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Using corrective circuits and filtering for integration of low-cost inertial and satellite navigation systems

The stochastic filtering technique is applied to improve the performances of the integrated inertial and satellite navigation system synthesized using corrective circuits. Computer simulation and analysis of results are performed.

Introduction

Inertial navigation system (INS) is an automated system designed to measure one or more navigation parameters based on inertial path calculation and to process the received information and issue it in various forms to consumers. In this work described a way to use INS with SNS (Satellite Navigation Systems) - multi-position radio navigation systems designed to determine the spatial location and speed vector of consumers of satellite navigation information.

INS/SNS integration benefits advantages from both systems. Their combination gives a continuous, high-bandwidth, complete navigation solution with high long- and short-term accuracy. SNS measurement creates borders for inertial solution drift, and INS smooths the INS/SNS solution with possible signal outages. INS/SNS integration is suitable for many applications in practice with a low-cost budget. For example, in navigating ships, airlines, aircraft, helicopters, UAVs, small boats, vehicles, or personal navigation.

The basic configuration in fig. 1 shows an integration algorithm that compares the inertial navigation solution with the outputs of GNSS (Global Navigation Satellite System) user equipment and estimates correction to the inertial position, velocity and attitude.

The correction stage is usually processed by a Kalman filter which forms an inertial navigation solution. This architecture depends on GNSS signal availability because the solution is continuously produced [1].

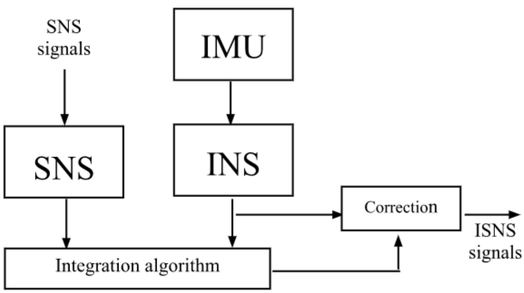

Fig. 1. Universal INS/GNSS integration architecture

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Currently, schemes combine INS and SNS to resolve weakly bound, tightly bound, and deeply integrated circuits. They are divided by type of feedback, open and closed systems.

If the level of integration between the two systems increases, the benefits of such an integrated system generally increase. A comparison of tightly integrated and deeply integrated circuits indicates that the deeply integrated approach is more efficient, although it requires finding adequate models to describe the errors [2].

Existing integration schemes of inertial and satellite navigation systems (ISNS) do not fully meet the goals and accuracy required for modern low-cost UAVs [3]. The analysis shows that the accuracy of navigation information, tactical and technical characteristics, and level of potential anti-interference integrated ISNS significantly increased with increasing depth of integration [4].

Existing systems require very significant computational resources and expensive components for harmonization of air traffic [5]. This problem can be solved by developing an accurate navigation system based on corrective ISNS circuits, thus reducing the required computing resources and system error.

In work [6], the scheme of integrating inertial and satellite navigation systems with corrective circuits for low-cost unmanned aerial vehicles was proposed. The study of system accuracy in static and dynamic operation modes has been done. The result demonstrates that in the steady state operation, the characteristics of the integrated navigation system can provide solutions for navigation tasks with sufficient accuracy. Outliner method can be used to detect illegal activity in the system during calculation tests [7].

Problem statement

The integrated inertial and satellite navigation systems scheme with corrective elements in the feedback circuit proposed earlier is represented [6].

On the scheme, there are denoting the errors of position, speed, and acceleration determination: $\Delta S_m = S_m - S$ is the error of determining the coordinates S; $\Delta V_m = V_m - V$ is the error of determining the speed V; $\Delta \dot{V}_m = \dot{V}_m - \dot{V}$ is the error of determining acceleration and β is the angular error of the gyro platform horizontalizing; Δa is the error of the accelerometer; ω_{dr} is angular velocity INS drift; g is the acceleration of gravity; $\Delta S_k = S_k - S$, $\Delta V_k = V_k - V$ are the errors of SNS for coordinate and speed respectively.

There are some blocks of correction coefficients in corrective circuits: K_3 for correction of position, K_1, K_2 for correction of speed. The paper [6] showed how to set the values of the correction coefficients under the assigned transient performance in INS.

In the given work, this scheme is considered, and an optimal Kalman filter is additionally inserted (Fig.1). Optimistic stochastic filtering implies improving the accuracy due to the filtering of high-frequency measurement errors of SNS.

The subtracter forms the difference between the output signal of the satellite system containing information about the object's position and the output signal of the corrected inertial system. As a result of compensation of the actual value of object position, the difference of INS error and SNS error is input to the filter.

After filtering a high-frequency component of SNS error, a low-frequency component of the integrated system error is formed at the filter output. This is the optimal estimation of the difference between INS error and SNS error $\Delta\hat{S}_{ISNS} = \Delta\hat{S}_k - \Delta\hat{S}_m$, which is used to correct the measurement of aircraft position to increase accuracy.

