AEROSPACE SYSTEMS FOR MONITORING AND CONTROL

UDC 623.746-519:656.7.052.4 (045)
DOI: 10.18372/2306-1472.81.14598

Oleksandr Ivanov[1]
Volodymyr Ivanov[2]

METHOD FOR FORECASTING THE RELIABILITY OF AN EXTERNAL PILOT OF A REMOTE PILOTED AERIAL SYSTEM

[1,2] National Aviation University, 1, Lubomyra Husara ave., Kyiv, 03058, Ukraine
E-mails: [1]alexkorea5@gmail.com, [2]iva39@meta.ua

Abstract

The stochastic model of actions of the human operator of the ergatic system is proved. The model is based on a simple Markov circuit in the form of a unipolar signal. In it, the set of "logical zeros" corresponds to the error-free operation of the operator, and the presence of "logical units" indicates the presence of errors in its actions. The model is used to predict the reliability level of an external pilot of a remotely piloted system. The primary data required to fill it is collected during the testing of the applicant for the post of external pilot under a special program on a special simulator. Simple ratios were obtained to calculate the probability of error-free operation of the pilot, the coefficient of his readiness or unpreparedness, the probability of making the wrong decision in the remote control of the object.

Keywords: ergatic system (ES), external pilot (EP), human operator (HO), human factor (HF), human operator reliability

1. Formulation of the problem

The effectiveness and reliability of the functioning of any ergatic system (ES), significantly depends on the professional, psychological and physiological characteristics of the human operator (HO), which are manifested at the time of taking the appropriate decisions and in practical implementation of them by tactile action on the joystick, toggle switch, button, other sensors, or combinations thereof. Making any decision on the part of HO requires real time, necessary to comprehend the current situation (0.1 - 1.0 sec.). At the same time, each decision of HO can be accompanied by errors of the first or second kind. The tactile actions of the HO on ES governance also take time and can also occur erroneously. Therefore, HO is the most inertial and low-reliable element of a complex ergatic system.

This is evidenced by the alarming statistics of accidents in civil aviation related to the human factor (HF) [1]. You can recall that the percentage of negative incidents in the ES, which include remotely piloted aircraft systems (RPAS) [2], fit into these statistics. Therefore, the applicant for the post of external pilot (EP) of the RPAS must be timely assessed for compliance with psychological, physiological and professional dignity. Reducing the influence of the HF on the number of unintentional destruction of RPAS can be ensured already at the stage of selection of applicants for the post of civil defense by the results of their training and timely testing [2]. A feature of the HO, as an element of the ES, is its ability to identify and eliminate possible system malfunctions and its own errors with some probability, each of which can lead to undesirable consequences, as failure to fulfil a flight mission, collision of RPAS with others. The number of errors corrected and system technical failures are random variables. Therefore, as criteria for the reliability of the EP it is possible to take the probability of its error-free operation, the availability coefficient, the temporary operating time for one error, or others.

Statistical data, which are necessary for the quantitative assessment of any of the above criteria, can be obtained during scheduled testing of the EP using a special technique and the program on the appropriate simulator. Thus, the training time of the EP is limited. Therefore, the relatively small amount of statistical data that can practically be obtained during the training of a particular person is not enough to correctly obtain moment functions or the probabilistic law of the distribution of errors that may arise in the actions of the applicant for the position of the EP. This circumstance does not allow the use of well-known formulas and methods for assessing the reliability indicators of technical systems when assessing the personal reliability of the EP. Therefore, it is necessary to justify a possible way to quantify the reliability of the EP in a limited amount of initial statistical data and specific features of a person. The basis of this method, it is advisable to introduce a formalized stochastic model that reflects the actions of the EP, which he performs during the management of RPAS. In the future, it is advisable to compare the obtained quantitative assessment of the reliability of the EP with the acceptable value of the selected reliability indicator of the corresponding system. If we consider that at the stage of the RPAS flight all technical subsystems work flawlessly, then its reliability as a whole can be identified with the reliability of the EP and vice versa.

2. Stochastic model of external pilot actions

Consciousness of the EP and the corresponding motor skills create a single continuous process of managing the RPAS. This process can be compared with its corresponding signal, for example, electric.

