MULTILEVEL PROCESSING OF FIBER-OPTIC-GYRO SIGNALS IN STRAPDOWN INERTIAL NAVIGATION SYSTEMS *

Yu.N. Korkishko[1], V.A. Fedorov[2]
RPC "OPTOLINK" Ltd, 5, proezd 4806, 124498, Moscow, Zelenograd, Russia,
Tel. (+7-495) 651-0960, Fax. (+7-495) 651-0961, e-mail: opto@optolink.ru
A.V. Chernodarov[3], A.P. Patrikeev[4]
Zhukovsky Air Force Engineering Academy, 3, Planetnaya St., 125190, Moscow, Russia,
Tel. (495) 155-1808, e-mail: chernod@mail.ru
S.E. Perelyaev[5]
Moscow Institute of Electromechanics and Automatics, 5, Aviatsionny Pereulok,
125319, Moscow, Russia, e-mail: aomiea@aviapribor.ru

Abstract

Key words: fiber-optic gyro, signal processing, protection from outliers, polynomial and temporal filtering, error estimation

This paper is devoted to the problem of implementation of analytical approaches to the improvement of the accuracy and reliability of fiber-optic gyros (FOGs) in autonomous modes of the functioning of strapdown inertial navigation systems. The proposed solution of the above problem relies on the bringing of the problem of digital processing of FOG signals to a polynomial and temporal construction and on the tuning of such a construction to the functioning under a priori uncertainty and possible discordant measurements. The results of experimental studies are given, which corroborate the effectiveness of applying the proposed approach in practice.

Introduction

The present state of strapdown navigation systems is characterized by the introduction of inertial measurement units built around fiber-optic gyros (FOGs). Compared to ring laser gyros, the FOGs do not require either a high-voltage power supply or a dither. However, the problem of increasing the FOG accuracy characteristics under actual operating conditions still remains topical.

The present-day level of the development of onboard electronics permits one to estimate FOG errors and to compensate for such errors in the course of primary signal processing in real time. To do this, use can be made of mathematical and software tools that were formerly employed only for a second information processing in the integration of navigation systems (NSs). Such tools rely on the models of NS errors and on the Kalman filtering of the noise of observations. The analysis of studies in the field of integrated primary processing of inertial-sensor signals indicates that the possibility exists of a practical implementation of analytical approaches to the improvement of the FOG accuracy characteristics in autonomous modes of the functioning of strapdown inertial navigation systems (SINSs).

The purpose of these studies is an increase in the accuracy characteristics of SINSs, based on the estimation of FOG instrumental drifts and on compensation for such drifts at the level of primary signal processing.

Structure of a System for the Primary Processing of Fiber-Optic-Gyro Signals

The accomplishment of the purpose in view is based on the bringing of the problem of digital signal processing to a Kalman construction and on the tuning of such a construction to the functioning under a priori uncertainty and possible discordant measurements. Estimation systems that are Kalman ones in structure include loops intended for parameters prediction and for their updating on the basis of observation processing. When implementing the prediction loop, provision should be made for models that reflect variations in sensor output signals between the sessions where observations are formed. We propose that such models should be constructed, on a real-time basis, from the moving sample of readings of sensor signals by the use of the Chebyshev orthogonal polynomials. In view of the smoothing properties of the Chebyshev polynomials, it is apparently also possible to perform preliminary filtering of noise at the prediction stage. In elaboration of [1], a procedure for robust prediction is proposed, which enables the readings of outlying signals to be detected and excluded from processing.

---

[1] Dr. Phys&Math. Sc., Professor, General Director.
[2] Dr. Phys&Math. Sc., Professor, Technical Director.
[3] Cand. Tech. Sc.., Ass. Prof., Sr. Res. Wkr.
[4] Cand. Tech. Sc.., Head of Laboratory.
[5] Dr. Tech. Sc., Ch. Res. Wkr

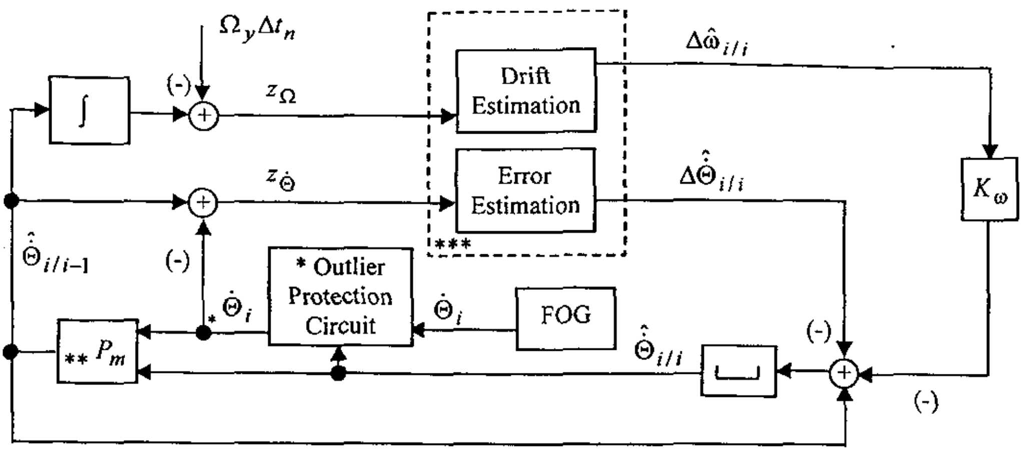

Fig. 1

Such a procedure depends on the comparison of a diagnostic parameter with its tabulated tolerance. The diagnostic parameter was formed as the ratio of a squared residual of the predicted value to the variance of this residual. The variance was taken with respect to the reference phase path that was determined from smoothed signals. The necessity of protecting SINSs built around FOGs from discordant signals is connected with the fact that fiber optic tools intended to measure angular-rotation rate are highly sensitive to external disturbances. Updating of the predicted signal and estimation of the instrumental drifts of sensors are realized from the processing of observations. As observations, we propose that the residual between the predicted and actual FOG signals should be used, along with the appropriate invariants. In the course of the initial alignment of a SINS the invariant is, for example, a change in the rotation angle of a measurement unit in an inertial space, and in the operating mode the invariant is a change in the FOG output signal of the appropriate order.