The task of this work is to synthesize the Kalman filter algorithm and study the accuracy of integrated ISNS by computer simulation.

Problem solution

Applying Kalman filtering is necessary to assign a mathematical model of the estimated process and measurement model in the appropriate standard form. A mathematical description of the errors of an integrated system with correctors was presented previously in [6] by the system of differential equations.

In this representation of the mathematical model for the filter, the unknown parameters except for the state vector are: ω_{dr} is the gyro drift; $\Delta\alpha$ is the error of the accelerometer; ΔV_k is INS systematic error; ΔS_k is the error of position determination by INS.

The study of a synthesized integrated navigation system with corrective circuits and optimum filtration was carried out by computer simulation in the Matlab environment using a discrete Kalman filter.

The results of the simulation are present in Fig.2–3.

Fig.3 shows three signals: the modeled value of INS error fluctuation (curve 1), the composition of the SNS and INS errors (curve 2), and the estimated Kalman filter INS error (curve 3).

For quantitative estimation of the simulation accuracy, multiple statistical modeling was carried out to obtain the variance of the estimation error of the integrated INS. Fig. 4 shows a graph of RMS error of estimation of INS error (curve 2) compared with the theoretical value of the mean square error (curve 1) obtained by the Riccati equation solution (9). Both graphs almost coincide, indicating the high quality of the error identification process and certainty of statistical modeling.

The computer simulation results show that the optimal filter evaluates the quality assessment and INS error, and the estimation is close to the "real" error value.

The modeling results show that the optimal filter estimates the INS error quite well, and estimation is approaching the "real" value.

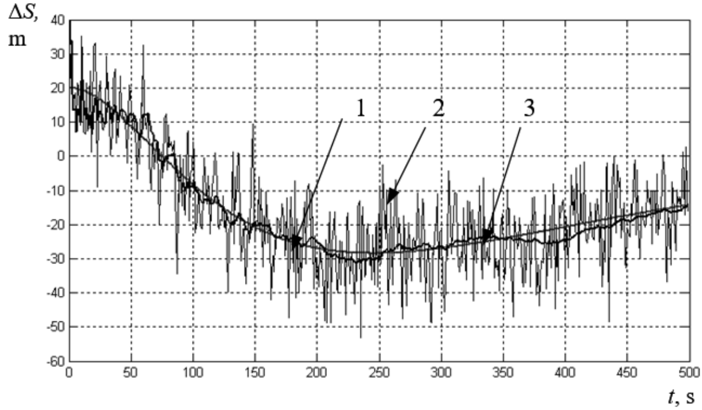

Fig. 2. The results of computer simulation

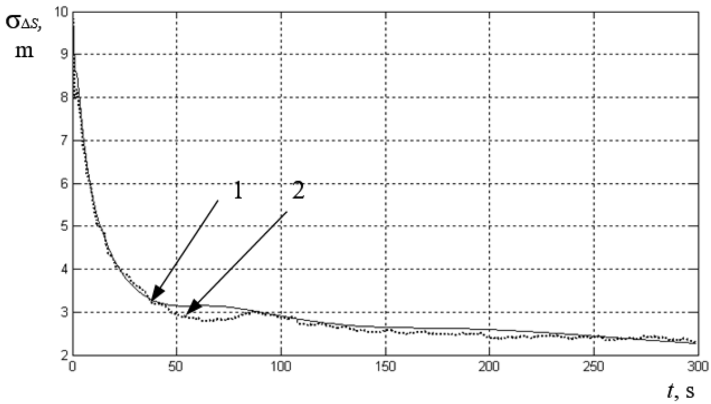

Fig. 3. Mean square value of the estimation error of INS position error

Thus, using a synthesized integrated inertial-satellite navigation system with corrective elements and optimal parameter estimation using the Kalman filter makes it possible to improve the accuracy of the primary navigation performances significantly, processing the measurements in real-time, using not a lot of computer memory and computational resources.

Conclusions

This work proposes an integrated scheme of inertial and satellite navigation systems with corrective circuits and simultaneous filtration of a high-frequency component of measurement errors.

The algorithm for optimal estimation of INS error was synthesized based on the Kalman filter. To satisfy the mathematical model of the Kalman filter of the estimated process and mathematical model of the measurements was derived.

Computer simulation has demonstrated that using corrective circuits and optimal filtration in an integrated scheme of inertial and satellite navigation systems enables it to improve its required performances and obtain more accurate navigation parameters of the aircraft flight trajectory.

The final solution provides better accuracy, decreases navigation signal peaks, and less error of ISNS.

Areas to improve in this ISNS are the more detailed model of sensor errors, a more precise matrix of tuning Kalman filter, and the different frequencies of both systems.

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