A separate implementation of the signal corresponds to one training "flight" of the EP on the simulator, carried out according to a special test program. By its properties, a signal is a stochastic unipolar process in it at the moment of the appearance of a separate pulse and its duration corresponds, for example, to the presence of a detected turmoil and the time that the EP spent on eliminating it. The time intervals between the pulses can be considered as the ES practices between the EP errors during a single flight. Therefore, the mathematical model is appropriate to provide the EP as a limited time of simple Markov chain with delay by one step. The duration of the step τ is chosen so short that during it the EP cannot do more than one tactile operation to manage the RPAS or to eliminate the identified turmoil of any origin. Naturally, τ depends on the individual psychophysical and motor properties of a person. In the selected model, one step corresponds to one “logical zero” or one “logical unit”. Logical zeros “0” correspond to discrete time instants; in the action of a EP, it is error-free. Logical units "1" indicates the presence of errors in the actions of the operator. A random sequence of these logical zeros and units is a collection of individual bits, which contains all the information about the reliability of the EP. At time τ, the value of the signal, which is the model of the EP action, can be in one of two incompatible states: “0” with probability P(0), or “1” with probability P(1). These probabilities depend on the probabilities of the signal state p(0), or p(1) at the initial moment of time and on the probabilities $p_i(j)$ the conservation of the signal state or transition from one state i $(i = 0; 1)$ to the state j (j = 0; 1) in one step. A stochastic estimate of the process, which from the initial state in n steps can turn into a process characterized by one of two incompatible states with the probability of strict disjunction P (i ∨̈ j), can be provided in the form of a product

$$\|P(i \ \ddot{\vee} \ j)\| = \alpha_0 \, \alpha^n \ , \tag{1}$$

where:

$$\alpha_0 = \ \| \, p(0) \quad p(1) \, \| = \ \| \, p(0) \quad 1 - p(0) \, \|, \tag{2}$$

is the matrix of the initial states of the RPAS control process,

$$\alpha^n = \begin{Vmatrix} p_{00} & p_{01} \\ p_{10} & p_{11} \end{Vmatrix}^n = \begin{Vmatrix} 1 - p_{01} & p_{01} \\ p_{10} & 1 - p_{10} \end{Vmatrix}^n \tag{3}$$

is the matrix of probabilities of transitions of a process from one state i to state j in n steps. The elements p_{ij} of the matrix (3) are the probabilities of the transition of the process from one state to another in one step, or the probabilities of maintaining the previous state of the unipolar process.

In ratios (1) and (3), the moment of decision-making is determined by the number of elementary pulses n for a chosen value of τ:

$$t = n\tau \, . \tag{4}$$

Thus all intervals in the general relation (1) becomes a multiple of the selected value of τ.

p_{ij} transition probabilities in the matrix α are determined for each candidate for the position of EP during his testing program, which provides for the simulation of emergencies in flight task execution time length $T = n_T\tau$. From simple considerations imply the following:

$$n(0) + n(1) = n_T \, , \tag{5}$$

$$p_{01} = \frac{N(1)}{n(0)} \, , \tag{6}$$

$$p_{00} = 1 - p_{01} \, , \tag{7}$$

$$p_{10} = \frac{N(0)}{n(1)} , \tag{8}$$

$$p_{11} = 1 - p_{10} \, , \tag{9}$$

where:
$N(1)$ - the number of errors and failures of the EU, identified a contender for the position of the EP when tested over time $T = n_T\tau$;
$N(0)$ - the number of EU errors and failures suspended by the applicant in the time interval $T = n_T\tau$;
$n(1)$ – the total number of "logical units", each of which can change its state to the opposite;
$n(0)$ – the total number of "logical zeros", each of which can change its state to the opposite.

If ΔT_k is the duration of the existence of the k mistakes avoided, then the ratios (5), (6), (8):

$$n(1) = \frac{1}{\tau}\sum_{k=1}\Delta T_k \ ;$$

$$n(0) = n_T - n(1)$$

Calculations based on ratios (5) ÷ (9) are the initial statistics which are necessary for predicting the reliability of EP in the future as a certified specialist. After retraining the EP, the value of n (1) may.

Equation (1), with regard to (2) - (9), can be considered a stochastic model of the EU formalized process control by a human operator.

