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METHOD OF PATH CONSTRUCTING OF INFORMATION ROBOT ON THE BASIS OF UNMANNED AERIAL VEHICLE

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Abstract

Purpose: *The purpose of this article is to present a method for constructing the branching path of the information robot (IR) that is a compound dynamic system (CDS) allowing us to formulate, in terms of optimal control theory, conditions of CDS path modeling with an arbitrary branching scheme.* ***Methods:*** *The article describes a method of theory of discontinuous dynamical systems optimal control, which is used to prove the optimality conditions for phase coordinates in the points of structural transformations of the IR's branching path.* ***Results:*** *The necessary conditions for the optimality of the branching path along which the IR moves are defined. These conditions allow using standard subprograms to solve ordinary differential and algebraic equations and thereby to solve the task of modeling the optimal path of CDS with an arbitrary branching scheme.* ***Discussion:*** *The proposed method is the methodological basis for definition the computing algorithms allowing to simulate the optimal CDS paths. The proposed procedure of optimal branching paths simulating is part of the IR's computer-aided design software and can be used to define computing algorithms taking into account the peculiarity of information-telecommunication interaction of CDS's specific elements.*

Keywords: unmanned aerial vehicles; information robot; compound dynamic system; optimal control; branching path

1. Introduction

Currently, the successes achieved in the development of unmanned aerial vehicles (UAVs), both military and civilian, create technological conditions for expanding the areas of its application. One of the promising areas is creation of an information robot based on the UAV group for on-line collection and transmission the data about the state of operational landscape and environment in the protected areas of critical infrastructure facilities (nuclear power plants, oil and gas pipelines, military bases and warehouses, chemical industry enterprises, etc.), in the natural or anthropogenic disasters area.

Information robot (IR) is a compound dynamic system (CDS) [5], its elements are: a basic UAV (UAV-carrier); a group of various mobile UAVs (drones) equipped with multisensors and interconnected through a common information and telecommunications network.

The basic UAV is used as an airplane for drones delivery and primary deployment in studied (investigated) area; to collect, accumulate, preprocess on-line data received from the drones; and to retransmit real-time received data to a command control post. Depending on the tasks to be performed, various scenarios of drones mobility, deployment plan and its interaction with the basic UAV can be provided.

Depending on specified scenario, separate drones can operate as independent repeaters or data storage devices, as well as a network of interacting nodes, and can be used as a repeater for other drones.

2. Analysis of the research and publications

The efficiency of using the IR will depend on spatial coordinates and time instants when the structural transformations occur, as well controlling IR's components as they move along the path branches in time intervals between sequential structural transformations.

The paths of such CDS in the modern scientific literature have been called 'branching paths', knowing that they consist of sections of joint movement of constituent parts and segments of its individual movement to the target along separate path branches.

The prototypes in theory of such systems are systems considered in the publications of Bryson E., Ho Y. [1], Aschepkov L. T. [2], Samoylenko A. M, Perestyuk N.A. [3], Lysenko A.I. [4] and others.

However, all these publications were of a theoretical nature and did not contain detailed study, which would provide to design a computer-aided technology of optimal branching path automated synthesis and optimal control of CDS for each specific case.

Therefore, the scientific problem, related to improvement and development of methods of designing branching paths that would allow to solve on a real time basis the tasks of CDS' definition optimal paths of this type, is actual.

3. Aim of the paper

The purpose of this article is to present a method for constructing the branching path of the IR that is a compound dynamic system allowing us to formulate, in terms of optimal control theory, conditions of CDS path modeling with an arbitrary branching scheme.

4. Problem statement

Consider, for example, the motion of a hypothetical IR, which includes a basic UAV and four drones, three of those are based on the UAV, and fourth one starts motion out of the UAV. During motion, the IR's elements can: be grouped together for data exchange; be separated for the purpose of individual performance of the task; to influence mutually on the motion dynamics of the IR's elements. The scheme of the motion of the IR's elements is shown in Fig. 1.

