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RESEARCH OF THE INERTIAL NAVIGATION SYSTEM

Abstract. *The purpose of this work is to study methods and algorithms for improving the accuracy of a strapdown inertial navigation system (SINS) by correcting it using an optoelectronic system for orientation and navigation (OESON). Although SINS are fully autonomous systems, their main disadvantage is the accumulation of errors in determining coordinates and orientation over time. This research focuses on analyzing SINS error models and the mathematical foundations of OESON operation, which are based on LiDAR survey and "machine vision" methods. An increase in the accuracy of the navigation complex is achieved by synthesizing a compensation scheme based on a Kalman filter (KF), which processes the difference in the output data of both systems.*

Key words: *strapdown inertial navigation system (SINS), optoelectronic system for orientation and navigation (OESON), correction, Kalman filter (KF), SINS errors, systems integration, LiDAR survey, machine vision.*

Introduction. Modern requirements for navigation systems demand high accuracy, reliability, and continuity in determining an object's motion parameters. Strapdown inertial navigation systems (SINS) are widely used due to their autonomy. However, their fundamental problem is the accumulation of errors over time, primarily caused by gyroscope drift and accelerometer zero-bias. This necessitates the integration of SINS with navigation systems based on non-inertial principles. While integration with satellite navigation systems (SNS) is common, SNS are vulnerable to interference and signal loss. Therefore, a relevant task is to study SINS correction methods using optoelectronic orientation and navigation systems (OESON), which do not exhibit temporal error accumulation. The goal of this work is to investigate and develop algorithms for such integration and to evaluate their effectiveness.

Methods and Materials. This paper analyzes the mathematical model of a SINS, which includes two main modes: initial alignment and navigation. The initial alignment process allows for the autonomous determination of the initial orientation angles (roll, pitch, yaw) using accelerometers and gyroscopes on a stationary base. The main operational mode consists of an orientation channel (integrating kinematic equations, e.g., Poisson's equations) and a navigation channel (double integration of measured accelerations) [3, 4]. The sources of SINS errors are analyzed in detail. It is shown that accelerometer zero-bias leads to a quadratic error in position determination, whereas gyroscope drift leads to a cubic dependence of the error on time [3]. The operating principles of OESON, based on "machine vision" technologies, are investigated. These systems determine position by comparing the current terrain image with a reference, which can be a digital elevation model (DEM). The LiDAR (Light Detection and Ranging) survey method is considered as a means of forming such reference 3D models [2]. A compensation scheme is used for SINS correction from OESON (Fig. 1).

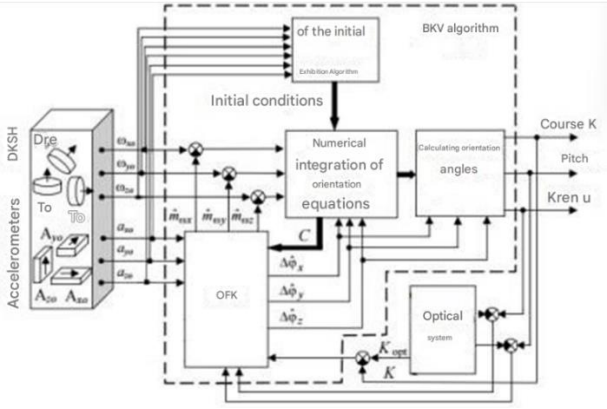

Fig. 1. Functional diagram of SINS and OESON integration

An integration algorithm based on the Kalman filter (KF) is synthesized [1, 2]. The SINS error model is represented in state-space form, and the data from OESON is used as the measurement vector [2]. The Kalman filter recursively estimates the SINS error vector [1], which is then subtracted from the system's current calculations, providing correction of the output navigation parameters. The effectiveness of the method is shown in Fig. 2.

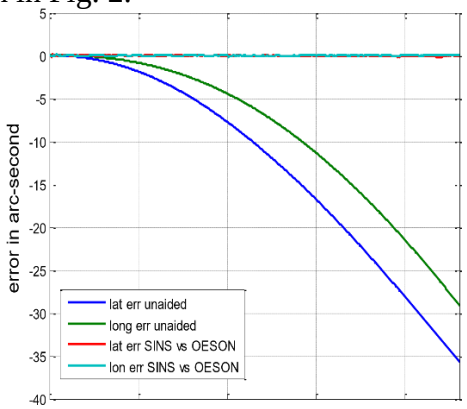

Fig. 2. Latitude and longitude errors
(blue/green – uncorrected, red/turquoise – corrected)

Conclusions. During the master's work, SINS models and their error sources were analyzed, and the principles of OESON construction were reviewed. An algorithm for SINS and OESON integration based on the Kalman filter was substantiated and synthesized. Simulation modeling was carried out in the MatLAB environment, which confirmed the correctness and effectiveness of the proposed algorithm. The simulation results (see Fig. 2) demonstrate that correction from OESON significantly reduces the accumulated errors of the SINS. Over a simulated period of 20-25 minutes, the object's position determination errors were reduced to 2–10 meters, velocity errors to 4 m/s, and orientation angle estimation errors did not exceed 180 arcseconds.

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