Thus, the appearance in the RPAS management model of separate arrays of “logical units” indicates the presence of errors from the EP. The length of the array n (1) τ corresponds to the time that the operator spent on eliminating the identified problems, each of which could occur critical.

In the presence of external factors preventing EP from the RPAS management process, in the stochastic bipolar ES governance model, there may also be household errors.

3. The procedure for estimating the values of matrix elements “α^n

Elements of the resultant matrix α^n contain all the information about the reliability of the EP during the flight mission during time T. Moreover, the quantitative values of degree n of the matrix (3) can be very large. Therefore, the determination of individual performance elements for any values of degree n is a relatively difficult task. Individual elements of the matrix α^n for this case can be determined by applying the procedures that are given, for example, in [2]. After their implementation, we obtain the same relation for the elements of the resultant matrix (3), which are correct for any moment in time $n\tau \leq T$:

$$p_{00}(n) = \frac{p_{01}}{p_{10} + p_{01}} \times$$
$$\times \left[\frac{p_{10}}{p_{01}} + (1 - p_{01} - p_{10})^n\right], \qquad (10)$$

$$p_{01}(n) = \frac{p_{01}}{p_{10} + p_{01}} \times$$
$$\times [1 - (1 - p_{01} - p_{10})^n], \qquad (11)$$

$$p_{10}(n) = \frac{p_{10}}{p_{10} + p_{01}} \times$$
$$\times [1 - (1 - p_{01} - p_{10})^n], \qquad (12)$$

$$p_{11}(n) = \frac{p_{10}}{p_{10} + p_{01}} \times$$
$$\times \left[\frac{p_{01}}{p_{10}} + (1 - p_{01} - p_{10})^n\right]. \qquad (13)$$

The physical meaning of the obtained ratios at a time $n\tau$ is such:
$p_{00}(n)$ – the probability of error-free EP action in the management of RPAS flight;
$p_{01}(n)$ - probability of making a wrong decision in the management of RPAS flight;
$p_{10}(n)$ – probabilistic readiness coefficient;
$p_{11}(n)$ – probability coefficient of unavailability of the EP to control the flight of RPAS.
It is obvious that:

$$p_{00}(n) + p_{01}(n) = 1,$$

$$p_{10}(n) + p_{11}(n) = 1.$$

Certain probabilistic estimates of the possible states of the RPAS control process are simultaneously simple estimates of the reliability of the EP.

Component contained in parentheses ratios (10) ÷ (13) is less than one. Therefore, for $n \gg 1$, it becomes much smaller than the first term in the corresponding ratio and can be neglected in the future. Therefore, relation (10) ÷ (13) are simplified and take the form:

$$p_{00}(n) \approx \frac{p_{10}}{p_{10}+p_{01}} \ , \qquad (14)$$

$$p_{01}(n) \approx \frac{p_{01}}{p_{10}+p_{01}} \ , \qquad (15)$$

$$p_{10}(n) \approx \frac{p_{10}}{p_{10}+p_{01}} \ , \qquad (16)$$

$$p_{11}(n) \approx \frac{p_{01}}{p_{10}+p_{01}} \qquad (17)$$

In ratios (14) ÷ (17), the dependence of the VP reliability indices on the values of n is practically lost. In this case, the quantitative values of the indicators $p_{00}(n)$ and $p_{10}(n)$, too $p_{01}(n)$ and $p_{11}(n)$) of different contents become the same.

Applying the matrix multiplication rules and taking into account the ratios (10) ÷ (13) or (14) ÷ (17), the general ratios n (1) can be formally written as a matrix row:

$$\| P(i \ddot{\vee} j) \| = \| p(1)\, p_{11}(n) + p(0)\, p_{01}(n) \quad p(0)\, p_{00}(n) + p(1)\, p_{10}(n) \| \tag{18}$$

If $p(0) = 1$, than

$$\|[P(i \ddot{\vee} j)\| = \|p_{01}(n) \quad p_{00}(n)\| \tag{19}$$

and $N(1) = N(0)$.

If $p(0) = 0$, than

$$\| P(i \ddot{\vee} j) \| = \| p_{11}(n) \quad p_{10}(n) \| \tag{20}$$

and $N(1) > N(0)$.

Various initial conditions (19) and (20) affect the value of the transition probabilities (6) ÷ (9) and the final results of reliability evaluation EP.