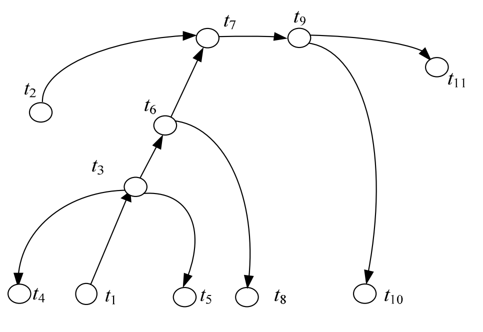

Fig.1. The example of an arbitrary branching scheme for the path of IR's elements

At the initial time t_1 – the basic UAV starts as a single unit containing three drones. During the motion at the time t_3 – the basic UAV drops two drones, completing its motion at time points t_4 and t_5. Next, at the time t_6 – there is a separation of the third drone completing the motion at the time t_8. At the time point t_7 – the base UAV and the fourth drone (started at the time t_2) are mated (mechanically or by compactly grouping, then the fourth drone follows the UAV as follower after leader). At the end of joint motion at the time t_9 – the basic UAV and the fourth drone are unmated and move individually up to time points t_{10} and t_{11}. The path of CDS motion shown in Fig. 1. is related to the class of branching paths [4].

The task will be to find the optimal control vector that minimizes energy consumption for control, providing the maximum coverage area of monitored territory and uninterrupted transmission of information about its state.

5. Method of path constructing of information robot

When solving the tasks of modeling the optimal CDS motion, it is necessary to consider branching paths of various complexity in comparison with the scheme given in the example. At present, optimality conditions are formulated for particular schemes of branching paths, it requires a complete solution of the task whenever the new branching path does not coincide with known particular cases [6, 7]. Before proceeding to generalized formulations, consider the examples of elementary branching paths (Fig. 2), which enable us to ground the required generalizations.

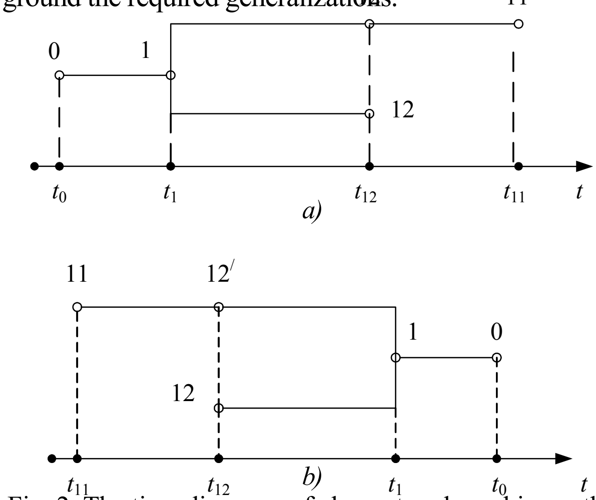

Fig. 2. The time diagrams of elementary branching paths: *a* – scheme with separation of subsystems; *b* – scheme with grouping of subsystems

The equations describing the CDS motion with separation (Fig. 2, *a*) are as follows:

$$\dot{x}_1 = f_1(x_1,u_1), t \in [t_0,t_1], \tag{1}$$

$$\dot{x}_{11} = \begin{cases} f_{11}^{12}(x_{11},u_{11};x_{12},u_{12}), t \in [t_1,t_{12}], \\ f_{11}(x_{11},u_{11}), t \in [t_{12},t_{11}], \end{cases} \tag{2}$$

$$\dot{x}_{12} = f_{12}^{11}(x_{12},u_{12};x_{11},u_{11}), t \in [t_1,t_{12}], \tag{3}$$

where $x_p(t) \in R^n$, $u_p(t) \in R^{m_p}$, $u_p \in \Omega_p$, p–quantity of subsystems (1, 11, 12).

