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[1]M. K. Filyashkin,
[2] A. P. Prymak,
[3] A. N. Babeniuk

AUTOMATIC CONTROL CONTOURS OF UAV USING ONLY RELIABLE INFORMATION FROM SENSORS OF DIRECT MEASUREMENT INFORMATION

Aviation Computer-Integrated Complexes Department, National Aviation University, Kyiv, Ukraine
E-mails: [1]filnik@ukr.net, [2]primak.artem@gmail.com, [3]anitabaly@mail.ru

Abstract**—***This paper presents principles of the reconfiguration of automatic control loops of UAV in which at the stage of exit from zone of the active jamming uses only reliable information that's obtained only by autonomous measurement and can't cause the loss of the UAV. Designed control laws of the UAV's autopilot and execute their comprehensive investigation.*

Index Terms—Angles of roll and pitch; unreliable information; autonomous measurement; control loops; laws aileron and elevator.

I. INTRODUCTION

The current approach to information support of the flight of small and miniature UAV is based on the use of inertial and navigation satellite systems as the primary source of information about the flight and navigation parameters.

But, with this approach there is a risk of loss of information support of the flight in the presence of intensive radio jamming. The loss of information about the angular orientation of the parameters, in particular on the angles of the pitch and roll, may lead to loss of the UAV. And in the absence of navigational information from Global Navigation Satellite System (GNSS) alone rough micromechanical Strapdown inertial navigation systems (SINS) not able to provide UAV's exit from zone of the active jamming and his return to the starting point.

To save information about the parameters of the angular orientation has developed a number of alternative methods for measuring the roll and pitch angles, such as pyrometric or magnetometric methods. Another solution is the joint signal processing of gyroscopes and accelerometers of SINS. For this purpose are developed various embodiments of algorithms of data fusion (for the signals gyroscopes and accelerometers), for example, so-called complementary filters or Kalman filter algorithms.

For the decision of navigation tasks in the absence of information from the GNSS, the navigation system of UAV commonly switches to the aero course dead reckoning. Televisions and other approaches to solving navigation tasks such as visual odometry according to information from the onboard webcam UAV [3].

Thus, research intended at improving the reliability of information support of the flight of the UAV are highly relevant.

II. PROBLEM STATEMENT

The paper proposes at flight of UAV in zone of the active jamming to reconfigure automatic control loops and eliminate the use of unreliable information that is obtained not by direct and autonomous measurement and can cause to the loss of the UAV.

For example, if the information about the angles of roll and pitch is obtained by estimating of the state vector, the work failure SNS almost instantly lead to a distortion of the information. Distortions of the flight information can lead to unacceptable evolutions of UAV and as a consequence to his loss.

Thus, the problem statement can be formulated as follows: design algorithms of automatic control loops UAVs emerging from zone of active radio jamming and execute their comprehensive investigation.

III. PROBLEM SOLUTION

The UAV flight navigation complex includes inertial sensors block (three-axis angular velocity sensor and three-axis accelerometer), magnetometer, which provides correction of unsustainable azimuth channel SINS, and pressure sensors block, which provide the information about barometric flight altitude for correction the vertical channel SINS and gives an opportunity to form the automatic control laws of the UAV flight path.

The classical control laws of the aerial vehicles of this type are simple PD or PID controllers. So in elevator channel (in channel of δ_a) the flight altitude control is formed based on pitch angle control loops, for example, such as:

$$\delta_a = K_\vartheta(\vartheta - \vartheta_s) + K_{\omega_z}\omega_z, \tag{1}$$

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where $\vartheta_s = -\frac{K_H}{K_\vartheta}(H - H_s)$.

Here K_ϑ, K_H, K_{ω_z} are transfer numbers of the control law; ϑ, ω_z, H are pitch angle, angular speed of the pitch, flight altitude; ϑ_s, H_s are set values of pitch angle and flight altitude.

