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M. K. Filiashkin

HINGED SET OF GUIDANCE OF A CONTROLLED FIRE-EXTINGUISHING BOMB

Aviation Computer-Integrated Complexes Department, Faculty of Air Navigation, Electronics and Telecommunications, National Aviation University Kyiv, Ukraine
E-mail: filnik@ukr.net

Abstract—*The guidance system of a fire-extinguishing bomb in the form of a hinged guidance kit is considered, which turns the bomb into a simple and fairly cheap fire-extinguishing device of the "throw and forget" type, optimized for mass production and use. In order to increase the accuracy of dropping a fire-extinguishing bomb, it is proposed to install a cheap high-precision and compact GPS navigation satellite system and a strapdown inertial system on an ordinary fire-extinguishing bomb. The algorithm of complex information processing of their systems, built on the basis of the improved method of the mutual compensation, in which for improve the quality of the error estimation procedure, the sluggishness of second-order Butterworth filters is compensated is proposed. The guidance system controls the trajectory of the fire-extinguishing bomb as a means of "first strike" and this increases the efficiency of further use of traditional flood systems by 50...70 times.*

Index Terms—Fire-extinguishing bomb; hinged guidance kit; compensation scheme; strapdown inertial navigation system; navigation satellite system.

I. INTRODUCTION

In Ukraine, 300,000 to 1,000,000 hectares of forest are burned every year, while the number of fires is increasing exponentially. The experience of the forest fire services of Ukraine, the USA, Canada and a number of other countries has proven the perspective of using air tanker technologies, which under certain conditions can significantly increase the effectiveness of fighting forest fires. But the grandiose forest fires in Russia, the USA, China and a number of countries in Europe, Africa, and Australia convincingly proved that the effectiveness of dropping large masses of water from airplanes on a forest fire is significantly reduced due to a number of factors:

- up to 95–98% of liquid fire extinguishing agents (FEA) is dispersed in the atmosphere, evaporates during contact with rising streams of smoke and flames, as a result of which only a small part of water reaches the surface, the cooling of which determines the success of extinguishing, which leads to large costs – hundreds of tons of water and a large number of expensive flights;
- it is impossible to drain water from the plane in a targeted manner, therefore, water is poured onto the area where the local fire is located, and mostly it falls on the unburned territory, the area of which can be up to 90% of the area of the drain;
- the practical impossibility of timely delivery of means of fire extinguishers – therefore, the impossibility of quickly extinguishing most of the foci of forest fires.

In order for aerial forest fire extinguishing to be effective, it is necessary, by reducing the height of water discharge (this is very problematic in case of intense forest fires), to increase the efficiency of water delivery from an aircraft by 10–100 times to cool the charred surface of burning wood – the energy basis of a forest fire. And to reduce water spray, it is necessary to create a squall with a powerful gas phase. To solve these problems, the technology of extinguishing forest fires with the help of fire-extinguishing bombs (FB) is proposed

Fire-extinguishing bombs creates a cone-shaped, pulsed vortex of sprayed FEA with an expanding, compacted, powerful front, which carries out effective, instantaneous, continuous extinguishing of upper and lower fires on an area of up to 450 square meters.

Fire-extinguishing bombs in the form of FEA was developed as part of the conversion of defense production. It was assumed that the FB would enter the air regiments as training aerial bombs to be used by fighter-bombers which, honing their target bombing skills, would take part in extinguishing catastrophic fires.

Firefighting specialists have developed carpet extinguishing technologies for catastrophic fires using aviation. In the event of significant fire outbreaks, three shock echelons were supposed to be used. Bombers of the first echelon - they are the first to work, with the help of fire extinguishing bombs, they bring down the fire and the heat of the fires. Following them, fire airplanes in a low-level flight would douse with water large burning areas. And finally, low-hanging helicopters with point discharges of water were to finally eliminate the last foci of fires.

The use of FB as a means of "first strike" increases the efficiency of further use of traditional drainage systems by 50...70 times. Several echelons of carpet extinguishing equipment will take no more than an hour. That is why the idea of reviving aviation means of fire-fighting in the form of controlled FBs is very relevant.

II. Problem Statement

In order to increase the accuracy of dropping liquid warheads, it is proposed to install a cheap high-precision and compact GPS navigation satellite system and an inertial autopilot in the form of a JDAM-type attached guidance kit [2] which turns the warhead into a guided bomb of the "drop-and-forget" type optimized for mass production and application.

Externally, the attachment kit looks like (Fig. 1) an elongated tail fairing that is screwed onto the body of the bomb instead of a simple inert tail. The inertial autopilot, GPS navigator, rudder servos and thermal battery are located inside the fairing.