The vector criterion for the quality of CDS functioning can be written in the additive form

$$\begin{aligned} I = S(x_1 t_0), t_0; x_1(t_1), t_1; x_{12}(t_{12}), t_{12}; x_{11}(t_{11}), t_{11}) + \\ + I_1 + I_{11} + I_{12}, \end{aligned} \tag{4}$$

where

$$I_{12} = \int_{t_1}^{t_{12}} \Phi_{12}(x_{12},u_{12};x_{11},u_{11})dt,$$

$$I_{11} = \int_{t_1}^{t_{12}} \Phi_{11}^{12}(x_{12},u_{12};x_{11},u_{11})dt + \int_{t_{12}}^{t_{11}} \Phi_{11}(x_{11},u_{11})dt.$$

The optimality criterion corresponds to Bolze's form, where the function $S(\cdot)$ physically reflects the requirements for the values of coordinates of the CDS elements motion at the moments of start and end, as well as for the values of time moments. The integral terms of criterion show the requirements for character of the motion of CDS elements along corresponding path branches. The mutual influence of elements within the time interval $[t_1,t_{12}]$ is described as in the equations of its motion (2), (3) as well in particular integral criteria I_{11} and I_{12}. The equations describing the motion of elements and the criterion in the scheme with grouping (Fig. 2, *b*) have the same form as ones for the scheme with separation, differing only in the sign of the time variation.

It is necessary to choose the controls $u_1(t)\, t \in [t_0,t_1]$, $u_{11}(t)\, t \in [t_1,t_{11}]$, $u_{12}(t)\, t \in [t_1,t_{12}]$, vectors of phase coordinates $(x_1(t_0), x_1(t_1), x_{11}(t_{12}); x_{12}(t_{12}), x_{11}(t_{11}))$ and time points t_0, t_1, t_{11}, t_{12} for both branching schemes (Fig. 2, *a, b*), so that the functional I takes the smallest possible value. We formulate the necessary conditions for the optimality of branching path along which the CDS moves (Fig. 2, *a, b*) [5].

Let $x_1(t), u_1(t)\, t \in [t_0,t_1]$; $x_{11}(t), u_{11}(t), x_{12}(t), u_{12}(t)\;\; t \in [t_1,t_{12}]$; $x_{11}(t), u_{11}(t)\;\; t \in [t_{12},t_{11}]$; – allowable processes. For the optimality of processes, solutions must exist $\lambda_1(t) \in [t_0,t_1]$; $\lambda_{11}^{12}(t)$, $\lambda_{12}(t)$, $t \in [t_1,t_{12}]$, $\lambda_{11}(t) t \in [t_{12},t_{11}]$ for the adjoint vector equations

$$\dot{\lambda}_1 + \frac{\partial H_1}{\partial x_1} = 0, \dot{\lambda}_{l_1}^{12} + \frac{\partial H_{11}^{12}}{\partial x_{11}} + \frac{\partial H_{12}}{\partial x_{11}} = 0, \tag{5}$$

$$\dot{\lambda}_{12} + \frac{\partial H_{11}^{12}}{\partial x_{12}} + \frac{\partial H_{12}}{\partial x_{12}} = 0, \dot{\lambda}_{11} + \frac{\partial H_{11}}{\partial x_{11}} = 0, \tag{6}$$

such that the conditions are valid:

1) transversality for complementary functions and Hamiltonians

$$\left.\frac{\partial S}{\partial x_1(t_0)}\right|_{\wedge} - (-1)^{\beta}\lambda_1(\hat{t}_0) = 0; \left.\frac{\partial S}{\partial t_0}\right|_{\wedge} + (-1)^{\beta} H_1\Big|_{\wedge} = 0, \tag{7}$$

$$\left.\frac{\partial S}{\partial x_{1i}(t_{1i})}\right|_{\wedge} + (-1)^{\beta}\lambda_{1i}(\hat{t}_{1i}) = 0; \left.\frac{\partial S}{\partial t_{11}}\right|_{\wedge} - (-1)^{\beta} H_{11}\Big|_{\wedge} = 0, \tag{8}$$

