UDC 656.7.052.002.5:681.32(045)

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LANDMARKS NAVIGATION SYSTEM FOR UNMANNED AERIAL VEHICLES

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Abstract. *The structural scheme of landmarks navigation system for unmanned aerial vehicles is developed. It is supposed the algorithm of this system. The software of landmarks navigation system is developed.*

Keywords: landmarks navigation system; synthetic aperture radar; barometric altimeter.

I. Introduction

Unmanned aerial vehicles (UAV) are used for tasks solution which are early relied for aircrafts. But the solutions of these tasks with help of UAV are simpler and cheaper. For the solution this tasks it is necessary to supply the precise navigation of UAV under the condition of limitations for size, weight for navigation complex. It has been doing with help of MEMS-technology. But it doesn't supply the high accuracy of the navigation parameters determination. The basic autonomous navigation systems for UAV are inertial navigation systems (INS), but they have a rising time error.

These problems are solved by use of additional satellite navigation systems (SNS). Such navigation complex is known as integrated navigation complex (INC). This increases the accuracy of the navigation complex, but leads to a loss of autonomy and noise immunity. Thus, we have a typical conflict: methods that lead to improved accuracy of navigation, while leading to a loss of autonomy and system noise immunity. This contradiction is solved by additional introduction in composition of INC a landmarks navigation system (LNS) which detects landmarks with given coordinates and then determines the coordinates of UAV.

II. Design of LNS structure

The functional scheme of LNS is represented in Fig. 1.

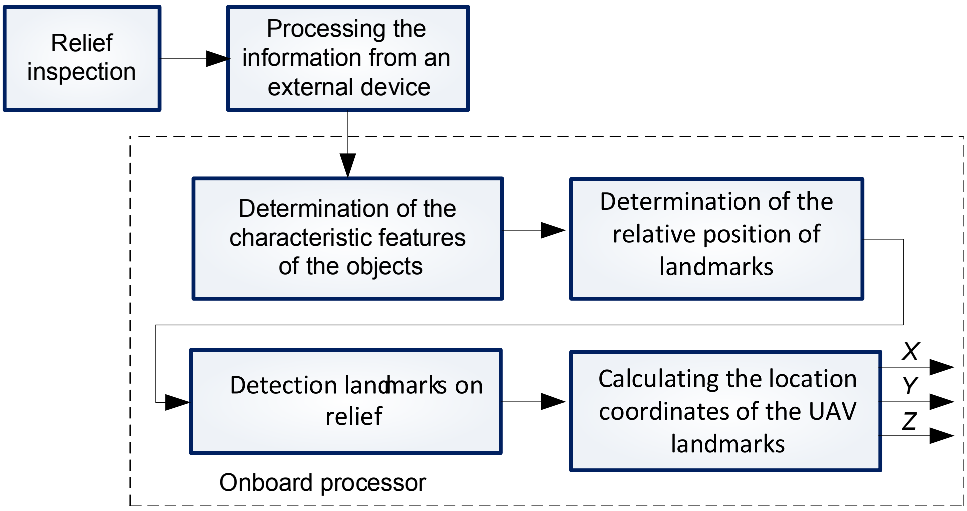

Fig. 1. Structural scheme of solar power plant

The inspection of relief represents the information receiving about Earth's to detect targets surface with help of photo, video or radar devices.

This information is processed with a view of determination of signal characteristic parameters, by which it is defined on based of available electronic map of area the landmark (landmarks) with its (there) precise coordinates. By measuring the distance to the reference point and the azimuth angle the coordinates of the UAV are estimated.

General scheme of LNS is represented on Fig. 2.

The elements in this scheme are: unit of Earth's surface inspection, onboard processor, database, unit of information transfer to UAV operator.

The unit of Earth's surface inspection supplies to get the information about relief which after recording in database is processed by onboard processor, with a view to the estimation of UAV coordinates. The LNS coordinate estimates are used in INC. The structural scheme of LNS represented in Fig. 3.

