

INTEGRATED INERTIAL SATELLITE NAVIGATION SYSTEMS

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

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Preface 5-9

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

G.Schaenzer

A High Precision Integrated Navigation System for Vehicle Guidance 10-25

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.

O.A.Stepanov

Peculiarities and Prospects of Integrated Inertial Satellite Navigation Systems 25-43

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.

S.P.Dmitriev, O.A.Stepanov, D.A.Koshaev

Methods of Integrating the Data in Inertial Satellite Navigation Systems 43-59

Different algorithms for integrating position and velocity measurements from inertial and satellite systems are analyzed. Two of the most frequently used schemes are discussed in detail. The first one (the loosely coupled scheme) uses the measurements as the difference between coordinates or velocities from inertial and satellite systems, the other one (the tightly coupled scheme) uses the measurements as the difference between ranges or range rates from each satellite and their values calculated with the use of the inertial system data. The advantages and disadvantages of the both schemes are discussed. The estimation accuracy of navigation parameters is analyzed. The effect of vehicle maneuvering on the efficiency of alignment and calibration for a strapdown inertial navigation system is investigated.

O.N.Anuchin, G.I.Yemelyantsev

About the Influence of the Object's Angular Oscillations on Heading Accuracy and Alignment Time for an Integrated Orientation and Navigation System 60-66

The problem of heading estimation for a strapdown inertial measurement system under the vehicle's angular oscillations with modulation turns of the inertial sensors unit (ISU) is analyzed. The modulation turns are realized within 0...360° in the deck plane. The ISU is located at a large distance from the ship's center of mass. The velocity of the satellite navigation system antenna is used as the reference information.

The simulation results of the integrated system using inertial and satellite data are given. The angular oscillations of the ISU when it shifts 10 m from the center of mass along the ship's longitudinal axis are shown to decrease alignment time and increase heading estimation accuracy under dynamic disturbances.

S.P.Dmitriev, O.A.Stepanov

Non-Invariant Algorithms Using the Vehicle Dynamics for Integrated Inertial Satellite Navigation 67-82

Optimization of the algorithms for integrated inertial satellite navigation systems based on a non-invariant approach that uses additional information about the vehicle dynamics is proposed in this paper to be used to improve the motion control efficiency. The statement of the filtering problem and the simulation results of its solution are considered for the case of a ship track-keeping. The prospects for the application of the algorithms suggested are discussed.

M.S.Yarlykov, N.D.Prigonyuk

An Airborne Inertial Satellite System for Aircraft Navigation and Landing 83-100

The noise-immune suboptimal algorithms for an airborne integrated

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

E.Gai

Guiding Munitions with a Micromechanical INS/GPS System 101-109

Micromechanical inertial sensors are the current leading edge technology in the development of guidance systems. Their small size, low cost and ruggedness make them excellent guidance, navigation and control sensors. Combined with miniature GPS receivers they can provide low cost guidance for munitions with protection against jamming. In this paper the author reviews the micromechanical sensors and systems programs at *Charles Stark Draper Laboratory, Inc.* - the developer of the first INS/GPS guidance system for the US Navy 5" gun.

B.Kaspar, N.Dahlen

Demonstration of the DARPA Global Positioning System Guidance Package on a U.S. Navy F/A-18 110-115

This paper reports on the Global Positioning System (GPS) Guidance Package results obtained from flight demonstration on a United States Navy F/A-18 aircraft. The flight tests were conducted at the *Naval Air Warfare Center, Aircraft Division, Patuxent River, Md.* Ten successful flight tests were performed between November 26 and December 20, 1996. The GPS is an inertially aided, multi-channel P(Y) code, miniature GPS receiver tightly coupled to an interferometric fiber optic gyro based, navigation grade, miniature inertial navigation system (INS). The GPS is 295 cubic inches in volume, weighs 15 pounds, and draws 31.8 watts of power. The GPS program emphasizes technology for affordable, high performance, and small integrated GPS/INS units that will support a broad spectrum of applications.

A.M.Tazba, Yu.V.Levi

Structures of Integrated Navigation Systems Based on Strapdown Inertial Navigation Systems of Average Accuracy 115-127

The paper investigates the possibility to develop integrated inertial satellite navigation systems for civil aviation based on inertial average-accuracy sensors. Various designs of these systems and results of their development are presented. The problems of increasing the integration level of inertial satellite navigation systems are stated.

P.E.Pommellet, D.Portal, P.J.Clemenceau

TOTEM 3000: the New Generation of INS/GPS from SEXTANT 127-134

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

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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

Low Cost Strapdown Inertial/GPS Integrated Navigation for Flight 144-161
Test Requirements

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'.

E.G.Kharin, A.F.Yakushev, V.A.Kopelovich

Reference Determination of an Aircraft Trajectory by Optimal 162-181
Processing of Inertial and Satellite Data

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.

A.M.Boronakhin, A.V.Mochalov, M.Reichel, Y.Schmeister

Investigation of the Integrated Navigation System on the Rail Track 181-196

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**

O.A.Stepanov, D.A.Koshaev

The Analysis of Methods Used in Solving Orientation Problems by 197-221
Data from Satellite Navigation 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.

L.P.Nesenjuk, L.P.Staroseltsev, G.A.Parr, V.I.Kokorin, Yu.L.Fateev, S.P.Barinov, S.M.Bublik, A.A.Shashkov

An Integrated Inertial Satellite Orientation and Navigation System 221-229
with Space-Apart Receiving Antennas

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.