2) jump for complementary functions and Hamiltonians

$$\left.\frac{\partial S}{\partial x_1(t_1)}\right|_{\wedge} + (-1)^{\beta}\left[\lambda_1(\hat{t}_1) - \lambda_{11}^{12}(\hat{t}_1) - \lambda_{12}(\hat{t}_1)\right] = 0, \tag{9}$$

$$\left.\frac{\partial S}{\partial t_1}\right|_{\wedge} - (-1)^{\beta}\left[H_1\Big|_{\wedge} - H_{11}^{12}\Big|_{\wedge} - H_{12}\Big|_{\wedge}\right] = 0, \tag{10}$$

$$\left.\frac{\partial S}{\partial x_{11}(t_{12})}\right|_{\wedge} + (-1)^{\beta}\left[\lambda_{11}^{12}(\hat{t})_{12} - \lambda_{11}(\hat{t})_{12}\right] = 0, \tag{11}$$

$$\left.\frac{\partial S}{\partial t_{12}}\right|_{\wedge} - (-1)^{\beta}\left[H_{11}^{12}\Big|_{\wedge} + H_{12}\Big|_{\wedge} - H_{11}\Big|_{\wedge}\right] = 0, \tag{12}$$

3) minimum of the Hamiltonians at the time $t \in [t_q, t_p]$ for control $u_p \in \Omega_p$

$$H_p\Big|_{\wedge} = \min H_p\Big|_{\wedge, u_p(t)}, \tag{13}$$

where p – quantity of subsystems, q – indices of sections of the branching path (p=1, q=0; p=11, q=12),

4) minimum of the linear combination of Hamiltonians at time instants $t \in [t_1,t_{12}]$ for control $u_p \in \Omega_p$ (p=11, q=12),

$$H_{11}^{12}\Big|_{\wedge} + H_{12}\Big|_{\wedge} = \min\begin{bmatrix} H_{11}^{12}\Big|_{\wedge, u_{11}(t), u_{12}(t)} + \\ + H_{12}\Big|_{\wedge, u_{12}(t)} \end{bmatrix}. \tag{14}$$

Herein icon «^» notes the optimal variables and parameters; symbol $\Big|_{\wedge,\xi}$ means that the expression should be calculated for the optimal values of variables and parameters, except for ξ; parameter β takes the value = 1 or 2, for the related scheme with separation or grouping; $H_p(\cdot) = \Phi_p(\cdot) + \dot{\lambda}_p^{\mathrm{T}} f_p(\cdot)$ (p=1, 11, 12), $H_{11}^{12}(\cdot) = \Phi_{11}^{12}(\cdot) + _{11}^{12}\lambda^{\mathrm{T}} f_{11}^{12}(\cdot)$.

On the basis of stated above conditions (5) – (14) and considering a complex branching path as a package of simple ones, we formulate the following method for modeling the optimal branching path of the CDS with an arbitrary branching scheme.

For the optimality of a branching path with an arbitrary branching scheme, existence of solutions of adjoint vector equations in the intervals of time between t_N-start of the motion, t_R-separation, t_G-groupings, t_K- end of motion of compound elements, is required.

$$\dot{\lambda}_L + \frac{\partial H_L}{\partial x_L} + \sum_q^M \frac{\partial H_q}{\partial x_L} = 0 \qquad (15)$$

where L – index of section of the branching path; M– quantity, q– indices of sections of the branching path whose partial Hamiltonians depend on the phase coordinates of L-section so that the following conditions are valid:

1) transversality at time instants $\hat{t}_N = \hat{\tau}_1$ and $\hat{t}_k = \hat{\tau}_2$

$$\left.\frac{\partial S}{\partial x_{L(\tau_i)}}\right|_\wedge - (-1)^i \lambda(\hat{\tau}_i) = 0, \ (i=1,2), \qquad (16)$$

$$\left.\frac{\partial S}{\partial \tau_i}\right|_\wedge + (-1)^i H_L\Big|_\wedge + \sum_\nu^p \left(H_\nu\big|_{\wedge,\hat{\tau}_i-0} - H_\nu\big|_{\wedge,\hat{\tau}_i+0}\right) = 0, \qquad (17)$$

where p - quantity of subsystems whose motion is affected by start or end of the motion of subsystem along the L-section; ν– indices of the sections of branching path along which these subsystems move;