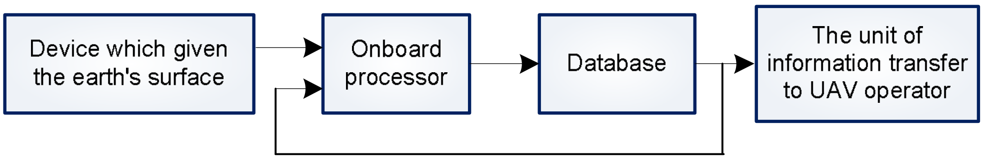

Fig. 2. General scheme of LNS

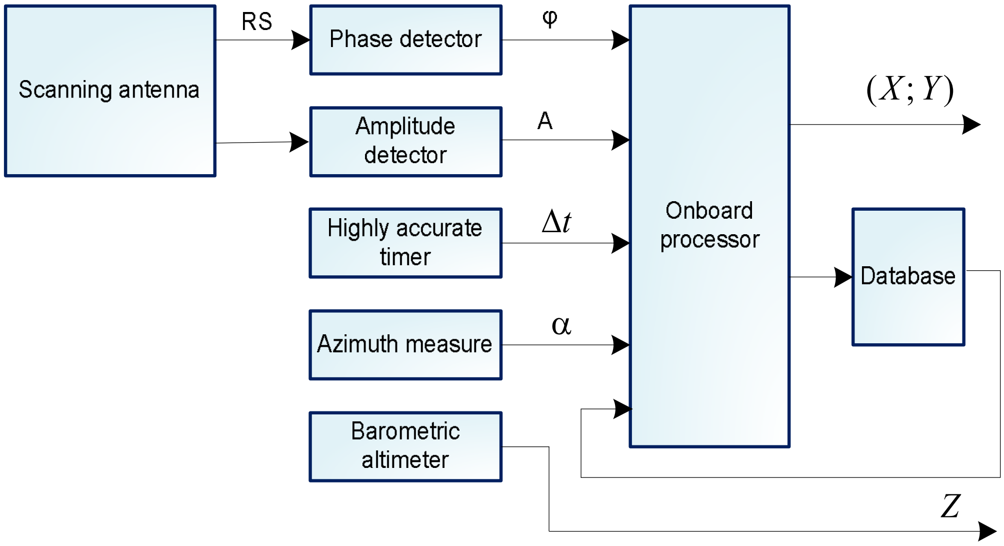

Fig. 3. Structural scheme of LNS

We'll consider each element of the system.

1. Scanning antenna.

Scanning antenna irradiates the Earth's surface by electromagnetic waves and then receives the reflected signals.

2. Received signals (RS) are processed with help of the phase and the amplitude detectors.

3. High-accurate timer.

It measures the difference in time between transmitted and received signals.

4. Measurement of azimuth.

It permits to determine the direction of antenna during receiving of reflected signals with respect to the aircraft course.

5. Database (DB) reserves the received data and landmarks data (parameters, location).

6. With help of onboard processor (OP) it is made the necessary calculations to determine the location.

III. Mathematical Models of Structural Scheme Components

Mathematical model of barometric altimeter (BA).

For BA the mathematical model (for heigh upper 11,000 m) can be written as:

$$H = \left[1 - \frac{P_n}{P_0} t_{\deg} R\right] \frac{T_0}{t_g} + \Delta H,$$

where R is gas constant (29,27 m/deg); P_n *is* pressure at flight altitude; P_0, T_0 are air pressure and temperature at sea level; t_g is temperature gradient; ΔH is the sum of instrumental, wind, temperature errors and terrain correction over which the aircraft flies.

Mathematical model of the phase detector.

For phase detector the mathematical model can be written as:

$$\varphi = \arccos(u) + \omega t,$$

where u is signal's voltage; ω is frequency of received signal.

