Synergistic approach to amphibian aircraft nonlinear adaptive regulator design: Harmonic disturbance observers

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Abstract: Aircraft amphibian (SA), as a control object, has an extremely complex structure consisting of a set of subsystems including exchange processes of force, energy, matter and information. This control object operates in the complex environments as atmosphere as well as adjoining surface of water and air.
The problem is to design a regulator that to control the flight modes with impact on the surrounding environment. Requirement to designed regulator is quick responsibility to adapt to the impact of chaotic disturbances of environments. In this report we consider a method synthesis nonlinear control system of aircraft amphibian motion with state observers of harmonic disturbances based on synergetic approach in modern control theory
Keywords: Synergistic, system's synthesis, regulator design, chaotic disturbances, aircraft amphibian, nonlinear dynamic modeling.

1. Introduction

The solution of the various control tasks based on using of a control object state vector. In real conditions of full state vector measurement for one reason or another is not feasible. For this purpose, the control system introduces a subsystem of state estimation - a state observer.
For linear systems, it is distinguished full-order state observers (Kalman Observer), which have a dimension of the state vector as same as that of the control object, reduced order observers (Luenbergera Observer) and observers of increased order (adaptive observers) [1, 2]
Proposed in this article, the nonlinear observer can be referring to the reduced order observers. Even more challenging is a problem of estimating the unmeasured external disturbances. The basic idea of perturbation estimation is as follows: To construct a model of external influences, which is in the form of a homogeneous differential equation system with known coefficients and unknown initial conditions. The model is combined with the perturbation model and with this received enhanced system observer is constructed. Obtained with it estimates include the estimates of object state variables, and evaluation of external influences.

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The asymptotic observer design methods are applicable for a wide class of nonlinear systems proposed in [3, 4, 5]. In this work, a new version of an amphibian control methods and problems, which are solved by the dynamic synergistic regulators to such observers, is described. These observers have carried out a unmeasured harmonic external disturbance evaluation effecting on the amphibian. The nonlinear external perturbation observers (NEPO) consist of a monitoring contour and a control circuit that operates in parallel.

2. The Problem Statement

Suppose that the control object's behavior and an external disturbances effecting on it could be described by the differential equations system:

$$\dot{x} = g(x, z, u);$$
$$\dot{z} = h(x, z, u).$$

Where n vector x и m vector z – components of state vector; u – a control vector; $g(.)$ и $h(.)$ – continuous nonlinear functions. Vector x is assumed observable, and vector z – unobservable.

Then the observer synthesis problem can be formulated as follows. Need to synthesize NEPO with form:

$$\dot{w}(t) = R(x, w);$$
$$\hat{z}(t) = K(x, w),$$

where w – observer state vector; $\hat{z}$ – unmeasured external disturbances evaluation vector.

In this case, NEPO must provide:

- a closed system asymptotic stability;
- stabilization of the pitch angle, altitude and flight speed;
- assessment of unobserved external perturbations;
- compensation of external disturbances.

The NEPO synthesis procedure is divided into three stages:

a) Synthesis of control laws u_i to ensure implementation of the required technological problem (in this case assume that all control object state variables are observable);
b) Synthesis of an observer for the unobservable state variables and unmeasured disturbances.
c) Replacement of unobservable variables in the synthesized controls by their evaluations.

3. The synergistic procedure of the control laws for the longitudinal motion with harmonic disturbances

a). Synergistic synthesis procedure of control laws u_i

Common model of SA's space movement is present by 12th order differential equations system through Euler angles. In SA's movement on water or in taking off, it's rational to consider longitudinal motion model:

$$\begin{cases} \dot{x}_1(t) = b_1 x_3 x_2 - g\sin x_5 + a_1\left(P_x - F_{ax} - F_{hx}\right) + M_1(t); \\ \dot{x}_2(t) = b_2 x_2 x_3 - g\cos x_5 + a_2\left(P_y + F_{ay} + F_{hy}\right) + M_2(t); \\ \dot{x}_3(t) = a_3\left(M_z^a + M_z^h\right) + M_3(t); \\ \dot{x}_4(t) = x_1\sin x_5 + x_2\cos x_5; \\ \dot{x}_5(t) = x_3; \\ \dot{x}_6 = x_1\cos x_5 - x_2\sin x_5; \end{cases} \qquad (1)$$