2) jump at instants $\hat{t}_R = \hat{\tau}_1$ and $\hat{t}_G = \hat{\tau}_2$, related with division of the subsystem moving along the L–section, by r–subsystems or grouping r–subsystems into the subsystem moving along the L–section of the branching path

$$\left.\frac{\partial S}{\partial\, {}_j x_L(\tau_i)}\right|_\wedge + (-1)^i\, {}_j\lambda_L(\hat{\tau}_i) - (-1)^i \sum_\nu^p {}_j\lambda_q(\hat{\tau}_i) = 0;$$

$$\left.\frac{\partial S}{\partial_n x_L(\tau_i)}\right|_\wedge + (-1)^i\, {}_n\lambda_L(\hat{\tau}_i) - (-1)^i \sum_q^r \xi_{q_n} \lambda_q(\hat{\tau}_i) = 0;$$

$$(j = \overline{1, n-1}; i = 1,2), \xi_q \ge 0, \sum_q^r \xi_q = 1, \qquad (18)$$

$$\left.\frac{\partial S}{\partial \tau_i}\right|_\wedge - (-1)^i H_L\Big|_\wedge + (-1)^i \sum_q^r H_q\Big|_\wedge + \sum_\nu^p \left(H_\nu\big|_{\wedge,\hat{\tau}_i-0} - H_\nu\big|_{\wedge,\hat{\tau}_i+0}\right) = 0; \qquad (19)$$

where q – indices of sections of the branching path along which the subsystems move after separation or before grouping; p – quantity of subsystems, ν– indices of sections of the branching path, along which these subsystems move, not participating in the points of time t_R and t_G in division or grouping, but the motion of which is affected by the separation or grouping of subsystems moving along sections with indices L and q; ${}_n x_L(t)$– phase coordinate describing mass change; jump condition on the μ-section of branching path at time $\hat{t}_s$, coinciding with one of the instants associated with structural changes in the CDS caused by start or end of the motion, separation or grouping of subsystems not related to μ–section, but influencing it

$$\left.\frac{\partial S}{\partial x_\mu(\tau_s)}\right|_\wedge - \lambda_\mu(\hat{\tau}_s - 0) + \lambda_\mu(\hat{\tau}_s + 0) = 0; \qquad (20)$$

3) minimum of the linear combination of Hamiltonians at the instants between the moments t_N, t_R, t_G, t_K

$$\left.\sum_q^\Lambda H_q\right|_\wedge = \min_{u_q \in \Omega_q} \left.\sum_q^\Lambda H_q\right|_{\wedge, u_q} \qquad (21)$$

where Λ– number of subsystems with interacting controls within specified time intervals; Q –indices of the sections of branching path along which these subsystems move.

The stated method is the methodological basis for constructing computing algorithms that allow modeling the optimal paths of the CDS motion. The method for modeling optimal branching paths is a part of the software of CDS computer-aided design system.

Consider an example illustrating use of the simulation method for the optimal branching path.

According to the specified scheme of branching path (Fig. 1), its time diagram is drawn up (Fig. 3), in which the time instants of structural transformations in the CDS motion pattern with indication its membership to the corresponding types of time moments are arranged chronologically: $\hat{t}_N$, $\hat{t}_R$, $\hat{t}_G$, $\hat{t}_K$.