Is offered during flights in the zone of active radio interferences as internal contour in the elevator channel use instead of pitch loop the control loop of the normal overload. Thus, it is possible to eliminate the influence of disruptions in the work of pitch angle estimation algorithms on the safety of the UAV flight. The control law in this case is transformed into the form:

$$\delta_a = \frac{K_{n_y}}{T_{n_y} p + 1}\left(\Delta n_y - \Delta n_{ys}\right) + K_{\omega_z}\omega_z, \quad (2)$$

where $\Delta n_{y_s} = -\frac{1}{K_{n_y}}\left(K_H \Delta H + K_{V_y} V_y\right)$; ΔH is the deviation from the given flight altitude; K_{n_y}, K_{V_y} are transfer numbers of the control law; $V_y \equiv pH$ is the vertical speed providing the structural stability of the control loop.

Information about current overloading excess, ($\Delta n_y = n_y - 1$), where $n_y = \frac{a_y}{g}$ can be obtained by means of the SINS vertical accelerometer considering that a_y is the vertical acceleration measured by the accelerometer; g is the gravitational acceleration is equal to 9,81 m/s^2.

Accelerations measured by the accelerometer have noise and systematic components of errors.

The noise component of the measurement, including the UAV measurement component of the engine vibration is filtered by aperiodic filter $\frac{1}{T_{n_y} p + 1}$, and the systematic component of the error accelerometer is a quasi-stationary, contrary to the growing of pitch angle formation errors in time.

Structural analysis of the flight altitude control loop (Fig. 1) shows that even static control law (2) provides astatic flight altitude stabilization during the influence of the wind disturbances fw contrary to the control law (1). The constant component of the measurement errors of vertical acceleration $f_{\text{meas}}^{n_y}$, reduced to the entrance of the inner loop-normal overload control loop $\Phi_{n_y}^{n_{ys}}$, as well as the measuring error of the barometric flight altitude f_{meas}^{H} show the constant error in the altitude stabilization. It should be noted that in contour with control law (1) growing of the pitch angle formation error in time, lead to the progressive flight altitude stabilization errors.

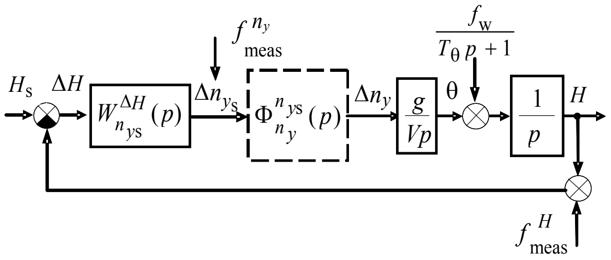

Fig. 1. Structural scheme of the flight altitude control loop

During maneuvering in the vertical plane in such control loop is much easier to realize control influences, forming the given values of the vertical speed $V_{y_{\text{s}}}$ as a function of a given flight altitude.

$$\Delta n_{y_{\text{s}}} = -\frac{K_{V_y}}{K_{n_y}}\left[\left(V_y - F_{\text{lim}}^{V_y} V_{y_{\text{s}}}\right)\left(H - H_{\text{s}}\right)\right]$$

where $F_{\text{lim}}^{V_y}$ is the limitation imposed on vertical speed of climbing and descend.

Similar contours used in maneuvering aircraft shown its high efficiency, as they have higher speed of response in comparison with pitch angle control loops [1].

At the stage of exit from the area of active radio interferences after the disappearance of the GNSS signals the navigation complex goes to the autonomous operational mode uses for saving acceptable accuracy work, extrapolated evolutions values of its errors. During the long radio silence “return mode” is switched on.

During the return mode in accordance with information about current coordinates of the UAV x, z (geographical coordinates φ, λ, given in rectangle coordinate system) and about coordinates of the start point $x_{\text{s. p}}$, $z_{\text{s. p}}$ given heading can be calculated:

$$\psi_{\text{s}} = \operatorname{arctg}\left[(z_{\text{s. p}} - z)\cdot(x_{\text{s. p}} - x)^{-1}\right].$$

In the control channel of ailerons δ_{a} the control law can be realized in the following way:

$$\delta_{\text{a}} = K_\gamma \gamma + F_{\text{lim}} K_\psi \left(\psi - \psi_{\text{s}}\right) + K_{\omega_x}\omega_x, ,$$

where F_{lim} is the limitation function of the given roll angle, K_γ, K_ψ, $K_{\omega x}$ are the transfer numbers on roll γ, heading ψ, angular speed ω_x. During realization of the given control law, UAV starts to execute turn in order to change heading into opposite one. The given value of the heading infinitely recalculated depending on current coordinates change. In the moment of coinciding the current heading with a given one the stabilization regime is switched on. Then UAV in the shortest way flies to the start point and in the same moment realizes heading mode of the flight in accordance to the route [2].