Where: x_1, x_2 – the projections of velocity vector V_x, V_y on corresponded the intertwined coordinate system axes; x_3 – longitudinal angular velocity μ_z; x_4, x_6 – projections coordinate SA's center of gravity y_c, x_c on corresponded axes Oy and Ox; x_4 – pitching angle g; m – SA's weight; $m_x = (1 + a_1)m,\ m_y = (1 + a_2)m$ – SA's «attached» weights; F_{ax}, F_{ay} – projections total vector of aerodynamic forces on corresponded intertwined coordinate system axes Ox and Oy; F_{hx}, F_{hy} – projections total vector of hydrodynamic and hydrostatic forces on corresponded intertwined coordinate system axes Ox and Oy; Oy; M_z^a, M_z^h – longitudinal aerodynamic moment and longitudinal moment formed by hydrodynamic and hydrostatic forces; $M_i(t)$ – disturbances;

$$a_1 = m_x^{-1};\ a_2 = m_y^{-1};\ a_3 = I_z^{-1};\ b_1\frac{m_y}{m_x};\ b_2 = -\frac{m_x}{m_y}.$$

In control the SA's longitudinal motion elevator, flaps and engine thrust control lever are the active control organs. Technical solutions that provide basing and operation of the aircraft on the water surface, effectively determine its shape - the seaplane aerodynamic scheme. Consequently, controls in the model (2) will be the engine thrust, depending on the deviation of the engine thrust control lever; the total aerodynamic forces and the total longitudinal moment, depending on changes in the flaps and elevator deflection.

For control the SA's longitudinal motion there are some strategies: controlling individual channels or all channels simultaneously. Of course that the vector strategy requires a more complex algorithmic structure of the regulator, but it allows more flexible three-channel control of SA.

The problem of controlling the longitudinal motion is finding the control vector. $u = \left\lfloor F_x\left(¢_{р.у.}, ¢_{р.в.}, ¢_з\right);\ F_y\left(¢_{р.у.}, ¢_{р.в.}, ¢_з\right);\ M_z\left(¢_{р.у.}, ¢_{р.в.}, ¢_з\right)\right\rfloor$ as a coordinate function of the system states, which provides SA's longitudinal short-period movement (2) at a given speed V_0, height H_0 and pitching angle γ_0, i.e. the following invariants:

$$x_1 = V_0;\; x_4 = H_0;\; x_5 = \gamma_0 \qquad (2)$$

Rewriting the mathematic model of the control object following:

$$\begin{cases} \dot{x}_1(t) = b_1 x_3 x_2 - g \sin x_5 + a_1 u_1; \\ \dot{x}_2(t) = -b_2 x_1 x_3 - g \cos x_5 + a_2 u_2; \\ \dot{x}_3(t) = a_3 u_3; \\ \dot{x}_4(t) = x_1 \sin x_5 + x_2 \cos x_5; \\ \dot{x}_5(t) = x_3; \\ \dot{x}_6(t) = x_1 \cos x_5 - x_2 \sin x_5; \end{cases} \qquad (3)$$

where $u_1 = P_x - F_{xa} - F_{xг}$, $u_2 = P_y + F_{ya} + F_{yг}$, $u_3 = M_{za} + M_{zг}$ – are control acts.

For model (3), the goal is implementation of desired invariants (2), we formulate the first set of macro-variables ψ_1, ψ_2, ψ_3,

$$\begin{aligned} \psi_1 &= x_1 - V_0; \\ \psi_2 &= x_2 - \varphi_1(x_4, x_5, z_1, z_2, z_3); \\ \psi_3 &= x_3 - \varphi_2(x_4, x_5, z_1, z_2, z_3), \end{aligned} \qquad (4)$$

which must satisfy the solution of following functional equations:

$$T_i \dot{\psi}_i(t) + \psi_i = 0, \quad T_i > 0, \quad i = 1\ldots 3,; \qquad (5)$$

At the intersection of invariant manifolds, $\psi_i = 0, i = 1,\ldots,3$, there is a dynamic "phase space compression", and the dynamics of closed-loop system will be described by decomposed model:

$$\begin{cases} \dot{x}_4(t) = V_0 \sin x_5 + \varphi_1 \cos x_5; \\ \dot{x}_5(t) = \varphi_2; \\ \dot{x}_6(t) = V_0 \cos x_5 - \varphi_1 \sin x_5; \end{cases} \qquad (6)$$

Now to introduce a second set of macro variables

$$\psi_4 = x_4 - H_0;\; \psi_5 = x_5 - \gamma_0. \qquad (7)$$

The set of macro variables introduced by (7) must satisfy solutions of functional equation systems:

$$(\;)$$

$$\ddot{\ }_1 = -\frac{T_4 V_0 \sin x_5 + x_4 - H_0}{T_4 \cos x_5};\ \ddot{\ }_2 = \frac{-x_5 + \mathrm{g}_0}{T_5}. \qquad (9)$$

