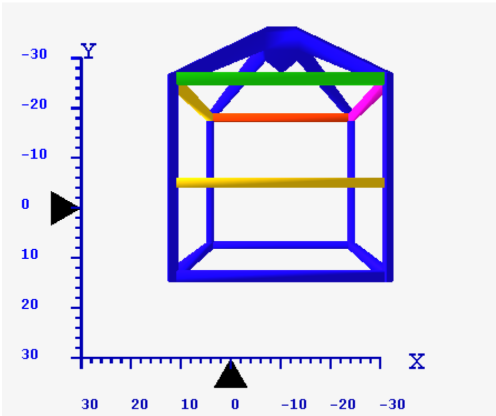

Figure 2 attitude detection experiment platform of the host computer

With attitude instrument in a quiescent state, the raw data of the gyro output direct input attitude algorithm functions for calculations recorded three groups boot after 30 seconds of data, the error curve with the ZedGraph control, the results are as follows:

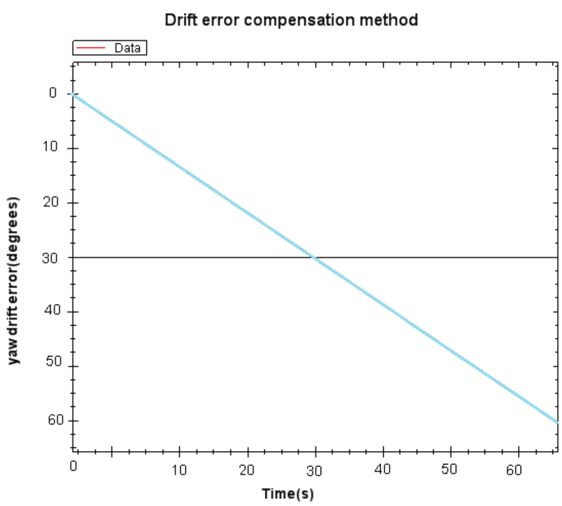

Figure 3 does not compensate for the yaw angle error curve

In Figure 3, three tests of the yaw angle in the time of only 30 seconds,respespectively drift 59.6°, 60.6°and 47.9°. This indicates that the gyro without calibration of the output of the error is very large, if the compensated output of the yaw angle attitude instrument will not moot. Contrasting gyro error model shows that such errors are mainly from the constant zero bias. Use the mean estimate to remove literal zero bias in the raw data in attitude solution. Mean method, a small amount of simple and suitable for low-power MCU is to complete. Use the formula (7), the length of the selection window of 1000,after turning data compensation. Compensate data into the attitude solution algorithm to calculate and record the data in the three groups after 10 minboot using the the ZedGraph Controls error curve, the results are as follows:

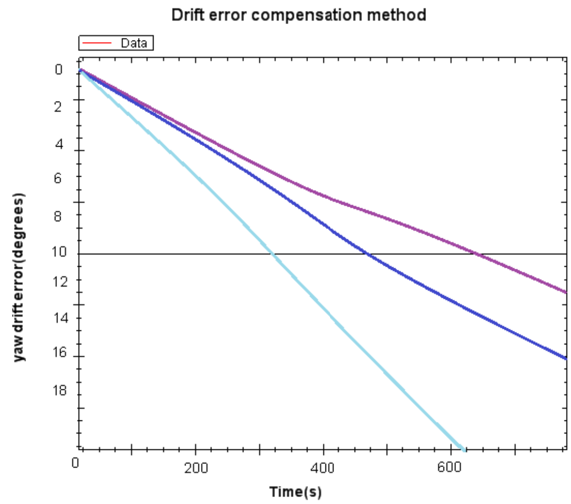

Figure 4 Front compensated error curve

Fig 3 Yaw error curve with front end compensation

Figure 3 shows, the gyro front-end data compensation and the yaw angle drift over time has been greatly improved and three drift within 10 mins are 11.8 °, 22.2 ° and 14 .9 °. Compared to compensation ,accuracy is increased by 30-60 times before the output of the yaw angle of practical significance. Also we find that the original data compensation residual drift error, the size and growth of each boot are quite random.

For practical application of the product, 10 minutes of about 20 ° drift is still too high, and therefore need to proceed to compensate for the error compensation on the basis of the front end of the original data in order to further improve the accuracy of the attitude instrument.

V. GYRO RANDOM DRIFT FITTING METHOD OF VALUATION

Seen by the gyro error model, the remainder of the yaw angle error is mainly derived from the random drift of the gyro.

Random drift error compensation methods have numerous studies, such as the use of ARMA, neural network, wavelet analysis method gyro error analysis modeling and the use of the Kalman filter for filtering. But such methods building models generally have a higher order and computationally demanding and complex algorithm is not suitable for underwater low-power single-chip control system environment.

In this paper, we consider the results-oriented.First record certain raw data after compensation residual error of the yaw angle data, and then use the curve fitting technique to fit the curve of error, and after posture output offset error curve function value in order to achieve the purpose of improving the accuracy of the yaw angle output.

During system boot and the original data compensation, continue to maintain the attitude instrument at rest and continuous recording 5 minutes yaw angle output data. The

ZedGraph control obtains the data input curve fitting function in the form of

$$y = at^2 + bt + c \qquad (11)$$

t is the time variable, a is quadratic coefficient, b is the linear coefficient, c is a constant. Due to system errors in the time 0 of 0, the value of the constant term c 0 can be omitted.

