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Vibration Error Research of Fiber Optic Gyroscope in Engineering Surveying

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Abstract

In the process of the engineering surveying by FOG (fiber optic gyroscope), there are a lot of measurement error caused by many kinds of factors, vibration error is one of them. Analyzing the output signal of FOG on the effect of vibration, Kalman filter can be used to inhibit the drift of output signal, and it is experimentally validated based on the filtering algorithm. The results show that, the vibration error of FOG was reduced, and the validity of the method has been proved.

Key words: *engineering survey, fiber optic gyroscope, vibration error, kalman filter*

1. Introduction

After years of development, the FOG has been gradually replacing the mechanical rotor gyroscope to become one of the mainstream instrumentation in the field of inertial measurement. With the variety of low-precision FOG achieve the practical and a range of products have been put into market, precision inertial navigation grade FOG gradually go into the applications market. The introduction of new technology, new production equipment and technology, make the accuracy of the FOG to further improve. The impact of the external environment, such as vibration, shock, and so on, has become the main error source of the high precision FOG.

Therefore, how to inhibit the FOG vibration error and improve the FOG environment adaptability is very important. At present, the FOG has a highly sensitive characteristics about the vibration in the application process, a lot of suppression measures have been put forward by domestic and international research institutions and scholars, such as, setting reasonable glue around the internal fiber ring, winding fiber ring by the quadrupole-symmetry method, installing the shock absorber around the gyro, optimizing the shell structure of FOG. All the plans improve the FOG environment adaptability to a certain extent, but the effect is limited. So, this article proposed using the Kalman filter to digital filter the output signal of the FOG. The scheme can effectively reduce the signal noise and drift caused by vibration, improve the FOG environment adaptability, and also proposed a better compensation measures for the above various plans.

2. Error Analysis of FOG in engineering Surveying

FOG is an angular motion measurement instrumentation, the measurement principle be applied to engineering is shown as Figure 1. The measurement system move forward along the testing line with FOG inside, in the moving process, the running direction and the angle of the measuring system will change, there will be angular velocity generated, using the sensitive characteristics about this angular velocity of high-precision FOG, the entire testing line can be measured.

As shown in Figure 1, the FOG move forward along the testing line in the engineering survey process, at the moment (i) to reach the point (Xi,Yi), so the coordinates of the point (i+1) can approximate calculation using the following Equation (1).

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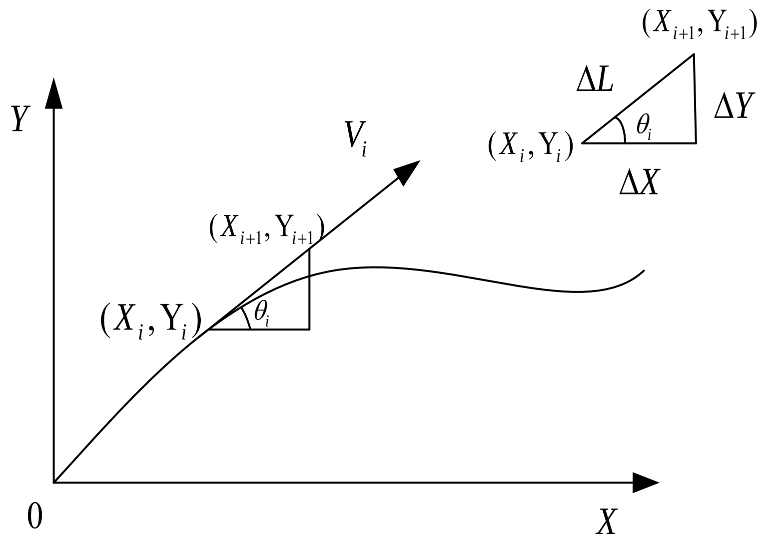


Figure 1. The Principle of Engineering Survey by FOG

$$\begin{cases} X_{i+1} = X_i + \Delta X = X_i + \Delta L * \cos\theta_i \\ Y_{i+1} = Y_i + \Delta Y = Y_i + \Delta L * \sin\theta_i \end{cases} \quad (1)$$