4. Examples of evaluating the reliability of EP.

Example 1. Let's say this:
T = 30 min.; τ = 1 sec.; $N(1) = N(0) = 4$;
ΔT_k = 20 sec.

In this case in model (19):
$p_{00}(n)$ = 0,956; $p_{01}(n)$ = 0,044;
$p_{10}(n)$ = 0,956; $p_{11}(n)$ = 0,044.

Example 2. Let's say this:
T = 30 min.; τ = 1 sec.; $N(1)$ = 5;
$N(0)$ = 4; ΔT_k = 20 sec.

In this case in model (20):
$p_{00}(n)$ = 0,9315; $p_{01}(n)$ = 0,0685;
$p_{10}(n)$ = 0,9315; $p_{11}(n)$ = 0,0685.

Thus, the EP error at the start reduces its reliability indices, all other things being equal.

5. Conclusions

1. The developed method for assessing EP reliability is based on the results of its testing after it has completed training on a simulator using a special technique and program.

2. Obtained data on the individual characteristics of the future pilot will be used in the future in predicting its reliability as a specialist in the management of RTAS.

3. The ratio for quantitative estimates of EP reliability indicators has simple mathematical expressions.

4. The developed method for assessing the reliability of the EP has a general nature and can be used to assess the reliability of pilots of aircraft of any type or to assess the reliability of operators of other ergatic systems.

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О.В. Іванов[1], В.О. Іванов[2]

Спосіб прогнозування надійності зовнішнього пілота дистанційно пілотованої авіаційної системи

Національний авіаційний університет, просп. Любомира Гузара, 1, Київ, Україна, 03058
E-mails: [1]alexkorea5@gmail.com, [2]iva39@meta.ua

Обґрунтована стохастична модель дій людини-оператора ергатичної системи. Основою моделі є простий ланцюг Маркова у вигляді уніполярного сигналу. Сукупність «логічних нулів» в ній відповідає безпомилковій роботі оператора, а наявність «логічних одиниць» свідчить про помилки в його діях. Модель застосовується для прогнозування рівня надійності зовнішнього пілота дистанційно пілотованої системи. Первинні дані, яки необхідні для її наповнення, збираються під час тестування претендента на посаду зовнішнього пілота за спеціальною програмою на спеціальному тренажері. Отримані прості співвідношення, які дозволяють розраховувати ймовірність безпомилкової роботи пілота, коефіцієнтів його готовності або неготовності, ймовірність прийняття помилкового рішення при дистанційному управлінні об’єктом.

Ключові слова: ергатична система, зовнішній пілот, людина-оператор, людський фактор, надійність людини-оператора.

А.В. Иванов[1], В.А. Иванов[2]

Способ прогнозирования надежности внешнего пилота дистанционно пилотируемой авиационной системы

Национальный авиационный университет, проспект Любомира Гузара, 1, Киев, Украина, 03058
E-mails: [1]alexkorea5@gmail.com, [2]iva39@meta.ua

Обоснована стохастическая модель действий человека-оператора эргатической системы. В основу модели положена простая цепь Маркова в виде униполярного сигнала. В ней совокупность «логических нулей» соответствует безошибочной работе оператора, а присутствие «логических единиц» свидетельствует о наличии ошибок в его действиях. Модель используется для прогнозирования уровня надежности внешнего пилота дистанционно пилотируемой системы. Первичные данные, необходимые для её наполнения, собираются во время тестирования претендента на должность внешнего пилота по специальной программе на специальном тренажёре. Получены простые соотношения, позволяющие рассчитывать вероятности безошибочной работы пилота, коэффициентов его готовности или неготовности, вероятности принятия ошибочного решения при дистанционном управлении объектом.

Ключевые слова: эргатическая система, внешний пилот, человек-оператор, человеческий фактор, надежность человека-оператора.

Oleksandr Ivanov. Radioengineer**.** Head of International Department of the National Aviation University.
Email**:** alexkorea5@gmail.com

Volodymyr Ivanov. Doctor of Technical Sciences, Professor, Professor of the Department of Radioelectronic Devices and Systems, Educational and Research Institute of Air-navigation, and Telecommunications, National Aviation University.
Email**:** iva39@meta.ua