

The Integrated navigation numerical correction and prediction of autonomous underwater vehicle (AUV) based on GM (1, 1) model

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Abstract. Navigation accuracy is one of the crucial performances for autonomous underwater vehicle (AUV), and is an important indicator of evaluating AUV performance. Typically, it is achieving AUV underwater navigation that adopting Doppler velocity log (DVL) integrated Strap down inertia Navigation System (SINS). To improve navigation accuracy of SINS / DVL, this paper embarks from the SINS / DVL integrated navigation model, to sets up filtering state equations and the measurement equation of integrated navigation system, then the grey prediction model GM (1, 1) is added to SINS / DVL integrated navigation system, and the grey prediction algorithm is applied to integrated navigation data analysis. Using the grey prediction model to predicate and correct the navigation data and, further improve the robustness and accuracy of the navigation system. Combined with actual project, the integrated navigation numerical correction and prediction of autonomous underwater vehicle (AUV) based on GM (1, 1) model is proposed. With the relative navigation error as the evaluation index, analyzes the navigation data, calculates relative navigation error of around predication and correction based on GM (1, 1) model; From the result, the introduction of grey prediction model carried on the forecast and the revision to the navigation data may increase the SINS/DVL navigation precision to a certain extent, it explained the accuracy and the usability of the method.

Introduction

With the implement of thriving marine with science and technology and the development of marine economy, marine technology and marine engineering have been vigorously promoted and received rapid development. Among them, autonomous underwater vehicle (AUV) as an intelligent power platform industry that can carry different loads to achieve the marine environment observation and detection, load delivery, target investigation and other functions has been a hot topic. As an important foundation of effectively control and recover AUV and an essential basis for interpreting the valid data that is probed by AUV [1, 2, and 3], AUV navigation is one of the hot issues in the field of contemporary research.

In the mode of AUV underwater navigation, integrated navigation system based on information fusion technology is commonly used to adaptively receive and process all the available source of navigation information data, such as Strap down inertial navigation system (SINS), Doppler velocity log (DVL), terrain aided navigation system (TAN), and fuse navigation data to provide accurate position, velocity, attitude and other navigation information for AUV [4]. In view of the integrated navigation information fusion, international and domestic academics estimate system error state by using Kalan filtering [5], and then correct the system. According a large amount of experimental study, to a great extent, the precision of integrated navigation has been improved [6]. To further improve the integrated navigation precision, this paper takes the strap down inertial navigation system (SINS) and Doppler velocity log (DVL) integrated navigation as the research object. According to the SINS / DVL integrated navigation model, set up integrated navigation model, and then add the grey model GM (1, 1) model to SINS / DVL integrated navigation system. An attempt is made to predict and correct the navigation data by using grey model, in order to further improve the robustness and accuracy of the navigation system. Using the grey model to predicate and correct the

navigation data and, further improve the robustness and accuracy of the navigation system. Combined with actual project, the integrated navigation numerical correction and prediction of autonomous underwater vehicle (AUV) based on GM (1, 1) model is proposed;

The establishment of the integrated navigation mode

Based on the output of SINS and DVL, SINS/DVL integrated navigation estimate system error status by using Kalman filtering, and then the system is corrected by the estimation of error status (shown in Fig.1). To establish integrated navigation model, it is necessary to convert the measurement of SINS and DVL to the same coordinate system, and then to establish the state equation and measurement equation.

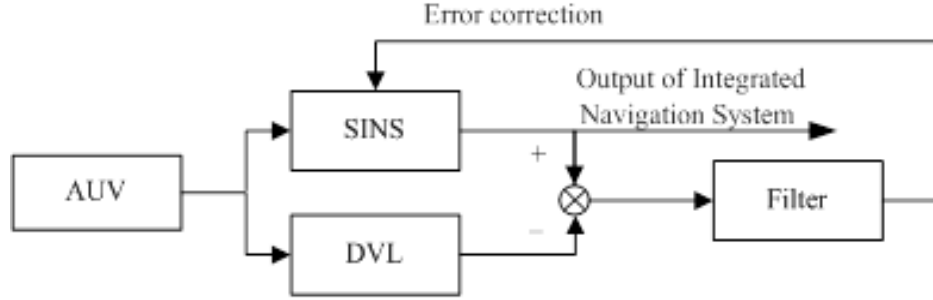


Fig.1 The integrated navigation mode of SINS/DVL

Coordinate Transformation. DVL measures each component of the velocity of AUV platform based on carrier coordinate system, SINS output relative information based on geographic coordinate system. Only when unify the two coordinate systems into geographic coordinate system, measuring values can be get from the subtraction. The position relationship between carrier coordinate system $X_b Y_b Z_b$ and geographic coordinate system $X_n Y_n Z_n$ is as follows:

$$\begin{bmatrix} X_b \\ Y_b \\ Z_b \end{bmatrix} = \begin{bmatrix} C\psi \cdot C\theta & S\psi \cdot C\theta & -S\theta \\ C\psi \cdot S\theta \cdot S\gamma - S\psi \cdot C\gamma & S\psi \cdot S\theta \cdot S\gamma & C\theta \cdot S\gamma \\ C\psi \cdot S\theta \cdot C\gamma + S\psi \cdot S\gamma & S\psi \cdot S\theta \cdot C\gamma - C\theta \cdot S\gamma & C\theta \cdot C\gamma \end{bmatrix} \begin{bmatrix} X_n \\ Y_n \\ Z_n \end{bmatrix} \quad (1)$$

Where, C represents cosine algorithm, S represents sine algorithm, ψ is the course angle of AUV, γ is the roll angle and θ is the pitch angle.

The position of AUV is commonly represented by earth coordinate system, that is to say, is represented with longitude and latitude. In fact, that is the position relationship between geographic coordinate system and earth coordinate system. The position in geographic coordinate system when relative to earth coordinate system is the geographic location, including longitude λ and latitude φ . The transformational relation between geographic coordinate system NED and earth coordinate system $X_e Y_e Z_e$ is as follows^[5]:

$$\begin{bmatrix} X_n \\ Y_n \\ Z_n \end{bmatrix} = \begin{bmatrix} -S\varphi \cdot C\lambda & -S\varphi \cdot S\lambda & C\varphi \\ -S\lambda & C\lambda & 0 \\ -C\varphi \cdot C\lambda & -C\varphi \cdot S\lambda & -S\varphi \end{bmatrix} \begin{bmatrix} X_e \\ Y_e \\ Z_e \end{bmatrix} \quad (2)$$

State Equation and Measurement Equation. Taking the error between SINS and DVL subsystem as system status, the state vector of integrated navigation system is $X(t) = [X_t^T \ X_d^T]^T$, and the system noise vector is $W(t) = [W_t^T \ W_d^T]^T$. When combined the both error equation of SINS and DVL, the state equation of system can be written as:

$$\dot{X}(t) = F[X(t), W(t), t] \quad (3)$$

Where, the state function $F[\bullet]$ is a nonlinear continuous function.

The measuring values is formed by the tracing speed to bottom which is get from DVL and the output of SINS, it need to unify the two kind values into navigation coordinate system. Various not

only the definitions of coordinate system but the calibration factors led to different transformation matrix. Here defines its transformation matrix as $C_b^{n'}$, thus, the measuring values get from SINS and DVL is as follows^[5]:

$$Z = \begin{bmatrix} V_{EI} - V_{ED} \\ V_{NI} - V_{ND} \\ V_{UI} - V_{UD} \end{bmatrix} = \begin{bmatrix} V_E + \delta V_E \\ V_N + \delta V_N \\ V_U + \delta V_U \end{bmatrix} - C_b^{n'} \begin{bmatrix} V_x + \delta V_{dx} \\ V_y + \delta V_{dy} \\ V_z + \delta V_{dz} \end{bmatrix} \quad (4)$$

When expanded above formula, and combined with previously selected system error state $X(t) = [X_I^T \ X_D^T]^T$, the both sides equation of composite systems $Z = H[X(t), V]$, can be obtained, where $H[\bullet]$ is a nonlinear continuous function and v is measuring noise.