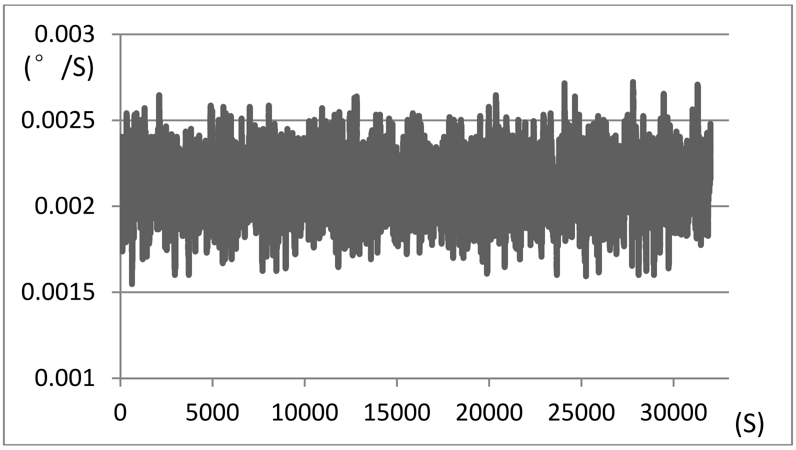
The above Equation (1), the angle between the running direction of FOG measurement system and the X axis is θi which can be obtained through integral for the measurement of the angular velocity of the FOG. The distance is ΔL traveled by the FOG measurement system in the time interval t. In the situation of t and ΔL are known, the exact coordinates of the next point can be got according to the above formula. So the moving trajectory of the FOG measurement system can be obtained by the accumulated calculated, and the measured data of the entire measurement line can be got too.

According to the application principle of the FOG engineering survey, the results of measurement is obtained from the integral operation of angular velocity based on the trajectory of the FOG measurement system, therefore, the noise and drift of the FOG output will cause the system error. As for which kind of error is the main role, it is related to the accuracy requirements of the system or work time. The angular velocity output data of FOG contains the desirable angular velocity, the drift angular velocity and the noise angular velocity. It is the superposition of these three kinds of data. The drift angular velocity is the output data when the FOG in the relative no angular velocity environment. The noise angular velocity is angular velocity output error under static conditions.

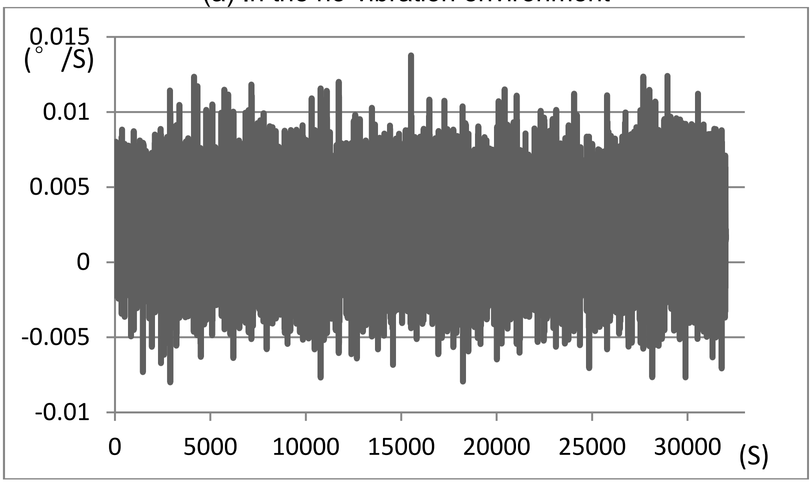
3. Vibration error of FOG in Engineering Surveying

In the application process of FOG in engineering surveying, vibration error from the carrier of FOG moving have a greater impact on the entire measurement results. In order to analyze the impact, FOG of engineering measurement system has been put into the no-vibration operation environment and the vibration operation environment, then, two groups of output data have been get from the measurement system and they can be shown in the Figure 2.

As shown in the Figure 2, on the condition in the same angular velocity input data, the FOG output average of the measurement system in the no-vibration environment is the component values of the Earth's rotation angular velocity in the measurement location. The output data is between 0.0015º/S and 0.0028º/S, the random drift data is 0.00025º/S. When the FOG measurement system in the vibration environment, the output average is close to the data of the no-vibration environment, but it is between -0.01º/S and 0.015º/S, the random drift data is 0.005º/S. So, the conclusion can be obtained that the influence of the vibration error of the measurement system on the results is larger than the angular velocity output from the FOG noise error. Therefore, how to eliminate the vibration error of the FOG measurement systems in engineering surveying applications is the one of the key problems to improve the overall accuracy.



(a) In the no-vibration environment



(b) In the vibration environment

Figure 2. The comparison of the angular velocity output of FOG between the no-vibration environment and the vibration environment

Currently, the main method to eliminate vibration error of FOG in engineering surveying is reducing the vibration of the measurement system by increasing damping device, firming hardware. These methods are more and more difficult in processing, manufacturing, assembly, debugging, and more costly. Therefore, the software method can be utilized to handling FOG signal, reducing vibration error and saving costs. It is an effective way to improve the measurement accuracy of FOG.