Note that in the aileron channel the same as in elevator channel it is necessary to eliminate the failure influence in the work of angular orientation of the parameters estimation algorithm on flight safety of the UAV. Attempt to go to the control of the latitude motion through the rudder channel, uses in this channel only magnetometer's information which is obtained by the direct measurement of the magnetometer's heading of the UAV, doesn't give positive results. This is because in the aileron's channel still necessary provide stabilization of the zero roll angle, the accuracy of its assessment at the stage of flight in the jammer zone is very doubly. That's why in the work is proposed the following algorithm of the realization of the control influences in the aileron's channel:

$$\delta_{\text{a}} = F_{\omega_x} \frac{K_{\omega_y}}{T_{\omega_y} p + 1} \omega_y + F_{\text{lim}} K_{\psi} \left(\psi - \psi_{\text{з}} \right) + K_{\omega_x} \omega_x \quad (3)$$

Where $K_{\omega y}$ is a transfer number of the angular speed, ω_y. $1/T_{\omega_y} p + 1$ is the filter which is smooth the oscillation motion component of the yaw and is preventing the buildup of the roll of UAV .

Signals ω_y, ω_x it is given from inertial sensor's block and the signal of the current magnetic heading from magnetometer i.e. they are the signals of the direct autonomous measurement.

Research of the proposed contours of control of the lateral motion of UAV carried out by mathematical modeling with a usage of the Simulink Software which is part of mathematical software Matlab.

During investigations the model of UAV was presented as a system of linear differential equations, describing the dynamics of lateral motion of the UAV in deviations:

$$\begin{aligned} &\dot{\Psi} = a_z^{\beta}\beta + a_z^{\gamma}\gamma + a_z^{\delta_{\text{r}}}\delta_{\text{r}}; \\ &\dot{\omega}_x = -a_{m_x}^{\omega_x}\omega_x - a_{m_x}^{\omega_y}\omega_y - a_{m_x}^{\beta}\beta + a_{m_x}^{\delta_{\text{r}}}\delta_{\text{r}} + a_{m_x}^{\delta_{\text{a}}}\delta_{\text{a}} + m_x^f; \\ &\dot{\omega}_y = -a_{m_y}^{\omega_x}\omega_x - a_{m_y}^{\omega_y}\omega_y - a_{m_y}^{\beta}\beta + a_{m_y}^{\delta_{\text{r}}}\delta_{\text{r}} + a_{m_y}^{\delta_{\text{a}}}\delta_{\text{a}} + m_y^f; \qquad (4) \\ &\dot{\psi} = \omega_y \cos\gamma + f_{\omega_z} \sin\gamma; \\ &\dot{\gamma} = \omega_x; \\ &\beta = \psi - \Psi + \beta_w. \end{aligned}$$

Additionally can be used designations: Ψ is the route angle; β is the slope angle; δ_{r} is the rudder deviation; $a_{m_z}^{k}$, $a_{m_x}^{k}$, $a_{m_y}^{k}$, where $k = \beta, \gamma, \omega_x$, $\omega_y, \delta_n, \delta_e$ are coefficients of a mathematical model, taking into account the aerodynamic characteristics of the UAV.

Simultaneously for execution of the comparative analysis it is formed two variants of the control law (3), (4) in the aileron's channel. In the rudder channel the classical law was modeled, providing the damping of the oscillation component of the jaw motion:

$$\delta_{\text{r}} = K_{\omega_y} \omega_y .$$

For research the system of equations of the dynamic motion of UAV has been added by disturbances m_x^f, m_y^f, β_w, f_{ω_z} which imitate the moment disturbances along two axis, wind disturbances and changes of the angular speed of jaw from the angular speed of the pitch. A wind disturbance was modeled in the form of the direct drift angle as in the form of the turbulent disturbance.