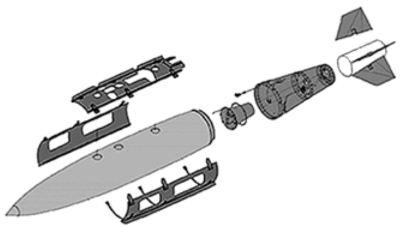

Fig. 1. Hinged set of guidance of a controlled fire-extinguishing bomb

An X-shaped wing is installed at the rear end of the fairing: three of the planes are movable and play the role of elevators and ailerons; the fourth is a simple stabilizer. Control of the FB is carried out with the help of air-dynamic servo drives.

The guidance system of the attached kit consists of three main components: a strapdown inertial navigation system (SINS) based on a laser gyroscope and quartz accelerometers; standard GPS navigator and control microprocessor. All these three components are interconnected in a single combined guidance system, in which satellite navigation provides high accuracy of hitting, and inertial navigation provides resistance to obstacles.

The SINS microprocessor, using an algorithm of complex information processing, calculates the current position of the bomb and controls the trajectory of the VB, which is formed so that its final section is close to the vertical. This significantly increases the efficiency of application and reduces the FB miss, since the vertical coordinate in satellite navigation is determined with the lowest accuracy [3].

The statement of the problem can be formulated as the development and research of algorithms for estimating errors in the calculation of SINS coordinates using information from the satellite navigation system with subsequent correction of the SINS output information. This scheme is an invariant complexing scheme, which is used to solve the problem of estimating the errors of one subsystem against the background of the errors of another subsystem.

III. Problem Solution

When solving the problem of complex information processing in inertial-satellite navigation systems (ISSN), the most attractive is, of course, Kalman filtering (KF). However, the use of the Kalman filter faces certain difficulties in its practical implementation. In particular, in BINS, the main sources of errors are the drifts of inertial sensors, as a result of the non-stationarity of the matrix of the transition from one coordinate system associated with the aircraft to another – the navigation one, will be non-stationary random processes even with the stationarity of random processes, which are the drifts of real sensors. This fact creates difficulties for the on-board implementation of Kalman filtering [1], in particular, it can cause a discrepancy ("collapse") of the computational process.

Currently, in modern on-board systems, in addition to algorithms for optimal estimation of the state vector, there are methods of processing homogeneous information that have proven themselves well in practice. In particular, this is a method of mutual compensation (MC). The expediency of using the MC method when processing information in ISSN is explained by the fact that in this case the measurement of navigation parameters is carried out by ratemeters based on different physical principles, and at the same time, the errors of these meters lie in different frequency ranges [1].

The structural diagram of the implementation of the MC method is presented in Fig. 2.

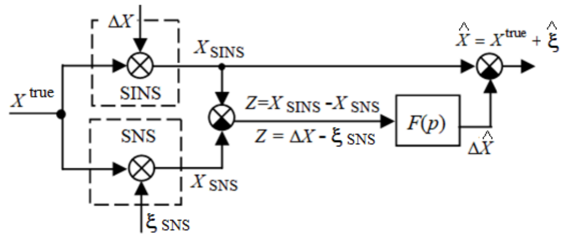

Fig. 2. Block diagram of the compensation method

Here $F(p)$ is the dynamic filter of the MC scheme; X_{SINS}, X_{SNS} are navigation parameters (coordinates and speed components) obtained from SINS and SNS; $\hat{X}$ is the estimate of given navigation parameter; X^{true} is the true value of navigation parameter; ΔX is the error of SINS; ξ_{SNS} is the noise component of SNS error; $\hat{\xi} = [1 - F(p)]\Delta X + F(p)\xi_{\mathrm{SNS}}$ is the error of data fusion; Z are navigation parameters of observation.

The algorithm of complex information processing using the MC method has the following form:

$$\hat{X} = X_{\mathrm{SINS}} - F(p)Z .$$

The equation of compensation scheme (Fig. 1) can be written as follows:

$$\hat{X} = X^{\mathrm{true}} + \Delta X - F(p)(\Delta X - \xi_{\mathrm{SNS}})$$

or

$$\hat{X} = X^{\mathrm{true}} + [1 - F(p)]\Delta X + F(p)\xi_{\mathrm{SNS}} = X^{\mathrm{true}} + \hat{\xi} .$$

The error $\hat{\xi}$ will be decreasing with greater difference between spectral characteristics of sensor errors ΔX and ξ_{SNS}. If the filter $F(p)$ is selected to minimize the distortion of disturbance ΔX and to suppress the noise ξ_{SNS}, then the error of complex system will be minimal, i.e. the error $\hat{\xi}$ decreases depending on the difference in spectral characteristics of noises ΔX and ξ_{SNS}. With significant difference in frequency characteristics of noises at the output of filter $F(p)$ (see Fig. 2) the disturbance ΔX will be reproduced without any changes, and at the output of compensation scheme the exact value of measured parameter X^{true} is obtained, since

$$\hat{X} = X^{\mathrm{true}} + \Delta X - \Delta X = X^{\mathrm{true}} .$$

In article [1] the dynamic filter of compensation scheme is developed, which is the third order link

$$F(p) = \frac{3T_F p + 1}{(T_F p + 1)(T_F p + 1)(T_F p + 1)} . \qquad (1)$$

Comparative analysis of schemes of complex information processing implementing the MC method and the KF algorithm was carried out by means of mathematical modeling using the Simulink program.