4. The Suppression Algorithm for FOG Vibration Error

4.1. Kalman filter

Kalman filter is a software filtering method, it is using observational data to calculate the state vector estimation of original system directly by iteration procedure. Kalman filtering method is based on the state space model of the signal and the noise, as the minimum mean square error as the best estimate standards, using the estimated data of the previous time and the observed data of the current time to update the estimates of the state variables, obtaining the estimated data of the current time. The filtering steps of the method can be shown as the following Equations (2)-(8).

1) The state prediction:

$$\hat{x}(n|L_{n-1}) = F(n, n-1)\hat{x}(n-1|L_{n-1}) \quad (2)$$

2) The calculation of new data by the observation signal z (n):

$$\alpha(n) = z(n) - \hat{z}(n|L_{n-1}) = z(n) - C(n)\hat{x}(n|L_{n-1}) \quad (3)$$

3) The autocorrelation matrix of prediction error:

$$P(n, n-1) = F(n, n-1)P(n-1)F^{H}(n, n-1) + \Gamma(n, n-1)Q_1(n-1)\Gamma^{H}(n, n-1) \quad (4)$$

4) The autocorrelation matrix of new data:

$$A(n) = C(n)P(n, n-1)C^{H}(n) + Q_2(n) \quad (5)$$

5) The gain Kalman filter:

$$K(n) = P(n, n-1)C^{H}(n)A^{-1}(n) \quad (6)$$

6) The state estimation:

$$\hat{x}(n|L_n) = \hat{x}(n|L_{n-1}) + K(n)\alpha(n) \quad (7)$$

7) The autocorrelation matrix of the state estimation error:

$$P(n) = [I - K(n)C(n)]P(n, n-1) \quad (8)$$

8) Repeating the seven steps above, the estimated data of Kalman filter can be obtained by the recursive calculation.

4.2. The Kalman Filter Model of FOG

Because application fields and environment of the FOG engineering surveying is different, the vibration error is also different when the system running. This paper discusses under the condition that in a certain engineering surveying environment, utilizing the FOG surveying system to measure a project curve, corrected the vibration error of the measurement process. In the parameter model of this measurement system, the Kalman filter state equations of the system can be set as shown in the following Equation (9).

$$x(n) = F(n, n-1)x(n, n-1) + \Gamma(n, n-1)\nu_1(n, n-1) \quad (9)$$

In the above Equation (9), the state vector of angular velocity is $x(n)$, the state noise of system are $\nu_1(n-1)$, the state transition matrix of the system $F(n, n-1)$ describe the change regulation of system angular velocity from the time n-1 to time n. The system angular velocity observation equation can be shown in the following Equation (10).

$$z(n) = C(n)x(n) + \nu_2(n) \quad (10)$$

According to the characteristic that the observation noise at different moments is statistically independent as the following Equations (11)-(12).

$$E[\nu_1(n)\nu_1^{H}(n)] = Q_1(n) \quad (11)$$
$$E[\nu_2(n)\nu_2^{H}(n)] = Q_2(n) \quad (12)$$

The initial conditions of the system model are that at the initial time, using the observed average data and the correlation matrix to describe the initial state of equations. In order to ensure the no bias of estimated, it is desirable that the initial data of filter as the following Equations (13)-(14).

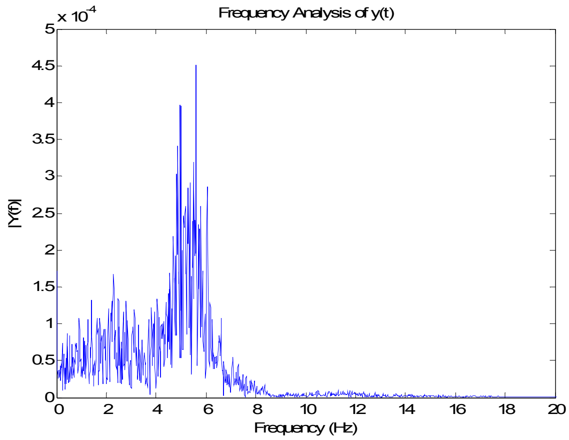
$$\hat{x}(0|L_0) = E[x(0)] \tag{13}$$

$$P(0) = E\left\{\left[x(0) - E[x(0)]\right]\left[x(0) - E[x(0)]\right]^H\right\} \tag{14}$$