Further external control vectors u_i is found by solving simultaneously functional equation systems (4) and equation model (1):

$$u_1 = \frac{1}{a_1}\left(g \sin x_5 + \frac{-x_1 + V_0}{T_1} - z_1\right);$$

$$u_2 = Ax_1 + Bx_2 + Cx_3 + Dx_4 - \frac{1}{a_2} z_2 + E; \qquad (10)$$

$$u_3 = -\frac{1}{T_3 T_5 a_3}\left((T_3 + T_5)x_3 + x_5 - \mathrm{g}_0\right) - \frac{z_3}{a_3}.$$

Where indicated: $A = -\frac{\sin x_5}{T_4 a_2 \cos x_5}$; $B = -\frac{T_2 + T_4}{a_2 T_2 T_4}$;

$$C = -\frac{x_4 \sin x_5}{a_2 T_4 \cos^2 x_5} + \frac{H_0 \sin x_5 - T_4 V_0}{a_2 T_4 \cos^2 x_5};$$

$$D = \frac{-1}{a_2 T_2 T_4 \cos x_5};\ E = \frac{H_0 - T_4 V_0 \sin x_5}{a_2 T_2 T_4 \cos x_5} + \frac{g \cos x_5}{a_2}.$$

Whereas synthesized control laws, u_1, u_2, u_3, of object (1), provide implementation required technological problems, it is necessary to move to description of the observer synthesis procedure.

b) The observer synthesis procedure

According to the method of Analytical Design of Aggregated Regulators, in synergistic synthesis procedure of observers it should be used following an extended system model (11) [3, 4]:

$$\begin{cases} \dot{x}_1(t) = -g \sin x_5 + a_1 u_1 + z_1; \\ \dot{x}_2(t) = -g \cos x_5 + a_2 u_2 + z_2; \\ \dot{x}_3(t) = a_3 u_3 + z_3; \\ \dot{x}_4(t) = x_1 \sin x_5 + x_2 \cos x_5; \\ \dot{x}_5(t) = x_3; \\ \dot{x}_6(t) = x_1 \cos x_5 - x_2 \sin x_5; \\ \dot{z}_1(t) = s_1;\ \dot{s}_1(t) = -\pm_1^2 z_1; \\ \dot{z}_2(t) = s_2;\ \dot{s}_2(t) = -\pm_2^2 z_2; \\ \dot{z}_3(t) = s_3;\ \dot{s}_3(t) = -\pm_3^2 z_3; \end{cases} \qquad (11)$$

Where $\pm_i$ – harmonic disturbance angular frequencies, z_1, z_2, z_3 – the projections of indignant linear, longitudinal and angular accelerations respectively.
The last six equations in system (11) is dynamic model of harmonic disturbances, and $z_i, s_i,\ i = \overline{1..3}$ are state variables.

The state variable observer design is based on the synergistic approach principles in the control theory, videlicet on the ADAR method, which is described in works [3, 4]. In particular case, when $\dim \cdot\ (t) = 1$, the expression

$$\dot{\cdot}\,(t) = L(y)\,\cdot \qquad (12)$$

Could be present in following form:

$$\dot{\cdot}_i(t) + L_i \cdot_i = 0, \quad L_i > 0. \qquad (13)$$

To conduct the synthesis of the observers for the object (1), let $y = [x_i],\ i = 1,...,5$, $v = \lfloor z_j, s_j \rfloor,\ \ j = 1,2,3$. To determine the assessments of the state variables z_1, s_1, choosing forms of $\cdot_1, \cdot_2$:

$$\begin{aligned} \cdot_1 &= \ _{11}(z_1 - \hat{z}_1) + \ _{12}(s_1 - \hat{s}_1), \\ \cdot_2 &= \ _{21}(z_1 - \hat{z}_1) + \ _{22}(s_1 - \hat{s}_1). \end{aligned} \qquad (14)$$