For errors estimation influence of the information sensors on static characteristics of the close loop contours of the sensors error control was modeled quasi-stationary and noise components.

The modeling results are given in Fig. 2, which show the changes of the lateral motion parameters during the turn on 90 degree with a usage of the control law (3) and (4).

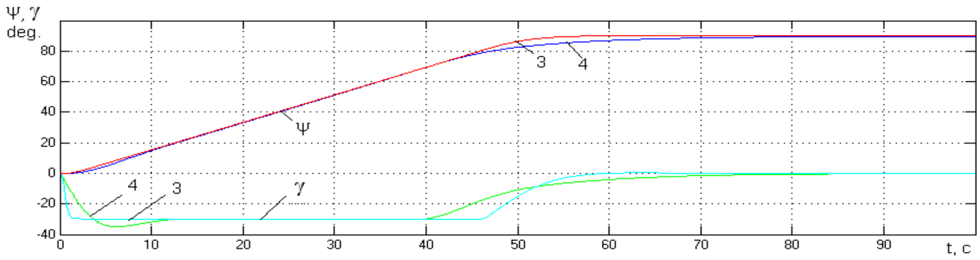

Fig. 2. The results of a turn on 90° with a usage of the control law (3) and (4)

The modeling results show that differences during the processing of the control signals by different control loops are absent only processes in automatic control loops (4) more slowly.

To address this shortcoming in the law aileron (4) introduced additional cross-links, taking into account the dynamics of change in the roll angle $\gamma \approx (\omega_y - a_z^{\beta}\beta - \dot{\beta}) / a_z^{\gamma}$, and the channel of the rudder moved to the mode compensation slip.

Control laws when account is taken that the signal side of overload, take the following form:

$$\delta_a = K_{\omega_y}\omega_y + \frac{1}{T_{n_z}p+1}\left(K_{n_z} + p\frac{K_{\dot{n}_z}}{T_f p+1}\right)n_z$$

$$+ F_{\lim}K_{\psi}(\psi - \psi_s) + K_{\omega_x}\omega_x; \qquad (5)$$

$$\delta_r = \frac{K_{\omega_y}p}{T_{\omega_y}p+1}\omega_y + K_{n_z}n_z.$$

Here aperiodic filter $1/T_{n_y}p+1$ filters out the noise component measurements of side overload, and filter $1/T_f p+1$ additional noise component of the signal, arising from the result of differentiation.

In the channel of rudder PID filter $p/(T_{\omega_y}p+1)$ cuts off constant component, which hinders reversal of the UAV

Comparative studies these control loops, and control loop implementing the control law (3) indicate their full identity at working off a predetermined course (Fig. 3).

Analyzed also processes of parry moment disturbances control loops utilizing control law (3), (5).

In Fig. 4 presents the results of simulation processes, parry the heeling moment m_x^f. Analysis of simulation results also show complete identity of the investigated control loops.

Fig. 5 illustrates the transition processes in control loops (3) and (5) at the parry unfolds moment.

Here at working off disturbance moment in control loop (5) observed an initial reverse reaction of the roll caused by spiral point. However, the overall compensation process unwrapping the moment quite satisfactory.

Finally, the developed control loop was investigated at the stage of the flight UAV in a turbulent atmosphere. In this case simulated errors of sensor date control loop. The simulation results are presented in Fig. 6.

Analysis of the simulation results show that due to energetic parry wind disturbances maneuver in roll, contour (5) provides increased accuracy of stabilization primary navigation of the parameter deviations from a predetermined course of flight.

That can be said about the control circuit (3), which increases with time the error stabilization of in the end, leads to disruption of stabilizing the roll angle and the UAV enters the critical flight regimes (Fig. 7).

