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INTEGRATED NAVIGATION COMPLEX BASED ON HYPERBOLIC AND SATELLITE NAVIGATION SYSTEMS

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Abstract*—The problem of integrated navigation complex structure is discussed. The hyperbolic and satellite navigation systems are proposed to be the consisting parts of such a complex. The problem of their integration is solved.*

Index terms—Hyperbolic navigation system; satellite navigation system; integration.

I. INTRODUCTION

The requirements for the navigational software are described by its following characteristics: precision, readiness (the degree of probability of operability of a complex), integrity (the degree of probability of failure detection within the given time) and reliability (the degree of preservation the necessary precision of complex operation during the given period of time). In the majority of cases the safety and quality of navigational software depends on the redundancy factor [1] – [3]. The most applicable navigational systems are hyperbolic and satellite navigational systems. However, separately each of these systems cannot provide a high quality solution of a navigation problem. Therefore, it is advisable to develop an integrated navigation complex consisting of a few navigation systems, which operate on different physical principles. Such an approach provides a possibility to enhance a reliability of navigation complex of the mobile robot motion both in the main and in autonomic regimes of operation. Enhancement of a safety of a navigation complex can be achieved by the maximal (also on an alternative) using of abilities of existing informational software and also using the new approaches to a problem of pilot-navigational information integration [4].

II. HYPERBOLIC NAVIGATION SYSTEM. LORAN C

Hyperbolic navigation refers to a class of navigation systems based on the difference in timing between the reception of two signals, without reference to a common clock. This timing reveals the difference in distance from the receiver to the two stations. Plotting all of the potential locations of the receiver for the measured delay produces a series of hyperbolic lines on a chart. Taking two such measurements and looking for the intersections of the hyperbolic lines reveals the receiver's location to be in one of two locations. Any other form of navigation information can be used to eliminate this ambiguity and determine a fix.

Consider a hyperbolic navigation system through LORAN C. The LORAN C system consists of a chain of transmitting stations, each separated by several hundred miles. Within the LORAN chain, one station is designated as the master station and the others as secondary stations. There must be at least two secondary stations for one master station; therefore, every LORAN transmitting chain will contain at least three transmitting stations. The master and secondary stations transmit radio pulses at precise time intervals. A LORAN receiver measures the time difference (TD) in reception at the vessel between these pulses; it then displays either this difference or a computed latitude and longitude to the operator. The signal arrival time difference between a given master-secondary pair corresponds to the difference in distance between the receiving vessel and the two stations. The locus of points having the same time difference from a specific master-secondary pair forms a hyperbolic line of position (LOP). The intersection of two or more of these LOP’s produces a fix of the vessel’s position. There are two methods by which the navigator can convert these time differences to geographic positions. The first involves the use of a chart overprinted with a Loran time delay lattice consisting of time delay lines spaced at convenient intervals. The navigator plots the displayed time difference by interpolating between the lattice lines printed on the chart. In the second method computer algorithms in the receiver’s software convert the time delay signals to latitude and longitude for display. Early receiver conversion algorithms were imprecise; however, modern receivers employ more precise algorithms. Their position output is usually well within the 0. 25 NM accuracy specification for LORAN C. Modern receivers can also navigate by employing waypoints, directing a vessel's course between two operator-selected points. Section 1207, section 1208, and section 1209 more fully explore questions of system employment.

The components of the Loran system consist of the land-based transmitting stations, the LORAN receiver and antenna, and the LORAN charts. Land-based facilities include master transmitting stations, at least two secondary transmitters for each master transmitter, control stations, monitor sites, and a time reference. The transmitters transmit the LORAN signals at precise intervals in time. The control station and associated monitor sites continually measure the characteristics of the LORAN signals received to detect any anomalies or any out-of-specification condition. Some transmitters serve only one function within a chain (i.e., either master or secondary); however, in several instances, one transmitter can serve as the master of one chain and secondary in another. This dual function lowers the overall costs and operating expense for the system. LORAN receivers exhibit varying degrees of sophistication; however, their signal processing is similar. The first processing stage consists of search and acquisition, during which the receiver searches for the signal from a particular LORAN chain, establishing the approximate location in time of the master and secondaries with sufficient accuracy to permit subsequent settling and tracking. After search and acquisition, the receiver enters the settling phase. In this phase, the receiver searches for and detects the front edge of the LORAN pulse. After detecting the front edge of the pulse, it selects the correct cycle of the pulse to track. Having selected the correct tracking cycle, the receiver begins the tracking and lock phase, in which the receiver maintains synchronization with the selected received signals. Once this phase is reached, the receiver displays either the time difference of the signals or the computed latitude and longitude as discussed above [7].

III. GLOBAL POSITIONING SYSTEM

Global Positioning System (GPS) is a space-based navigation system that provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites. The GPS system operates independently of any telephonic or internet reception. The GPS system provides critical capabilities to military, civil, and commercial users around the world.