Where $_{ij}\ \ 0$ – constants, $_{11}\ _{22} - \ _{12}\ _{21}\ \ 0$. In this the valuations $\hat{z}_1, \hat{s}_1$ of the state variables z_1, s_1 could be formed by

$$\begin{aligned} \hat{z}_1 &= f_1\ (x_1) + w_1, \\ \hat{s}_1 &= f_2\ (x_1) + w_2. \end{aligned} \qquad (15)$$

where $f_1(x_1),\ f_2(x_1)$ – unknown functions. Then to put (14) into the equation in formed (13):

$$\begin{aligned} &\dot{\cdot}_1(t) + L_1 \cdot_1 = 0,\ \ L_1 > 0; \\ &\dot{\cdot}_2(t) + L_2 \cdot_2 = 0,\ \ L_2 > 0, \end{aligned} \qquad (16)$$

while subject to the equations (15), receiving

$$\begin{aligned} &_{11}\left(\frac{dz_1}{dt} - \frac{\partial f_1(x_1)}{x_1}\frac{dx_1}{dt} - \frac{d(w_1)}{dt}\right) + \ _{12}\left(\frac{ds_1}{dt} - \frac{\partial f_2(x_1)}{x_1}\frac{dx_1}{dt} - \frac{d(w_2)}{dt}\right) + \\ &+ L_1[\ _{11}(z_1 - f_2(x_1) - w_1) + \ _{12}(s_1 - f_2(x_1) - w_2)] = 0, \\ &_{21}\left(\frac{dz_1}{dt} - \frac{\partial f_1(x_1)}{x_1}\frac{dx_1}{dt} - \frac{d(w_1)}{dt}\right) + \ _{22}\left(\frac{ds_1}{dt} - \frac{\partial f_2(x_1)}{x_1}\frac{dx_1}{dt} - \frac{d(w_2)}{dt}\right) + \\ &+ L_2[\ _{21}(z_1 - f_1(x_1) - w_1) + \ _{22}(s_1 - f_2(x_1) - w_2)] = 0. \end{aligned} \qquad (17)$$

With the equations (17) subject to the object equations (11), receiving:

$$
\begin{aligned}
&{}_{11}\left(s_1 - \frac{\partial f_1(x_1)}{x_1}\left(-g\sin x_5 + a_1u_1 + z_1\right) - \frac{dw_1}{dt} \right) + \\
&{}_{12}\left(-\pm_1^{\,2} z_1 - \frac{\partial f_2(x_1)}{x_1}\left(-g\sin x_5 + a_1u_1 + z_1\right) - \frac{dw_2}{dt} \right) \\
&+ L_1\left[\ {}_{11}\left(z_1 - f_1(x_1) - w_1\right) + \ {}_{12}\left(s_1 - f_2(x_1) - w_2\right)\right] = 0; \\
&{}_{21}\left(s_1 - \frac{\partial f_1(x_1)}{x_1}\left(-g\sin x_5 + a_1u_1 + z_1\right) - \frac{dw_1}{dt} \right) + \\
&{}_{22}\left(-\pm_1^{\,2} z_1 - \frac{\partial f_2(x_1)}{x_1}\left(-g\sin x_5 + a_1u_1 + z_1\right) - \frac{dw_2}{dt}\ {}_1 \right) \\
&+ L_2\left[\ {}_{21}\left(z_1 - f_1(x_1) - w_1\right) + \ {}_{22}\left(s_1 - f_2(x_1) - w_2\right)\right] = 0.
\end{aligned} \tag{18}
$$

In the equations of the observer (18) must not be present at unobserved coordinators z_1, s_1. In order to exclude them out of system, choosing

$$
\begin{aligned}
f_1(x_1) &= \frac{{}^2{}_{12}\ {}^2{}_{21} - \ {}^2{}_{22}\ {}^2{}_{11}}{{}_{12}\ {}_{22}\left(\ {}_{11}\ {}_{22} - \ {}_{12}\ {}_{21}\right)} x_1, \\
f_2(x_1) &= \left(\frac{{}_{21}\ {}_{22}\ {}^2{}_{11} - \ {}_{11}\ {}_{12}\ {}^2{}_{21}}{{}_{12}\ {}_{22}\left(\ {}_{11}\ {}_{22} - \ {}_{12}\ {}_{21}\right)} - \pm_1^{\,2} \right) x_1,
\end{aligned} \tag{19}
$$

$$
L_1 = -\frac{{}_{11}}{{}_{12}} > 0, \quad L_2 = -\frac{{}_{21}}{{}_{22}} > 0
$$