Mathematical model of the amplitude detector.

$$A = u/(\sin(\omega t + \varphi)),$$

where u is value of the voltage signal, ω is frequency of the received signal.

During the modeling process it is necessary to take into account the scanning antenna error

$$\xi \approx \frac{C\tau_i}{2q_0\sqrt{\pi}},$$

where c is speed of electromagnetic waves (c = = 2,997×10^8 m/sec); τ_i is duration of the effective scanning impulse; q_0 is detection parameter,

$$q_0 = \sqrt{\frac{2E_s}{N_0}},$$

where E_s is energy of the signal with fully known parameters

$$E_s = \int_0^{\tau_i} u_s^2(t)dt,$$

where $u_s(t)$ is instantaneous value of signal voltage at the input of receiver; N_0 is noise spectral density.

Energy of the radio signal, which transmitter from antenna into slaved with it receiver

$$E_s = \rho_{ra} S_{era} = \frac{E_{rad} G_{0tr} S_{eff\,0} S_{era}}{16\pi^2 D^4},$$

where ρ_{ra} is energy flow density in the receiving antenna; E_{rad} is radiation energy; G_{0tr} is maximum value of transmitting antenna gain coefficient by power; $S_{eff\,0}$ is middle value of effective area of target which reflects signal; D is distance to target; S_{era} is receiving antenna effective area, which is connected with geometric area of antenna (S_{gra}) revealing by expression

$$S_{era} = (0.5...0.7)S_{gra}.$$

After LNS structure has been determined, it is necessary to choose a complex of technical means, which meets the requirements of UAV mobility and quality.

IV. TECHNICAL MEANS OF LNS

For the solution of navigation problem by landmarks it is used observed relief means. That's why the solutions of some important problems as observation of a surface detection of small-sized targets receiving the high-detailed images of terrain, operative cartography of great terrain areas, especially in hard approachable places as regions, depend on presents of reliable information, received from technical means in staled in the board of UAV. Between this means the radars of Earth observation occupy especial place due to advantages peculiar to them:

– radars of Earth observation, installed on UAV, permit to receive radar's image of Earth's surface and objects (targets), disposed on it independently of time, lighting level, in any meteorological conditions and on great observe distances;

– new principles of radar Earth's observation permit to increase their resolution by distance and azimuth, and advance information possibilities of radar Earth's observation to optical ones.

V. THE STATEMENT OF THE PROBLEM

It's given the landmarks coordinates $A_i(x_i,y_i)$, where i = 1 … N, N – general landmarks number on the area, $\Delta\varphi$ – phase difference between two signals, λ – electromagnetic wave length of radar, β – azimuth of the received signal. The mathematical model of measurements with help of

$$y = a + \varepsilon,$$

where y – measured value of distance to target; a – true value of distance to target; ε – random error with normal distribution.

The measured value y is determined as

$$y = c\tau_i,$$

where c is speed of electromagnetic waves; τ_i is duration of the effective scanning impulse.

It's necessary:

– to detect landmarks;

– to determine the estimates of the $\hat{X},\hat{Y},\hat{Z}$, the coordinates (X, Y, Z) of UAV, which minimize the criterion

$$I = \left(X - \hat{X}\right)^2 + \left(Y - \hat{Y}\right)^2 + \left(Z - \hat{Z}\right)^2,$$

where X, Y, Z are true values; $\hat{X},\hat{Y},\hat{Z}$ are estimations.

The true landmarks detection depends on scanning antenna error ξ and detection parameter q_0.

In Fig. 4 it is shown how the probability of true landmark detection changes from relative detection distance change.