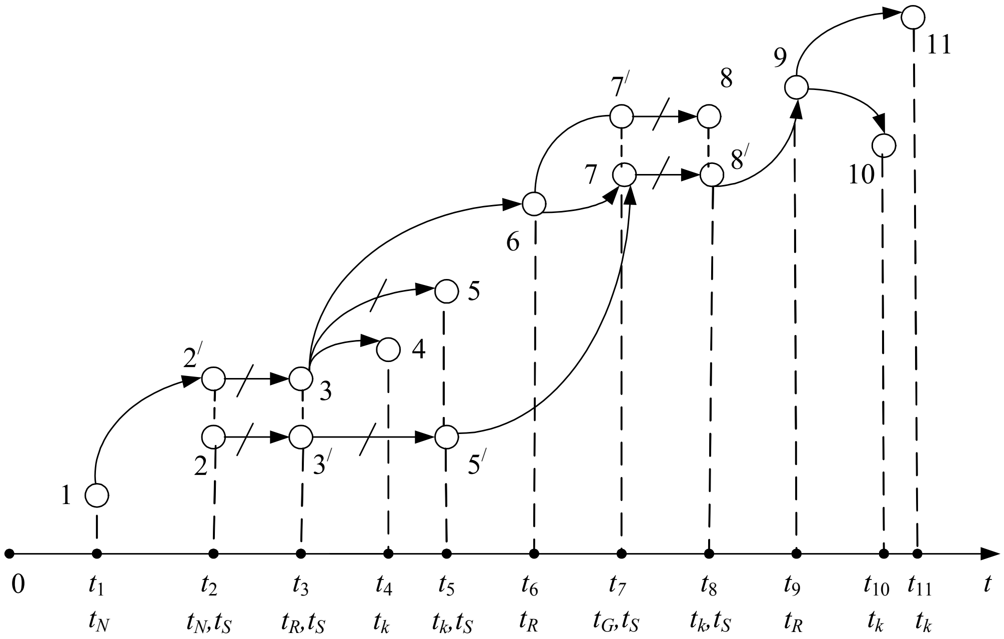

Fig. 3. Time diagram of the branching path

The path sections, moving along which the CDS elements interact each with other, are marked with a line.

The optimality criterion is written in the form consisting of the terminal part $S(\cdot)$, dependent on the coordinates of elements at time instants $t_i (i = \overline{1,11})$ and these moments of time, as well as the sum of particular integral criteria

$$I_i = \int_{t_a}^{t_b} \Phi_i(\cdot)dt \ (i = \overline{1,11}), (a \neq b), (a = \overline{1,11}), (b = \overline{1,11}),$$

recorded for the each section of branching path (Fig. 3), enclosed between neighboring points located on it.

The motion of elements along the path is defined by equations of $\dot{x} = f(\cdot)$ type, where $f(\cdot)$ – function that depends on the controls and coordinates of the subsystem, as well as on the controls and coordinates of the interacting subsystem, if the branch section is marked with a line. Applying the procedure formulated below, we obtain condition – for the optimality of path (Fig. 3) it is necessary to have solutions of adjoint vector equations of type (15) such there conditions of type (16-21) are valid.

To solve finally the task of modeling the optimal branching path, it is necessary to add the listed differential equations and algebraic conditions with the differential equations of motion of the subsystems along the path branches.

Note that the sequence of time instants $t_1 < t_2 < .... < t_{10} < t_{11}$ in the task with free time is given from physical considerations and is approximate. If it is disturbed, as a result of solution of the task, and the change in the sequence of branches of the path is permissible by the physical meaning of the task, then repeating all calculations for new refined sequence of time instants is required.

The information given in Tables 1 – 3 is initial data that allows using standard subprograms for solving ordinary differential and algebraic equations, and thereby complete practically solution the CDS optimal path modeling task.

Table 1

Conditions for formulation of equations for conjugate variables

Type of equation	Legend of branch, L							
	$1;2'$	$2';3$	$2;3'$	$3;4$	$3;6$	$3;5$	$3';5'$	$5';7$
(15)	M=0 –	M=1 q=(2; 3′)	M=1 q=(2′; 3)	M=0 –	M=0 –	M=1 q=(2′; 5′)	M=1 q=(3; 5)	M=0 –

Table 1 cont'd

Type of equation	Legend of branch, L						
	6; 7	6; 7′	7′; 8	7; 8′	8′; 9	9;10	9; 11
(15)	$M=0$ –	$M=0$ –	$M=1$ $q=(7;8')$	$M=1$ $q=(7';8)$	$M=0$ –	$M=0$ –	$M=0$ –

Table 2

The solutions of differential equations for conjugate variables must meet the following conditions