Take into account the underwater low-power MCU, as far as possible to reduce the computational burden, so the first quadratic coefficient a is set to 0, which will be recorded to the 5-minute data using a linear fitting formula

$$y=bt \qquad (12)$$

Calculate compensation formula b value after the output function of the yaw angle, the following results were obtained:

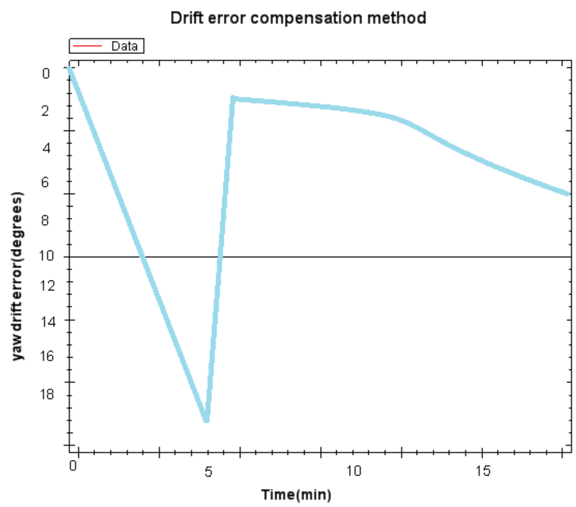

Figure 5 Yaw angle error curve linear fit

From the chart we can see the back-end data compensation shows good results. At an initial stage, the yaw angle error accumulation, the larger the slope, and after 5 minutes, linear fitting is complete, the rear end of the compensation is added to the results Claim zero error, and the smaller the slope of the growth, the error accumulated faster than before to improve times again.

To achieve better compensation effect, the second non-linear curve fitting and data record to five minutes use a linear fitting formula

$$y = at^2 + bt \qquad (13)$$

Calculate compensation formula a and b values after the output function of the yaw angle, the following results were obtained:

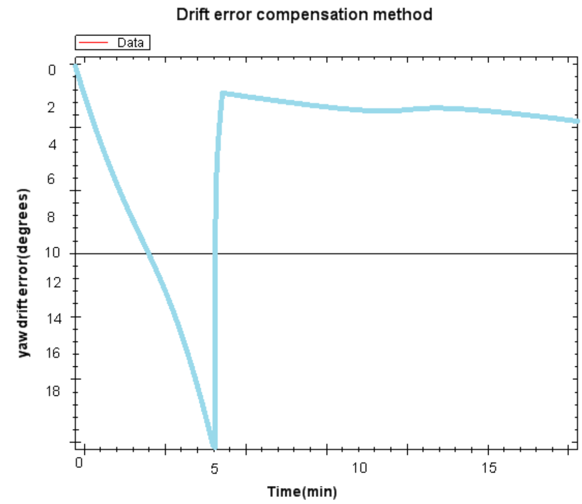

Figure 6 The nonlinear fitting yaw angle error curve

a = 0.0000028, b = 0.0233.

From the chart we can see nonlinear fitting the compensation shows very good results. The attitude instrument drift yaw angle within 30 minutes is controlled within 3 °, to achieve the requirements of the majority of underwater equipment.

In the final application of the system, the non-linear curve fitting is completed by the underwater system microcontroller MCU.Error frequency greater than 3 curve fitting calculation amount is too large, not suited to be completed by the MCU, so it applies MCU the quadratic nonlinear fitting method [7].

VI. SUMMARY AND OUTLOOK

Analysis of the experimental data shows that for fully autonomous inertial navigation attitude detection technology, the random drift error correction method proposed in this paper, the compensation method of the raw data of the gyro gyroscope yaw angle output data nonlinear quasi the aggregate valuation methods combined, can not significantly increase the burden on the MCU,making the drift error of the yaw angle output remain stable at a certain time to meet the small size, low power, low cost marine sensor attitude information accuracy requirements. MEMSgyroscope random drift error compensation meets the testing requirements of deepwater rigs in the attitude.Figure 7 shows the detection image

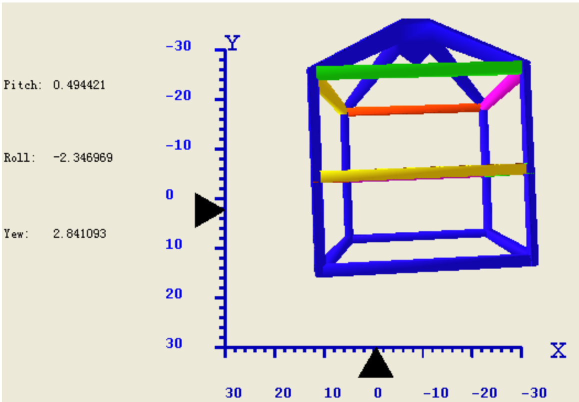

Figure 7 gesture detection image

Yaw = ψ the yaw angle, Pitch = θ Pitch angle ,Roll = φ the roll angle.

In this paper , the MEMS gyro random drift error correction method is proposed to ensure the accuracy of the yaw angle within a certain time in the certain computing capacity constraints. A cycle of deep-sea drilling rig works hours, if the need for a long time in the underwater equipment attitude detection recommends the introduction of a more accurate compensation method of the Kalman filter, of course, and this also means greater system overhead, so the effectiveness of the algorithm and hardware overhead always needs to weigh one aspect of future research.

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