The Global Positioning System concept is based on time and the known position of specialized satellites. The satellites carry very stable atomic clocks that are synchronized to each other and to ground clocks. Any drift from true time maintained on the ground is corrected daily. Likewise, the satellite locations are known with great precision. Global Positioning System receivers have clocks as well; however, they are not synchronized with true time, and are less stable. Global Positioning System satellites continuously transmit their current time and position. A GPS receiver monitors multiply satellites and solves equations to determine the precise position of the receiver and its deviation from true time. At a minimum, four satellites must be in view of the receiver for it to compute four unknown quantities (three position coordinates and clock deviation from satellite time).

The current GPS consist of three major segments. These are the space segment (SS), a control segment (CS), and a user segment (US). The U.S. Air Force develops, maintains, and operates the space and control segments. Global Positioning System satellites broadcast signals from space, and each GPS receiver uses these signals to calculate its three-dimensional location (latitude, longitude, and altitude) and current time.

The space segment is composed of 24 to 32 satellites in medium Earth orbit and also includes the payload adapters to the boosters required to launch them into orbit. The control segment is composed of a master control station (MCS), an alternate master control station, and a host of dedicated and shared ground antennas and monitor stations. The user segment is composed of hundreds of thousands of U.S. and allied military users of the secure GPS Precise Positioning Service, and hundreds of millions of civil, commercial, and scientific users of the Standard Positioning Service.

IV. PROBLEM STATEMENT

It is known the results of hyperbolic and satellite navigational systems functioning by the determination of mobile robots current coordinates x^1, y^1 and x^2, y^2 correspondingly. It is necessary to develop the procedure integration of two navigational systems: hyperbolic and satellite navigational systems into navigational complex and design its structure.

V. ARCHITECTURES OF INTEGRATION

There exist many ways to unify information which is obtained from a set of navigation systems, which form integrated navigation complex. A unification can be applied not only the systems, but also the separate sensors of primary information (pressure sensors, magnetoresistors, accelerometers and so on), which produce the very same parameters. During the unification of several navigational sensors two schemes have obtained a wide application. They, respectively, realize the filtering and compensation approaches. The works [3], [5] are devoted to a realization of a filtering approach, while the works [1], [4], [6] consider the compensation approach.

The most general method to use the whole information contained in a navigation system with many sensors is the well known centralized Kalman filter (CKF), which is the most optimal filter. In this case the model of process and the model of measurements must be the linear ones, while there noises must be the Gaussian ones and independent from each other. However, in many applications the model of process and the model of measurements are nonlinear ones. In these cases used the generalized Kalman filter (GKF). It does not possesses the properties of optimality and unbiasedness, but, if the nonlinearities are not important, it is close to the optimal filter. The architectures of centralized integration and of centralized integration which uses the basic solution are, respectively, shown in Figs. 1 and 2.

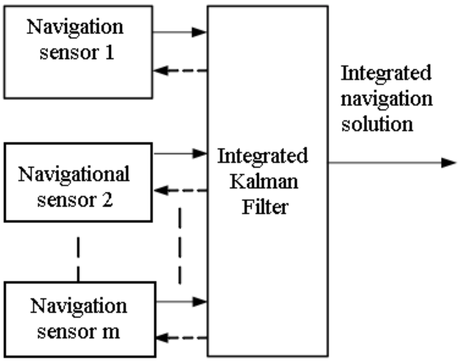

Fig. 1. General structure of centralized integration

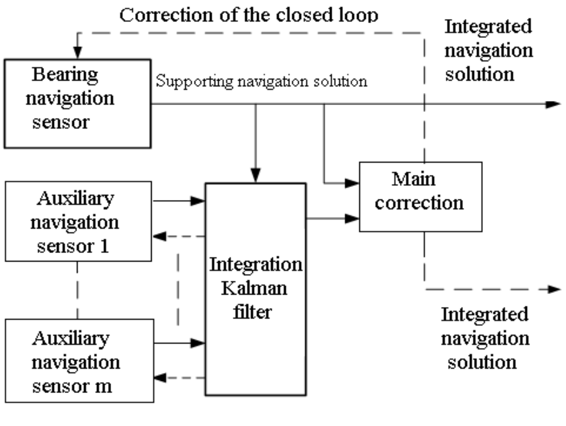

Fig. 2. Structure of centralized integration of a state error

In the centralized architecture of integration the systematic errors and the sources of noise of all navigation sensors are reflected in the same Kalman filter. This guarantees that all errors of correlation are taken into account, that all measurements are wighted optimally and that the maximum of information is used to gauge an every error. Besides an elimination of Kalman filter cascades allows one to use much higher coefficients of enhancement without the risk of losing stability. Thus, the centralized architecture of integration provides an optimal navigation solution with respect to error's accuracy and stability.

However, the major disadvantage of the centralized architecture of integration is a very high computational load on a processor.