Condition type	t_1	t_2	t_3	t_4	t_5	t_6
(16)	$L=(1;2')$; $i=1$	$L=(2;3')$; $i=1$	–	$L=(3;4)$; $i=2$	$L=(3;5)$; $i=2$	–
(17)	$L=(1;2')$; $i=1$; $p=0$	$L=(2;3')$; $i=1$; $p=1$; $\text{н}=(1;2';3)$	–	$L=(3;4)$; $i=2$; $p=0$	$L=(3;5)$; $i=2$; $p=1$; $\text{н}=(3';5';7)$	–
(18)	–	–	$L=(2';3)$; $i=1$; $r=3$; $q=(3;1),(3;5),(3;4)$	–	–	$L=(3;6)$; $i=2$; $r=2$; $q=(6;7'),(6;7)$
(19)	–	–	$L=(2';3)$; $i=1$; $r=3$; $p=1$; $q=(3;6),(3;5),(3;4)$; $\text{н}=(2;3';5')$	–	–	$L=(3;6)$; $i=2$; $r=2$; $q=(6;7'),(6;7)$
(20)	–	$\text{м}=(1;2;3)$	$\text{м}=(2;3;5)$	–	$\text{м}=(3';5';7')$	–

Table 2 cont'd

Condition type	t_7	t_8	t_9	t_{10}	t_{11}
(16)	–	$L=(7';8)$; $i=2$	–	$L=(9;10)$; $i=2$	$L=(9;11)$; $i=2$
(17)	–	$L=(7';8)$; $p=1$; $\text{н}=(7;8';9)$	–	$L=(9;10)$; $i=2$	$L=(9;11)$; $i=2$
(18)	$L=(7;8')$; $i=2$; $r=2$; $q=(6;7),(5';7)$	–	$L=(8';9)$; $i=2$; $r=2$; $q=(9;10),(9;11)$	–	-
(19)	$L=(7;8')$; $i=2$; $r=2$; $p=1$; $q=(6;7),(5';7)$; $\text{н}=(6;7';8)$	–	$L=(8';9)$; $i=2$; $r=2$; $p=0$; $q=(9;10),(9;11)$	–	-
(20)	$\text{м}=(6;7';8)$	$\text{м}=(7;8';9)$	–	–	-

Table 3

Conditions for Hamiltonian minimizing

Equation	Time space							
	t_1–t_2	t_2–t_3	t_3–t_4	t_3–t_5	t_3–t_6	t_5–t_7	t_6–t_7	t_6–t_7
(21)	$\text{Л}=1$ $q=(1;2')$	$\text{Л}=1$ $q=(2';2),(2;3')$	$\text{Л}=1$ $q=(3;4)$	$\text{Л}=2$ $q=(3;5),(3';5')$	$\text{Л}=1$ $q=(3;6)$	$\text{Л}=1$ $q=(5';7)$	$\text{Л}=1$ $q=(6;7)$	$\text{Л}=1$ $q=(6;7')$

Table 3cont'd

Equation	Time space			
	t_7–t_8	t_8–t_9	t_9–t_{10}	t_9–t_{11}
(21)	$\text{Л}=2$ $q=(7';8),(7;8')$	$\text{Л}=1$ $q=(8';9)$	$\text{Л}=1$ $q=(9;10)$	$\text{Л}=1$ $q=(9;11)$

6. Conclusion

The article suggests the method for constructing a branching path of the information robot motion that is a compound dynamic system. The method allows to formulate the procedure for modeling the optimal branching path of the compound dynamic system with an arbitrary branching scheme in terms of the theory of optimal control.

The procedure is a part of the software of information robot computer-aided design system and can be used to construct computing algorithms taking into account the specificity of information-telecommunication interaction of elements of specific compound dynamic systems.

References

[1]. Bryson E., Yu-Chi Ho. (1975) Applied Optimal Control. New York, USA, Revised edition, 482 p. (United States).

[2]. Ashchepkov L.T. (1987). Optimal'noye upravleniye razryvnymi sistemami [Optimal control of discontinuous systems]. Novosibirsk, Nauka Publ., 226 p. (in Russian).

[3]. Samoylenko A. M, Perestyuk N.A. (1987). Differentsial'nyye uravneniya s impul'snym vozdeystviyem [Differential equations with impulse action]. Kiev, Higher school, 228 p. (in Ukranian).

[4]. Lysenko A. I. (1988). Usloviye skachka v zadache optimal'nogo upravleniya ob"yektom [The jump condition in the problem of optimal control of a compound object]. Adaptive systems of automatic control, vol. 6, pp. 136-141. (in Ukranian).