Integrated navigation correction model

In traditional integrated navigation system, when its mathematical model is accurate and its noise is stabilized, and if ignoring the calculation error to some extent properly, more accurate result can be yielded by using Kalman filtering algorithm to estimate system state, and then system can be corrected. However, when mathematical model is in accurate or noise is shift, the filter precision will be reduced, even divergence will be occurred, and then navigation performance will be affected. From a practical standpoint, AUV is a product that integrated multi-device, there is more complex disturbance form system noise and environment both surface and underwater, to some extent, the navigation performance of AUV can be influenced. To further enhance the accuracy and robustness of navigation system, this paper presents a method that adding grey prediction algorithms based on navigation system Kalman filtering to make prediction and correction for system (the navigation model is as shown in Fig.2).

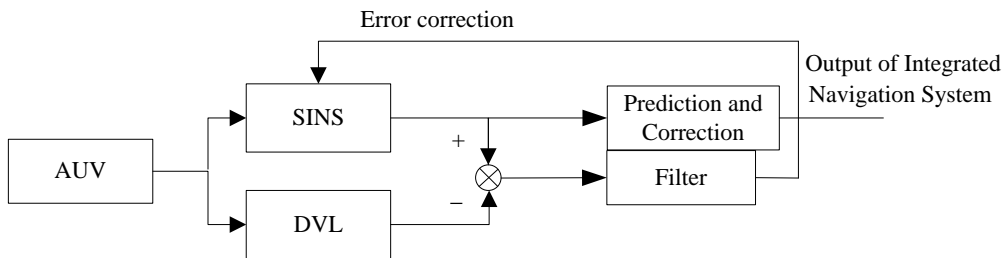


Fig.2 The correction integrated navigation mode of SINS/DVL

The process of integrated navigation prediction and correction based on grey prediction can be specific written as:

$$Z(k) = \alpha \phi + \beta f_{k-n+1}^k(\varepsilon) \quad (5)$$

Where, $Z(k)$ is the navigation numerical value of system output, ϕ is the SINS/DVL integrated navigation calculated value of k-point, $f_{k-n+1}^k(\varepsilon)$ is the predict calculated value of the grey sequence prediction (its length is n), α and β is weighting coefficient.

According to above process, grey prediction is added to integrated navigation calculation and makes irregular original data accumulate, so that the effect comes from random perturbation can be weakened. Theoretically, the accuracy and robustness of integrated navigation system can be enhanced by properly choosing the length of the sequence prediction and correction coefficient.

Analysis and verification test

The Method of Verification Test. To test the feasibility and validity of the method is proposed in this paper, which predict and correct the integrated navigation value based on grey prediction model GM (1, 1). Install inertial navigation device and DVL in carrier, fixedly. Keep them relative fixed, and take carrier GPS point as reference. Do field test and measure the error for SINS/DVL integrated navigation. Test respectively from two aspects:

1) On the one hand, the data of SINS/DVL is measured and recorded before adding grey prediction model GM (1, 1) through field test, and the navigation error is analyzed. Navigation data is predicted and corrected by adding grey prediction based on data recorded, and then navigation error is further analyzed. Compare and analyze the navigation precision that before and after adding grey prediction, this is called as offline observation.

2) on the other hand, do field test after writing grey prediction GM(1,1) into program, and make comparison with the navigation error of SINS/DVL before adding grey prediction GM(1,1). This is called as online observation, the field test photos is as shown in Fig.3.