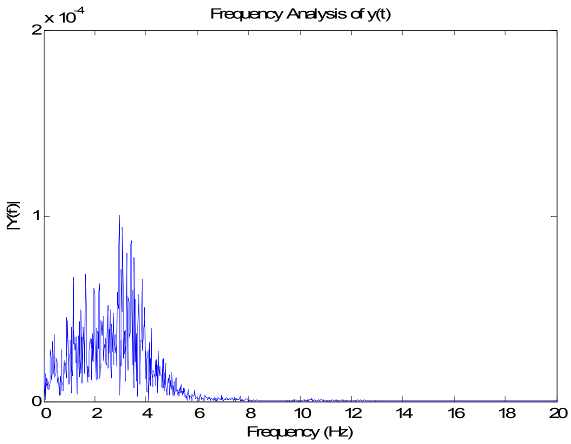
In the condition that the state equation of the whole system, the observation equation and the initial condition are known, the recursive calculation was run. According to the calculation result, it is possible that the vibration error will be filtered, which exist in the original measured data of the FOG surveying system. The more accurate measurement data will be obtained.

5. The Analysis of Filtering Experimental Results

In the Figure 2, the FOG engineering surveying system has been put into the no-vibration operation environment and the vibration operation environment. The Figure 2 (a) shows that the angular velocity output of FOG in the no-vibration environment and the Figure 2 (b) shows the data in the vibration environment. From the two groups of output data, the state vector of angular velocity x(n), the state noise of system $v_1(n-1)$ and the state transition matrix of the system F(n,n-1) can all be obtained. So the equation of state of the system, the observation equation and the initial conditions are not difficult to get.