[5]. Lysenko A. I., Tachinina O. M. (2014). Matematicheskaya postanovka zadachi optimizatsii dvizheniya gruppy letayushchikh robotov na baze bespilotnykh letatel'nykh apparatov [The mathematical formulation of the optimization problem of motion group flying robots based unmanned aerial vehicles]. Scientific Bulletin of the Academy of Municipal Management, vol. 1, no. 7, pp 83-100. (in Ukranian).

[6]. Lysenko A. I., Tachinina O. M. Alekseeva I.V, and Chumachenko S. M. (2015). The Scenario-Based Approach for Control of Multi-Object Dynamic System Motion. IEEE 3rd International Conference «Actual problems of unmanned aerial vehicles developments», October 13-15, pp. 305-308. (in Ukranian).

[7]. Lysenko A. I., Tachinina O. M. (2016). Optimal principle for dynamical system with alterative orbiting. Electronics and control systems, vol. 4, no. 50, pp. 108-113. (in Ukranian).

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Метод конструювання траєкторії руху інформаційного робота на базі безпілотного літального апарата

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Мета: Метою даної статті є викладення методу конструювання розгалуженої траєкторії руху інформаційного робота, що являє собою складену динамічну систему, який дозволяє сформулювати в термінах теорії оптимального управління умови моделювання оптимальної розгалуженої траєкторії складеної динамічної системи з довільною схемою розгалуження. **Методи:** У статті розглянуто метод теорії оптимального управління розривними динамічними системами, який застосовувався для доказу умов оптимальності фазових координат, в точках структурних перетворень розгалуженої траєкторії руху інформаційного робота. **Результати:** Сформульовано необхідні умови оптимальності розгалуженої траєкторії, по якій переміщається інформаційний робот, які дозволяють перейти до застосування стандартних підпрограм рішення звичайних диференціальних рівнянь та алгебраїчних рівнянь і тим самим вирішити задачу моделювання оптимальної траєкторії складеної динамічної системи з довільною схемою розгалуження. **Обговорення**: Запропонований метод є методологічною основою для побудови обчислювальних алгоритмів, що дозволяють моделювати оптимальні траєкторії руху складених динамічних систем. Запропонована процедура моделювання оптимальних розгалужених траєкторій є частиною математичного забезпечення системи автоматизованого проектування інформаційного робота і може бути використана для побудови обчислювальних алгоритмів, які враховують специфіку інформаційно-телекомунікаційної взаємодії елементів конкретних типів складених динамічних систем.

Ключові слова: безпілотні літальні апарати; інформаційний робот; складена динамічна система; оптимальне управління; розгалужена траєкторія.

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Метод конструирования траектории движения информационного робота на базе беспилотного летательного аппарата

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Цель: Целью данной статьи является изложение метода конструирования ветвящейся траектории движения информационного робота, представляющего собой составную динамическую систему, позволяющего сформулировать в терминах теории оптимального управления условия моделирования оптимальной ветвящейся траектории составной динамической системы с произвольной схемой ветвления. **Методы:** В статье рассмотрен метод теории оптимального управления разрывными динамическими системами, который применялся для доказательства условий оптимальности фазовых координат, в точках структурных преобразований ветвящейся траектории движения информационного робота. **Результаты:** Сформулированы необходимые условия оптимальности ветвящейся траектории, по которой перемещается информационный робот, которые позволяют перейти к применению стандартных подпрограмм решения обыкновенных дифференциальных уравнений и алгебраических уравнений и тем самым решить задачу моделирования оптимальной траектории составной динамической системы с произвольной схемой ветвления. **Обсуждение:** Предложенный метод является методологической основой для построения вычислительных алгоритмов, позволяющих моделировать оптимальные траектории движения составных динамических систем. Предложенная процедура моделирования оптимальных ветвящихся траекторий является частью математического обеспечения системы автоматизированного проектирования информационного робота и может быть использована для построения вычислительных алгоритмов, учитывающих специфику информационно-телекомуникационного взаимодействия элементов конкретных типов составных динамических систем.

Ключевые слова: беспилотные летательные аппараты; информационный робот; составная динамическая система; оптимальное управление; ветвящаяся траектория.

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