The analysis of the simulation results (Fig. 3) indicates the identity of the two complexing schemes, although the presence of a second-order Butterworth filter in the MC scheme allows more effective smoothing of the noise components of SNS errors.

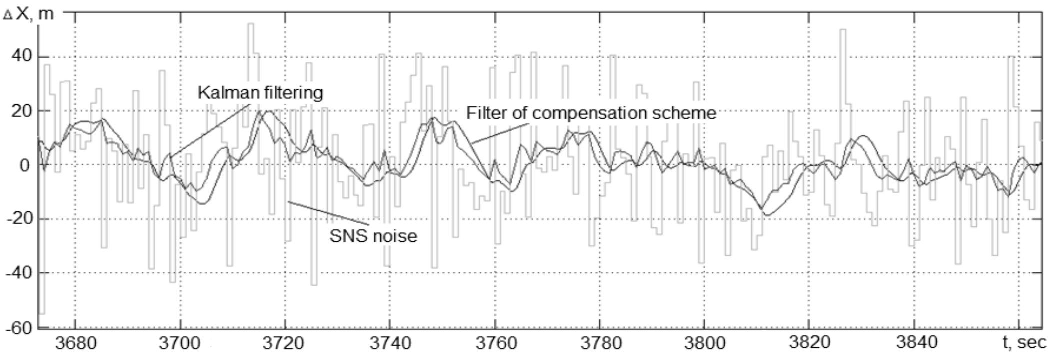

Fig. 3. Analysis of the simulation results of the two complexing schemes

To improve the quality of the error estimation procedure by the MC method, it is proposed to compensate the inertia of the second-order Butterworth filters in the coordinate channel using the component from the velocity error estimation channel, and in the velocity channel using the component from the horizontal acceleration error estimation channel.

The estimated value of the horizontal component of the acceleration of the center of mass is obtained by combining SINS information and the differentiated speed signal coming from the SNS. When differentiating a noisy SNS radio signal, the usual filtering procedures for such signals are performed.

In Figure 4 shows the structure of the dynamic filter $F_1(p)$ of the MC scheme in the coordinate channel.

The filter $F(p)$ in the speed channel has a similar structure, and the filter with the inertia compensation scheme (1) remains in the acceleration channel.

The simulation results, which illustrate the errors in the estimation of the coordinates and velocity of FB for various variants of complex formation, are shown on a larger scale in Figs 5 and 6.

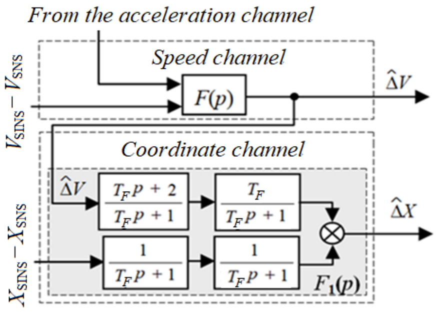

Fig. 4. Structure of the dynamic filter

A comparative analysis of the simulation results shows that the proposed compensation scheme with the dynamic $F_2(p)$ filter based on the second-order Butterworth filter is not inferior to the optimal Kalman filtering scheme in terms of the accuracy of the coordinate error estimation, but it even surpasses it in terms of the quality of filtering the noise components of SNS.

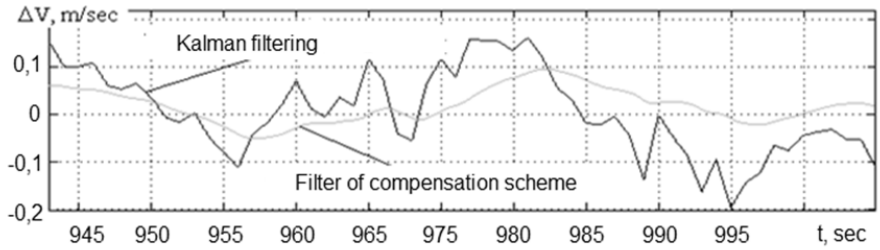

Fig. 5. Errors in the estimation of the coordinates of FB for various variants of complex formation