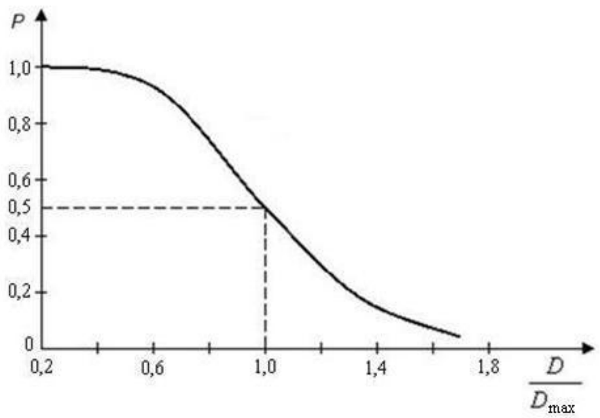

Fig. 4. Relation between the probability of true landmark detection and the relative detection distance, where P is probability of true detection; D – distance to target; D_{max} is maximum radar distance

VI. SOFTWARE DESIGN

Let UAV is at the point $C(x, y)$, and detected landmarks are at points $A(x_1, y_1)$ and B(x_2, y_2) (Fig. 5).

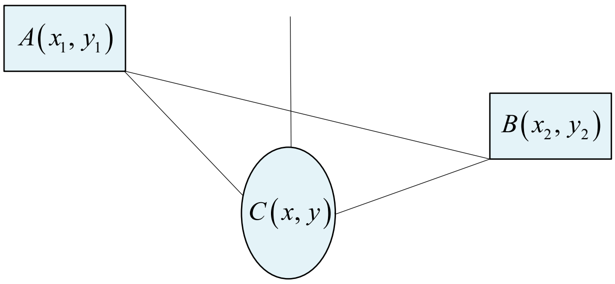

Fig. 5. Location UAV depends on landmarks

The algorithm of coordinates (*x*, *y*) estimation which must be realize in LNS can be represented as follow.

1. Determination of phase and amplitude of received signal using phase and amplitude detectors, mathematical models of which are presented above. The amplitude of received signal is defined as the maximum value.

2. Time detection of reflected signal, i.e. the time between transmitted and received signals.

3. Reservation in database the phase, the amplitude and the azimuth of the received signal with respect to the course of the aircraft. The recording is done by onboard processor.

4. The detection of object (landmark) in the OP.

5. Calculating the imperfection height (over 60 m), it's necessary to find coincidences in database.

6. Searching another landmark on terrain imperfection (over 60 m), it's necessary to find coincidences in database, as described in steps 1 to 5.

7. Determination of the distance between two landmarks on the terrain and comparison with data from database (it's determined the parameters (distance and angle) of landmarks location). This is done by using the cosine theorem, based on the fact that UAV and landmarks create the triangle between themselves, in which the known distances from the UAV to the landmarks and the angle between the directions to these landmarks (see Fig. 4).

8. Computation the location of UAV with regard to two landmarks used the values of distances between UAV and landmarks and corresponding azimuths

$$\begin{cases}(x-x_1)^2+(y-y_1)^2=\left(\sin(a_{za}+\varepsilon_{a1})(a+\varepsilon_{a2})\right)^2;\\ (x-x_2)^2+(y-y_2)^2=\left(\sin(a_{zb}+\varepsilon_{b1})(b+\varepsilon_{b2})\right)^2,\end{cases} \qquad (1)$$

where a is distance to the landmark A; b is distance to the landmark B; α_{za}, α_{zb} are angles between the perpendicular to the earth's surface and the direction of radar waves propagation; $\varepsilon_{a1},\varepsilon_{a2},\varepsilon_{b1},\varepsilon_{b2}$ are random Gauss errors of azimuth (ε_{a1}, ε_{a2}) and distance (ε_{b1}, ε_{b2}) measurements.

Solving the equations (1) we'll getting coordinates estimates of UAV $(\hat{X},\hat{Y})$. Unmanned aerial vehicles coordinate estimate $\hat{Z}$ is determined by the barometric altimeter.

The example of UAV coordinates determination is presented on Fig. 6.