The block diagram of the proposed system for multilevel processing of signals in the inertial measurement unit is depicted in Fig. 1, where the following notation is introduced: $\dot{\Theta}_i$ are observed readings of the FOG output signal; $\hat{\dot{\Theta}}_{i/i-1} = \sum_{k=0}^{m} \hat{q}_k P_k(t_i)$ is the predicted value of the FOG output signal; $P_k(t_i)$ are the Chebyshev normalized orthogonal polynomials; $\hat{q}_k$ are weight coefficients; P_m is the module for adaptive polynomial smoothing. Adaptation proceeds by use of recurrence smoothing of a retrospective sample of FOG signal readings from the results of observation processing; $\Delta\hat{\dot{\Theta}}_{i/i};\Delta\hat{\omega}_{i/i}$ are estimates of the errors of determination of the FOG angular rate and of its instrumental drift at the i-th step after observations are processed; $Z_\Omega ; Z_{\dot{\Theta}}$ are the signals of observations; K_ω is a scale factor; ⊔ is the delay by one bit; $\Omega_y \Delta t_n$ is the rotation angle (an invariant) of the FOG oy-axis in the inertial space over the time $\Delta t_n = t_i - t_{i-n}$ when the base has no motion with reference to the Earth; (*) is a first level of signal processing; (**) is a second level of signal processing; (***) is a third level of signal processing.

Analysis of the Results of Studies

The SINS-1000 system based on the SRS-1000 FOG [2] developed by the RPC "OPTOLINK" (Zelenograd) has been the object of our experimental studies. Random angular drifts of uncalibrated FOGs of such a type are several hundredths of a degree per hour.

Certain of the results of an experiment on the reduction of the above-mentioned instrumental errors of the SRS-1000 FOG are given in Figs. 2 and 3. Fig. 2 shows the following: an output signal (the light-colored graph, arc sec/sec) of the SINS-1000 "vertical" gyro; a signal smoothed through the use of an adaptive robust polynomial procedure (the dark-colored graph) of the same gyro. The smoothing was performed with a frequency of picking the signal of the FOG equal to 1 kHz. In Fig. 3 is depicted an actual instrumental FOG drift (the light-colored graph, deg/h), which was determined as a mean value of zero bias on time intervals equal to 10s; an estimate (the dark-colored graph) of the instrumental drift of the above-mentioned gyro (of its autocorrelated component), which was obtained when processing the observations z_Ω with a frequency of 1 Hz. An analysis of the results obtained has shown that the polynomial smoothing with a loop for protection from discordant signals permits one to reduce the noise component of the FOG angular error by no less than an order of magnitude. At the same time, the autocorrelated ("accumulated") component of the FOG drift is estimated through the use of the Kalman filter with an accuracy that is no worse than $0.001 \div 0.005$ deg/h.

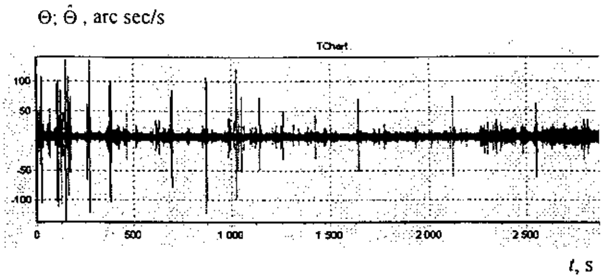

Fig. 2

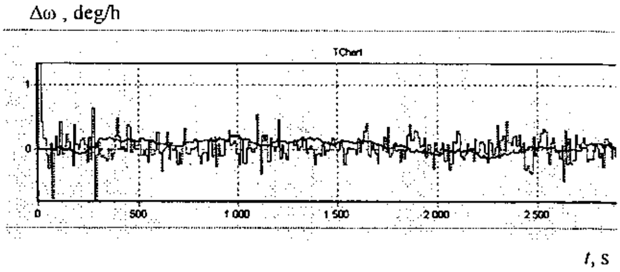

Fig. 3

Conclusions

The results of our studies corroborate the effectiveness of combination, into a unified technological process, of the following procedures for multilevel processing of FOG signals: adaptive robust polynomial smoothing of the signals; optimal estimation of instrumental FOG drifts with the use of the Kalman filter. With such an approach, noise components of FOG errors are "suppressed" at the stage of signals smoothing, and autocorrelated (systematic) components of FOG errors are "suppressed" at the stage of drifts estimation with due regard for information about the models of noise and invariants.

References

1. **Chernodarov A.V., Perelyaev S.E.** Monitoring and Estimation of the Inertial-Sensor Condition During Integrated Primary Processing of Signals // 14-th Saint Petersburg International Conference on Integrated Navigation Systems. – SPb: CSRI Elektropribor, 2007. -P. 91-93.
2. **Korkishko Yu.N., Fedorov V.A., Prilutskii V.E., Ponomarev V.G., Marchuk V.G., Morev I.V., Kostritskii S.M., Paderin E.M., Nesenyuk L.P., Buravlev A.S., Lisin L.G.** Navigation-Grade Interferometric Fiber Optical Gyroscope// 14-th Saint Petersburg International Conference on Integrated Navigation Systems. – SPb: CSRI Elektropribor, 2007. - P. 138-143.