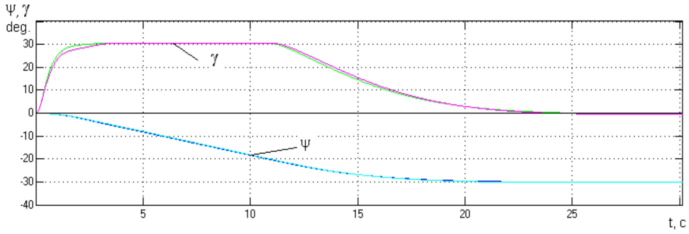

Fig. 3. Results of a turn on 30 with a usage of the control law (3) and (5)

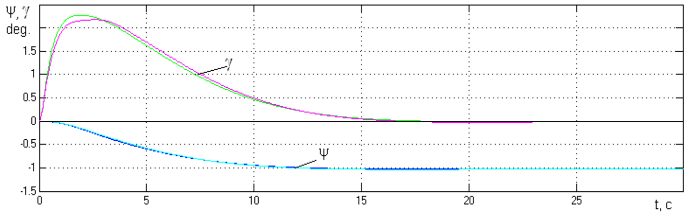

Fig. 4. Results of simulation processes, parry the heeling moment m_x^f

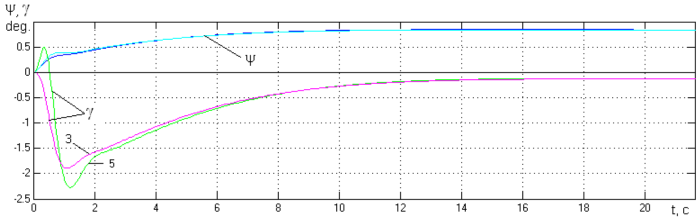

Fig. 5. Transition processes in control loops (3) and (5) at the parry unfolds moment

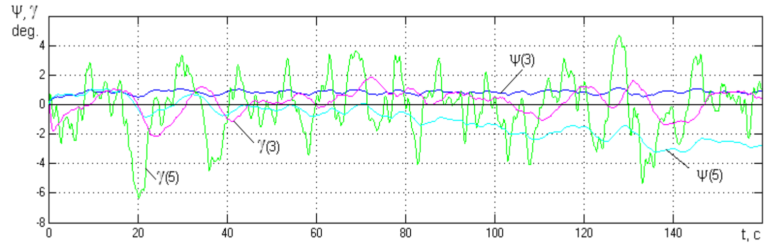

Fig. 6. Simulation results at the stage of the flight UAV in a turbulent atmosphere

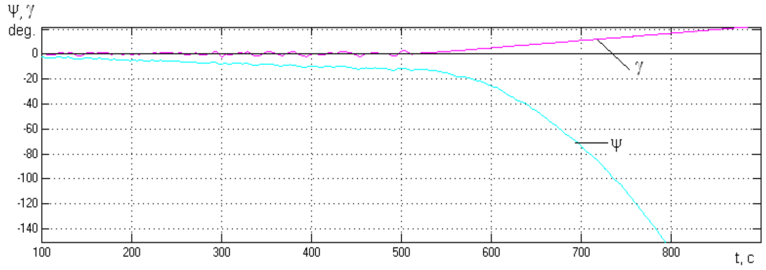

Fig. 7. UAV enters the critical flight regimes

Note that the reconfiguration of control loops in no way reflected on the algorithms for solving navigation tasks SINS, in particular on the algorithms matrix formation of direction cosines, demanding information about the parameters of angular orientation. Moreover, analyzing on steady rectilinear sites of steady flight, statistical values rate of change pitch and roll angles- Angular parameters are not participating in the formation control laws of flight UAV, we can estimate the error of sensor the primary information.

