# INTEGRATED INERTIAL SATELLITE NAVIGATION SYSTEMS

(Collected articles and papers, 235 pages) (in Russian)
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**CONTENTS**



The digest considers the theory and application of integrated inertial satellite navigation systems. Particular attention is paid to the experience accumulated by the designers in the development and usage of these systems for land, air and marine vehicles.

It includes 4 articles published in the journal **Gyroscopy and Navigation** since 1998 and 10 papers by Russian and foreign authors, presented in the same period at the Conferences in Memory of N.N.Ostryakov, the Saint Petersburg International Conferences on Integrated Navigation Systems and the Conferences of Young Scientists *Navigation and Motion Control*. Two articles have been prepared specially for the digest.

This collection of papers will give the reader a general idea of the current achievements and future trends in integrated inertial satellite navigation systems. The digest is intended for scientists and designers working in this area; it will be also useful for teachers of technical colleges, post-graduates and students.

## THE THEORY AND PRACTICE OF DESIGNING INTEGRATED SYSTEMS



The paper discusses possibilities of determining a vehicle position to a high accuracy using satellite navigation systems operating in different modes and data obtained from inertial sensors.



The paper considers the principles of inertial and satellite navigation systems, compares their key features. The peculiarities of integrated inertial satellite systems are studied, various versions of their configurations are analyzed. The basic trends in the further improvement of integrated systems are discussed.

navigation and landing system (INLS) are synthesized on the basis of the Markov theory of optimal estimation of random processes. This INLS consists of the following parts: an airborne GLONASS/GPS receiver, an inertial navigation system, radio and barometric altimeters. The potential accuracy of the airborne INLS based on the algorithms developed is analyzed.

## EXPERIENCE IN DEVELOPMENT AND APPLICATION OF VARIOUS INTEGRATED SYSTEMS

**Avionique**

Since the end of the eighties, *SEXTANT Avionique* have continuously improved the design and the industrial process of monolithic tri-axis laser gyros (PIXYZ) with two sizes of components: 14 cm for 0.1°/h applications and 22 cm for 0.001°/h applications.

The use of a monolithic tri-axis PIXYZ® for an Inertial Navigation System Sensor Assembly instead of 3 single axis ring laser gyro provides great advantages. Compared with a classical architecture, a PIXYZ Inertial Sensor Assembly is naturally symmetrical and balanced and its size allows significant volume reduction for the inertial navigation system, which is designed around this sensor.

PIXYZ 14 cm has been selected for a precise attitude-heading reference system, adapted to attack helicopters such as the Franco-German Tiger, or for cruise missiles programs such as Scalp EG and STORM SHADOW.

The SEXTANT TOTEM 3000 INS is the first industrial application of a high performance PIXYZ based ISA (22 cm) for fighter applications. The system contains a GPS board and an integrated filter for optimal navigation. Tests on lab vehicles and onboard a MIRAGE 2000 have demonstrated the excellent quality of the inertial sensors and the nominal behavior of the filter in operational conditions.

**B.A.Blazhnov, L.P.Nesenjuk, V.G.Peshekhonov, L.P.Staroseltsev**

**Miniature Integrated Orientation and Navigation Systems for Hydrographic Vessels and Inshore Survey Boats** 134-144

Integration of Inertial Measurement Units (IMU) with satellite receivers allowed using miniature and low cost inertial sensors for high precision integrated reference and navigation systems.

The Central Scientific and Research Institute *Elektropribor* has been involved in the development of miniature strapdown IMUs in the last few years. At present several types of miniature IMUs based on micromechanical, dynamically tuned and fiber-optic gyros have been designed and the results of the inertial sensors laboratory examination are presented. These results were taken into account in designing IMU for different applications: in a strapdown magnetic compass, attitude reference and heading system for oceanographic and cost guard vehicles, gyrocompass and attitude reference system. The strapdown magnetic compass is built on *Murata GyroStar* solid-state gyros and *Analog Devices ADLX* accelerometers. *Fizoptica* fiber-optic gyros were used in the last two systems that realize modulation of gyros output signals by IMU rotation. Two types of onboard microcomputers have been designed. A *Siemens SAK-C167*microcontroller is chosen for the IMU with micromechanical inertial sensors and boards of the PC-104 standard are used in the microcomputer for fiber-optic gyros. The test results of integrated systems are presented.

**B.W.Leach**

This paper describes the development of a capability to integrate low cost strapdown IMU data with differential GPS (DGPS) data, in an optimal fashion, using the principles of Kalman filtering and smoothing. The goal is to create a complete strapdown navigator, based on the low cost IMU, by employing an INS/DGPS Kalman filter in an error state feedback configuration. In this manner, the strapdown IMU's inherently large errors can be corrected in real time to provide a strapdown navigator of sufficient accuracy for all inertial sensing requirements. The raw IMU/DGPS data can also be optimally integrated postflight, using a Kalman filter-smoother, to establish an even more accurate aircraft inertial state time history 'after the fact'.



A reference measurement system including airborne equipment designed to determine a true aircraft trajectory is described. The information from inertial and satellite systems is used as the measurement data. A Kalman filter is employed for integrated processing of the data in the on-line mode and a smoothing filter is used in the off-line mode. Also given are the results of numerous tests of the developed system for different modes and aircrafts.



The problem of referring the results of railway track geometry measurements and detected defects of the rail track to the distance passed is considered. This problem is solved by an integrated system that includes odometer, inertial navigation system and satellite navigation system receiver. The algorithms developed are used to correct the railway odometer. Integrated systems of various designs based on these algorithms are studied.

## ATTITUDE DETERMINATION USING INTEGRATED INERTIAL SATELLITE SYSTEMS



The problem of attitude determination using satellite phase measurements is stated within the frames of the optimal estimation theory. The statement suggested allows taking account of both nonlinear dependence of the phase measurements used on the orientation angles and ambiguity of phase measurements. It is shown that two subproblems may be singled out within the optimal algorithm. One of them is ambiguity resolution of phase measurements and the other - a problem of attitude determination in the

conditions when ambiguity is resolved. The optimal algorithms are compared with the known ones. Simulation results of an integrated inertial satellite navigation system using angle, position and velocity data from the satellite system are given.



The paper considers the equipment intended for the determination of the vehicle attitude using phase measurements from GLONASS and GPS-Мтл-11 developed in the Scientific Research Institute (SRI) of Radio Engineering of Krasnoyarsk State Technical University. The results of the laboratory tests and ship trials of this equipment are given. The possibility to use the Мтл-11 together with the miniature strapdown inertial measurement unit developed in the Central SRI *Elektropribor* is discussed. A filter integrating the satellite and inertial data is introduced on the basis of experimentally obtained error characteristics of the satellite receiver and inertial sensors. The simulation results of the integrated system errors using the trial data are considered.