If the independent system of navigation solutions is unavailable, then it is necessary to use the highly productive parallel filters in order to meet the requirements of integrity.

VI. KALMAN FILTER

Algorithm of CKF combines solutions of two tasks: monitoring and filtering. Construction principle of CKF consider for the case of a linear system. The task is to find such evaluations $\hat{X}$ that evaluation errors

$$\Delta t = X(t) - \hat{X}(t),$$

were minimal. In other words, it is necessary to provide a minimum of amount of diagonal elements of matrix

$$\mathbf{P(t)} = \begin{bmatrix} p_{11} & p_{12} & p_{1n} \\ p_{21} & p_{22} & p_{2n} \\ \vdots & \vdots & \vdots \\ p_{n1} & p_{n2} & p_{nn} \end{bmatrix} = M\left[\Delta t \Delta^{\mathrm{T}}(t)\right].$$

In covariance matrix **P(t)** members $P_{ii} = D_i = \sigma_i^2$ characterized variances evaluation errors of coincident coordinates x_i, and members p_{ij} is their cross-correlation.

It's known that for a dynamical system CKF, which provides a minimum of a trace of the matrix $\mathbf{P}$, becomes algorithm, which consists of three blocks:

1) the main block

$$\dot{\hat{X}}(t) = A(t)\hat{X}(t) + K_{\mathrm{f}}(t)[Z(t) - H(t)\hat{X}(t)];$$

2) block of calculation of the correction coefficients

$$K_{\mathrm{f}}(t) = P(t)H^{\mathrm{T}}(t)R_z^{-1}(t);$$

3) block of solutions of covariance equations

$$\dot{P}(t) = A(t)P(t) + P(t)A^{\mathrm{T}}(t) - P(t)H^{\mathrm{T}}(t)R_z^{-1}(t)H(t)P(t) + B(t)R_x B^{\mathrm{T}}(t).$$

VII. CONCLUSIONS

The article considered an integration of two navigation systems, namely GPS and hyperbolic system. It was considered two architectures of integration, which realize the filtering and compensation approaches. This is the centralized integration and centralized integration which uses the basic solution.

REFERENCES

[1] V. M. Sineglazov, M. K. Filyashkin, F. M. Zacharin, and Sh. I. Askerov, "Computer-Integrated Navigation Complexes Aerial Vehicles". *1nd International Conference "Methods and Systems of Navigation and Motion Control". Proceedings*. Kyiv, NAU. (October 13–16, 2010). Kyiv: NAU, 2010, pp. 6–9.

[2] Sh. I. Askerov, "Integrated navigation complex of unmanned vehicle". *Automated engineering flight and navigation complexes of unmanned vehicle, Materials of XI International scientific and technical conference "Avia-2013"* (May 21–23, 2013), Kyiv, NAU, 2013, vol. 4, pp. 21.5–21.9.

[3] Sh. I. Askerov, "Complex treatment of data in navigation systems of unmanned vehicles". *Electronics and control systems*, no. 1(31), Kyiv, NAU, pp. 72–75, 2012.

[4] V. M. Syneglazov, M. K. Filyashkin, and Sh. I. Askerov, "The principles of integration of data in navigation systems unmanned vehicle". *Materials of scientific and technical conference "Topical problems of development unmanned vehicle"* (October 17–18, 2011), Kyiv, NAU, 2011, pp. 105–109.

[5] Sh. I. Askerov, "The choice of the solution filtration approaches intask of orientation." *Electronics and Control Systems*, no. 2(36), Kyiv, NAU, pp. 17–20, 2013.

[6] V. M. Sineglazov, and Sh. I. Askerov, "Computer Aided Design of UAV Navigation Complexes with Given Characteristics". *IEEE 2nd International Conference "Actual Problems of Unmanned Air Vehicles Developments". Proceedings,* (October, 15–17, 2013) – Kyiv, Ukraine, 2013, pp. 50–52.

[7] N. Bowditch, *The American Practical Navigator*, edition, National Imagery and Mapping Agency, Pub. no. 9. 1995, 882 p.

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І. В. Карачинецька, О. Ю. Коляда. Комплексний навігаційний комплекс на основі гіперболічної і супутникової навігаційних систем

Розглянуто проблему дослідження інтегрованої структури навігаційного комплексу. Запропоновано структуру комплексу складається з гіперболічної і супутникової навігаційних систем. Вирішено проблему їх інтеграції.

Ключові слова: гіперболічна навігаційна система; супутникова навігаційна система; інтеграція.

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И. В. Карачинецкая, А. Ю. Коляда. Комплексный навигационный комплекс на основе гиперболической и спутниковой навигационных систем

Рассмотрена проблема исследования интегрированной структуры навигационного комплекса. Предложена структура комплекса состоящая из гиперболической и спутниковой навигационных систем. Решена проблема их интеграции.

Ключевые слова: гиперболическая навигационная система; спутниковая навигационная система; интеграция.

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