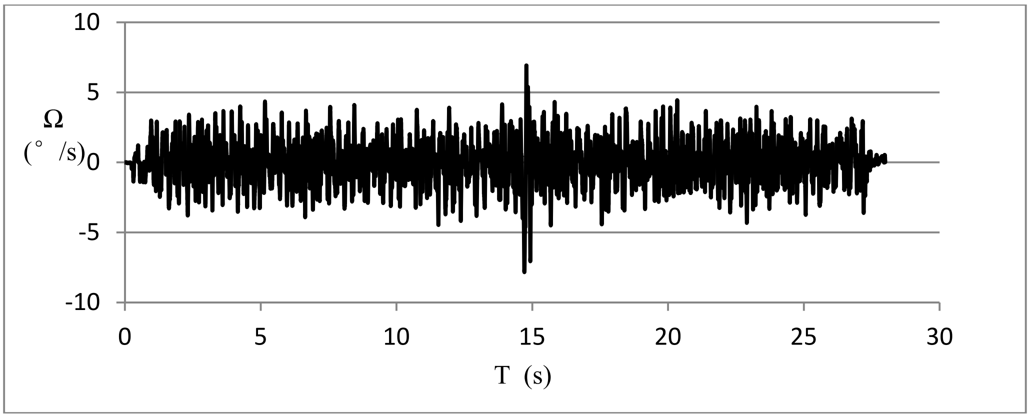
(a) Not filtered by the Kalman filter



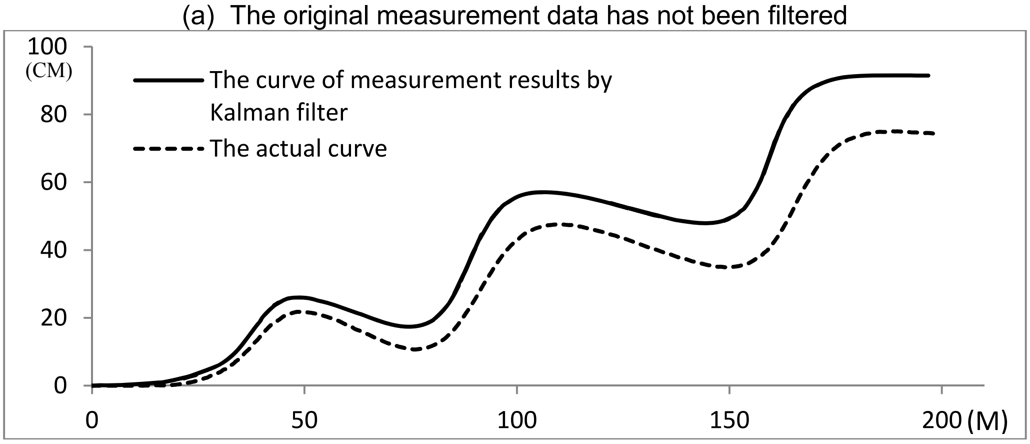
(b) Filtered by the Kalman filter

Figure 3. Frequency Analysis of the Measurement Data

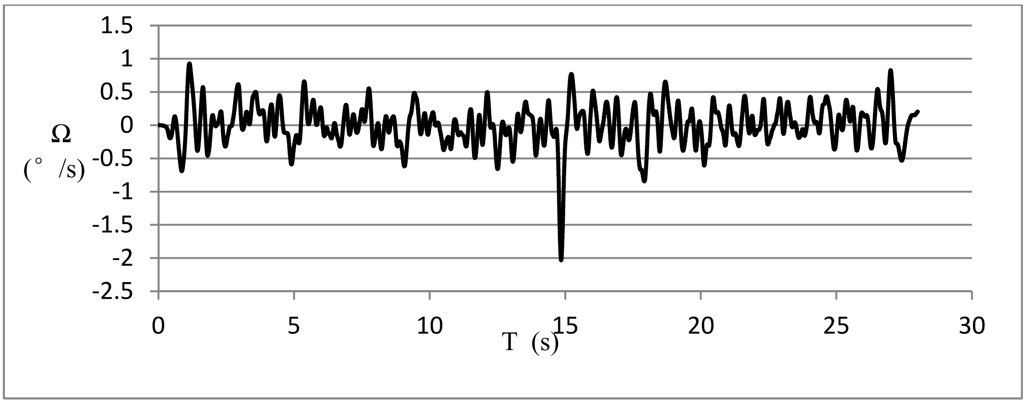
Using recursion calculation of Kalman filter, the vibration error will be filtered from the measured data. Figure 3(a) shows the frequency analysis of the measured data are not to be filtered by Kalman filter, and Figure 3(b) shows the frequency analysis of the measured data filtered by Kalman filter. From the results of experiment, the following conclusions can be drawn, in the application of FOG engineering surveying, the output measured data contains the vibration error, and the frequency and amplitude of the vibration error is unbefitting. The accurate measurement data will be got, because the vibration error will be filtered out by Kalman filter. In the region of 200m*1m, the FOG engineering surveying system has been used to measure a predetermined path. A group of the original measurement data can be got, and then the true measure data will be filtered by the calculation of Kalman filter. Figure 4(a) shows the original measurement data which the vibration error has not been filtered out, and Figure 4(b) shows the comparison of the measurement result based on the data with the predetermined path. Figure 4(c) shows the measurement data which the vibration error has been filtered out, and Figure 4(d) shows the comparison of the measurement result based on the data with the predetermined path.



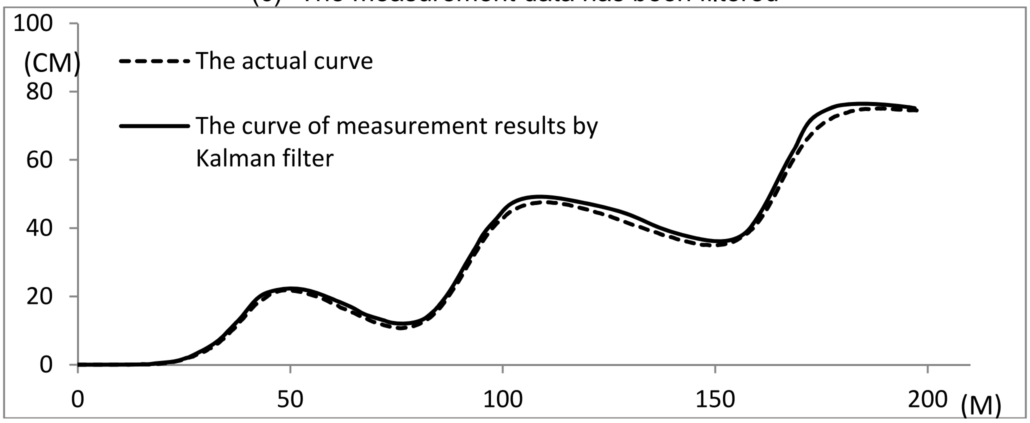
(a) The original measurement data has not been filtered



(b) The comparison of the measurement result based on the data with the predetermined path



(c) The measurement data has been filtered



(d) The comparison of the measurement result based on the data with the predetermined path

Figure 4. The Analysis of Experimental Results

From results of the experiment, the following conclusions can be drawn.

1) Because of the superposition during the integral calculation, which is from the measurement system vibration error, the measurement data increasingly deviate from the predetermined path. The measurement time is longer, the error is greater.
2) After the original measurement data are filtered by the Kalman filter algorithm, the vibration error of the data can be ignored, and the measurement accuracy of the system can be improved.

6. Conclusion

By analyzing the impact and manifestations of the vibration error from the FOG engineering surveying system, the Kalman filter algorithm can be used for the measurement data. The experiment results shows that the method can greatly reduce the impact of the vibration error in the system, and the accuracy of engineering surveying has been significantly improved.

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