IV. CONCLUSIONS

If the estimate unobservable components of the state vector (pitch and roll) obtained using the extended Kalman filter, that failures in the GNSS nearly instantly distort flight information. The proposed in article the variants of contours of automatic control using only the information from the sensors of direct measurement of flight parameters; can significantly reduce the risk of loss UAV at flights in the zone of the active jamming. Investigations of proposed control loops shown their high efficiency

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Filyashkin Mykola. Candidate of Engineering. Professor.
Aviation Computer-Integrated Complexes Department, National Aviation University, Kyiv, Ukraine.
Education: Kyiv High Military Engineering Aviation School of Air Forces, Kyiv, USSR (1970).
Research interests: correlation extreme navigation, non-linear estimation, Gaussian particle filtering.
Publications: more than 100 papers.
E-mail: filnik@ukr.net

Prymak Artem. 6th year of study student.
National Aviation University, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine, Bachelor (2014).
Research interests: the extremal control systems.
Publications: 2.
E-mail: primak.artem@gmail.com

Babeniuk Anna. 6th year of study student.
National Aviation University, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine, Bachelor (2014).
Research interests: correlation-extreme navigation system.
Publications: 4.
E-mail: anitabaly@mail.ru

М. К. Філяшкін, А. П. Примак, А. М. Бабенюк. Контури автоматичного керування БПЛА, що використовують тільки достовірну інформацію від датчиків прямого вимірювання

Наведено варіанти реконфігурації контурів автоматичного керування БПЛА, у яких на етапі виходу із зони активних радіоперешкод використовується тільки достовірна інформація, отримана шляхом автономного вимірювання, внаслідок чого знижується ризик втрати БПЛА. Запропоновано варіанти побудови контурів керування досліджених шляхом математичного моделювання.

Ключові слова: кути крена та тангажа; недостовірна інформація; автономні вимірювання; контури керування; закони керування рулем висоти та елеронами.

Філяшкін Микола Кирилович. Кандидат технічних наук. Професор.
Кафедра 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: кореляційно-екстремальна навігація, нелінійне оцінювання, гаусовський багатоточковий фільтр.
Кількість публікацій: більше 100 наукових робіт.
E-mail: filnik@ukr.net

Примак Артем Петрович. Студент 6-го курсу.
Національний авіаційний університет, Київ, Україна.
Освіта: Національний авіаційний університет, Київ, Україна, Бакалавр (2014).
Напрямок наукової діяльності: екстремальні системи управління.
Кількість публікацій: 2.
E-mail: primak.artem@gmail.com

Бабенюк Анна Миколаївна. Студентка 6-го курсу.
Національний авіаційний університет, Київ, Україна.
Освіта: Національний авіаційний університет, Київ, Україна, Бакалавр (2014).
Напрямок наукової діяльності: кореляційні-екстремальні навігаційні системи.
Кількість публікацій: 4.
E-mail: anitabaly@mail.ru

Н. К. Филяшкин, А. П. Примак, А. Н. Бабенюк. Контуры автоматического управления БПЛА, использующие только достоверную информацию от датчиков прямого измерения

Приведены варианты реконфигурации контуров автоматических управления БПЛА, в которых на этапе выхода из зоны активных радиопомех используется только достоверная информация, полученная путем автономного измерения, вследствие чего снижается риск потери БПЛА. Предлагаемые варианты построение контуров управления исследованы путем математического моделирования.

Ключевые слова: углы крена и тангажа; недостоверная информация; автономные измерения; контуры управления; законы управления рулем высоты и элеронами

Филяшкин Николай Кирилович. Кандидат технических наук. Профессор.
Кафедра компьютерно-интегрированных комплексов, Национальный авиационный университет, Киев, Украина.
Освіта: Киевское высшее военное инженерно-авиационное училище Военно-Воздушных Сил, Киев, СССР (1970).
Направление научной деятельности: корреляционно-экстремальная навигация, нелинейное оценивание, гауссовский многоточечный фильтр.
Количество публикаций: более 100 научных работ.
E-mail: filnik@ukr.net

Примак Артем Петрович. Студент 6-го курса.
Национальный авиационный университет, Киев, Украина.
Образование: Национальный авиационный университет, Киев, Украина, Бакалавр (2014).
Направление научной деятельности: экстремальные системы управления.
Количество публикаций: 2.
E-mail: primak.artem@gmail.com

Бабенюк Анна Николаевна. Студентка 6-го курса.
Национальный авиационный университет, Киев, Украина.
Образование: Национальный авиационный университет, Киев, Украина, Бакалавр (2014).
Направление научной деятельности: корреляционные-экстремальные навигационные системы.
Количество публикаций: 4.
E-mail: anitabaly@mail.ru