Fig.3 Field test photos

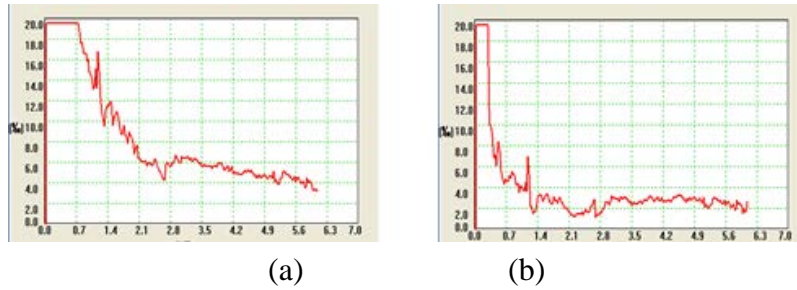


Fig. 4 The off-line observation test comparison chart

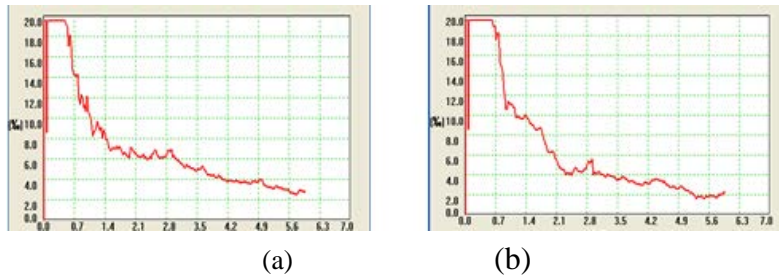


Fig. 5 Online observation test comparison chart

The Measurement Standard of Navigation Error. After the integrated navigation, the positions of integrated navigation and GPS, which are respectively labeled as a_1, a_2, a_3, \dots and A_1, A_2, A_3, \dots , is measured by the same time origin and the same time frequency; GPS position is taken as criterion, then $|A_k a_k|$ can be calculated, where $k = 1, 2, 3, \dots$; $|A_k a_k|$ is the absolute error of integrated

navigation at the location k ; the navigation range that corresponds to location k is $\sum_{i=2}^k |A_i A_{i-1}|$, where $k = 2, 3, \dots$, thus, the integrated navigation error that location k corresponds to navigation range is:

$$\delta = |A_k a_k| / \sum_{i=2}^k |A_i A_{i-1}| \times 100\% \quad (6)$$

The Analysis to Experimental Result. According above test methods, respectively, make both offline and online observation to SINS/DVL, take integrated navigation error that corresponds to

navigation range as interpret standard of precision. Then, SINS/DVL integrated navigation algorithm, which based on grey prediction GM (1,1), is tested. The test result is shown as Fig.4 and Fig.5, where, the result of SINS/DVL integrated navigation that adding GM (1,1) to is shown as Fig. (a), Fig. (b) is the result after adding GM(1,1).

From the test result, the error of SINS/DVL navigation corresponded to navigation range has largely reduced, that is to say, its navigation precision has largely improved after adding GM(1,1) to and having prediction and correction.

Conclusion

This paper tries to further improve the precision of SINS/DVL integrated navigation by adding grey prediction GM(1,1) to it and applying GM(1,1) to analysis of integrated navigation data. Based on above process, navigation model, state equation and measurement equation are established and, data prediction and correction model of AUV integrated navigation based on GM(1,1) model is proposed, which in detail expressed the application of GM(1,1) model in numerical prediction and correction of integrated navigation. At last, SINS/DVL integrated navigation precision before and after adding grey prediction and correction is analyzed through experimental comparison, and the method this paper proposed is tested with experiment is valid.

References

- [1] ZHANG Bo, XU W, LI J L. Particle Filter-Based AUV Integrated Navigation Methods [J]. ROBOT,2012,34(1):79-83.
- [2] Feng Z L, Liu J, Liu K Z. Dead Reckoning Method for Autonomous Navigation of Autonomous Underwater Vehicles [J]. ROBOT,2005,27(2):158-161.
- [3] John J. L, Andrew A. B, Christopher M. S, Hans Jacob S. F. Autonomous Underwater Vehicle Navigation [J]. MIT Marine Robotics Laboratory Technical Memorandum 98-1:1-2.
- [4] WANG Q, XUXS. Application of multi-sensor information fusion to underwater integrated navigation system[J]. Journal of Chinese Inertial Technology,2007,15(6):667-668.
- [5] Zhang Jianhui, Research on Application of SINS/DVL/GPS integrated navigation to long-distance AUV [D]. Xi'an: Northwestern Polytechnical University, 2006.10, 44-53.
- [6] QIAN H, DING Y Z. Research on Large Voyage AVU SINS/ DVL Combined Navigation Orientation Precision [J]. Ordnance Industry Automation, 2010, 29(2):46-48.
- [7] Pan Xuesong, Research on key technology on AUV integrated navigation system based on SINS/DVL/GPS [D]. Qingdao: Ocean University of China, 2011.39-40.
- [8] Deng J. The basis of grey theory [M]. Wuhan: Huazhong University of Science and Technology Press, 2002.6-45
- [9] Deng J. Grey prediction and grey decision-making [M]. Wuhan: Huazhong University of Science and Technology Press, 1988.7-20.