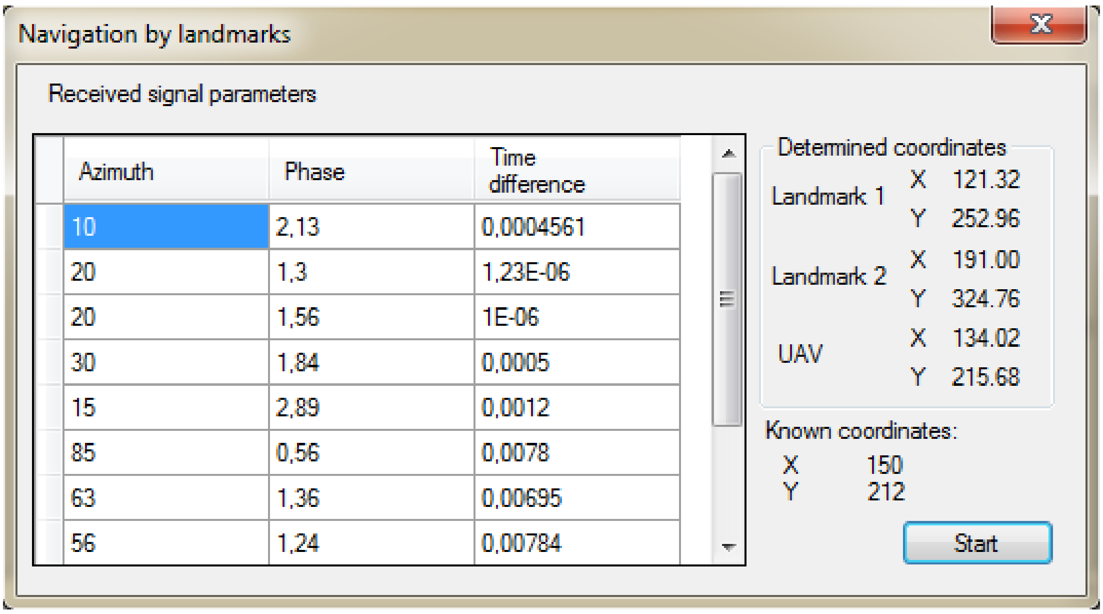

Fig. 6. Example of program realization

Determination of landmark is done by determination of characteristic imperfections at the earth's surface. According to the law of Rayleigh the surface is considered as smooth if

$$\Delta\varphi < \frac{\pi}{2},$$

where $\Delta\varphi$ – phase difference of two successive signals of phase detector.

If

$$\Delta\varphi > \frac{\pi}{2},$$

then the height of imperfections can be calculated by the formula

$$h = \frac{\Delta\varphi\lambda}{4\pi\sin\beta},$$

where λ is wave length; β is the angle of the reflected signal (azimuth).

VII. CONCLUSIONS

The software of landmark navigation system is designed. It is shown that the accuracy of this system in case of noise presence is about 15 m.

The proposed landmarks navigation system can be included to UAV navigation complex and will provide the improvement of navigation problem solution.

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Received 06 December

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В. М. Синєглазов, Ш. І. Аскеров, А. Р. Аксані. Система навігації за орієнтирами для безпілотного літального апарату

Розроблена структурна схема системи навігації за орієнтирами для безпілотного літального апарата. Вона відповідає алгоритму цієї системи. Розроблено алгоритмічне та програмне забезпечення.

Ключові слова: система навігації за орієнтирами, радіолокатор з синтезованою апертурою, барометричний висотомір.

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В. М. Синеглазов, Ш. И. Аскеров, А. Р. Аксани. Система навигации по ориентирам для беспилотного летательного аппарата

Разработана структурная схемв системы навигации по ориентирам для беспилотного летательного аппарата. Она соответствует алгоритму данной системы. Разработано алгоритмическое и программное обеспечение.

Ключевые слова: система навигации по ориентирам, радиолокатор с синтезированной аппертурой, барометрический высотомер.

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