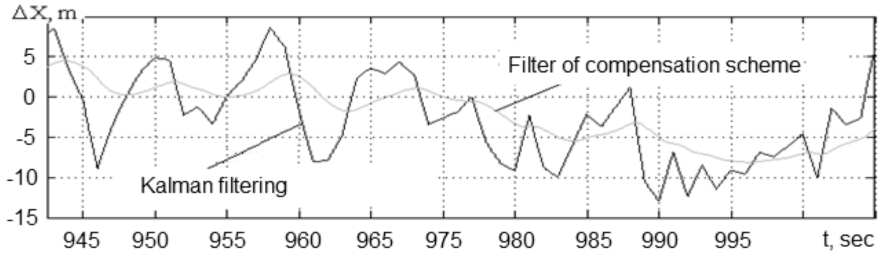

Fig. 6. Errors in the estimation of the velocity of FB for various variants of complex formation

The values of the current coordinates and path velocity vector obtained as a result of complex information processing are used for SINS Fig. 4. Analysis of the simulation results of the two complexing schemes correction.

The integration subsystem of inertial and satellite systems estimates the position and speed of the FB, and this data is provided not only to consumers, but also to the delay and phase monitoring circuits of SNS receivers. The application of filtering schemes, in contrast to the Kalman filter, ensures the arrival of these data at a high speed, allowing to divide the time period between measurements in the SNS subsystem into a large number of subintervals for the purpose of correction of observation contours. This is necessary in order to supply the monitoring circuit with information even when the input signal of the receiver is absent or suppressed by interference.

Therefore, if due to the trajectory evolution of an aerial bomb, tracking of the satellite constellation selected for navigation is lost, information recovery is carried out in a time of no more than 3 seconds. In the absence of information from the GPS-navigator, air bomb targeting signals are formed only on the basis of information processing from the block of sensitive elements of the SINS. The accuracy of SINS is quite sufficient for guidance during such failures in the operation of satellite navigation.

The bomb activates some time before being dropped to calibrate its laser gyroscope and get a GPS fix. After the navigation system is ready, the target coordinates are loaded from the carrier into the control compartment through the standard MIL-STD-1760 data bus connecting the armament suspension with the aircraft's weapons control system. Immediately at the time of release, the bomb receives data from the carrier about the altitude and flight speed, in order to calculate the optimal trajectory.

IV. CONCLUSIONS

A fire-extinguishing bomb is a simple and fairly cheap means of fire-extinguishing, which as a means of "first strike" increases the efficiency of further use of traditional drainage systems by 50...70 times.

The use of a JDAM-type attachment kit based on a cheap high-precision and compact ISSN with the proposed complex information processing algorithm creates a "drop-and-forget" type of FB guidance system.

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Filyashkin Mykola. Candidate of Science (Engineering). Professor.
Department of Aviation Computer-Integrated Complexes, National Aviation University, Kyiv, Ukraine.
Education: Kyiv High Military Engineering Aviation School of Air Forces, Kyiv, USSR, (1970).
Research interests: integrated processing of information in the flight control and navigation systems, automation and optimization of control of aircraft in different phases of flight.
Publications: more than 200 papers.
E-mail: filnik@ukr.net

М. К. Філяшкін. Навісний комплект наведення керованої вогнегасної бомби

Розглянуто систему наведення вогнегасної бомби у вигляді навісного комплекту наведення, що перетворює бомбу в простий і досить дешевий вогнегасний пристрій типу «кинув і забув», оптимізований для масового виробництва і використовувати. Для підвищення точності скидання вогнегасної бомби пропонується встановити на звичайну вогнегасну бомбу дешеву високоточну і компактну GPS-навігаційну супутникову систему та безплатформну інерціальну систему. Використовуючи запропонований алгоритм комплексної обробки інформації, побудований на основі вдосконаленого методу взаємної компенсація, в якому для підвищення якості процедури оцінки компенсується інерційність фільтрів Баттерворта другого порядку, система наведення керує траєкторією польоту вогнегасної бомби. Застосування вогнегасної бомби як засобу «першого удару» підвищує ефективність подальшого використання традиційних водозливних систем в 50...70 разів.
Ключові слова: вогнегасна бомба; навісний комплект наведення; схема компенсації; безплатформна інерціальна навігаційна система; навігаційна супутникова систему.

Філяшкін Микола Кирилович. Кандидат технічних наук. Професор.
Кафедра авіаційних комп’ютерно-інтегрованих комплексів, Національний авіаційний університет, Київ, Україна.
Освіта: Київське вище військове інженерно-авіаційне училище Військово-Повітряних Сил, Київ, СРСР, (1970).
Напрям наукової діяльності: комплексна обробка інформації в пілотажно-навігаційних комплексах, автоматизація та оптимізація керування повітряними суднами на різних етапах польоту.
Кількість публікацій: більше 200 наукових робіт.
E-mail: filnik@ukr.net