Subject to (19), to solve the system of equations (18), finding

$$
\begin{aligned}
\dot{w}_1 &= -\left[\left(\frac{{}_{11}}{{}_{12}} \right)^2 + \pm_1^{\,2} + \frac{{}_{21}\ {}_{11}}{{}_{22}\ {}_{12}} + \left(\frac{{}_{21}}{{}_{22}} \right)^2 \right] x_1 + \\
&\quad + \left(\frac{{}_{11}}{{}_{12}} + \frac{{}_{21}}{{}_{22}} \right)\left(w_1 + a_1u_1 - g\sin x_5\right) + w_2; \\
\dot{w}_2 &= \left(\frac{{}_{21}\ {}^2{}_{11}}{{}_{22}\ {}^2{}_{12}} + \frac{{}_{11}\ {}^2{}_{21}}{{}_{12}\ {}^2{}_{22}} \right) x_1 + \left(\frac{{}_{11}\ {}_{21}}{{}_{22}\ {}_{12}} \right)\left(g\sin x_5 - a_1u_1 - w_1\right) + \\
&\quad + \pm_1^{\,2}\left(a_1u_1 - g\sin x_5\right).
\end{aligned} \tag{20}
$$

And the valuations $\hat{z}_1, \hat{s}_1$ of the state variables z_1, s_1 are

$$\hat{z}_1 = \frac{{}^2_{12}\ {}^2_{21} - {}^2_{22}\ {}^2_{11}}{{}_{12}\ {}_{22}\left({}_{11}\ {}_{22} - {}_{12}\ {}_{21}\right)} x_1 + w_1,$$
$$\hat{s}_1 = \left(\frac{{}_{21}\ {}_{22}\ {}^2_{11} - {}_{11}\ {}_{12}\ {}^2_{21}}{{}_{12}\ {}_{22}\left({}_{11}\ {}_{22} - {}_{12}\ {}_{21}\right)} - \pm^2_1 \right) x_1 + w_2. \quad (21)$$

Similarly, to define the estimations $\hat{z}_2$, $\hat{s}_2$, $\hat{z}_2$, $\hat{s}_2$ of the state variables z_2, s_2, z_2, s_2, choosing following the macro variables

$$\begin{aligned} \cdot_3 &= {}_{33}(z_2 - \hat{z}_2) + {}_{34}(s_2 - \hat{s}_2); \\ \cdot_4 &= {}_{43}(z_2 - \hat{z}_2) + {}_{44}(s_2 - \hat{s}_2); \\ \cdot_5 &= {}_{55}(z_3 - \hat{z}_3) + {}_{56}(s_3 - \hat{s}_3); \\ \cdot_6 &= {}_{65}(z_3 - \hat{z}_3) + {}_{66}(s_3 - \hat{s}_3), \end{aligned} \quad \text{where} \quad \begin{aligned} &{}_{33}\ {}_{44} - {}_{34}\ {}_{43} \quad 0; \\ &{}_{55}\ {}_{66} - {}_{56}\ {}_{65} \quad 0;. \\ &{}_{ij} \quad 0. \end{aligned} \quad (22)$$

The assessments of state variables z_2, s_2, z_2, s_2 can be defined

$$\hat{z}_2 = f_3(x_2) + w_3, \quad \hat{s}_2 = f_4(x_2) + w_4,$$
$$\hat{z}_3 = f_5(x_3) + w_5, \quad \hat{s}_3 = f_6(x_3) + w_6, \quad (23)$$

The macro variables (22) must be satisfy functional equations

$$\dot{\cdot}_i(t) + L_i \cdot_i = 0, \ L_i > 0, \ i = 3,...,6. \quad (24)$$

With received equations formed by putting (22) in to (16) object to model (11), we need to choose functions $f_3(x_2)$, $f_4(x_2)$, $f_5(x_3)$, $f_6(x_3)$, L_i, $i = 3,...,6$ so that the expressions of the observers must not consist in itself the unobserved state variables. Choosing

$$f_3(x_2) = \frac{{}^2_{34}\ {}^2_{43} - {}^2_{44}\ {}^2_{33}}{{}_{34}\ {}_{44}\left({}_{33}\ {}_{44} - {}_{34}\ {}_{43}\right)} x_2;$$
$$f_4(x_2) = \left(\frac{{}_{43}\ {}_{44}\ {}^2_{33} - {}_{33}\ {}_{34}\ {}^2_{43}}{{}_{34}\ {}_{44}\left({}_{33}\ {}_{44} - {}_{34}\ {}_{43}\right)} - \pm^2_2 \right) x_2; \quad (25)$$
$$L_3 = -\frac{{}_{33}}{{}_{34}} > 0, \ L_4 = -\frac{{}_{43}}{{}_{44}} > 0$$
$$f_5(x_3) = \frac{{}^2_{56}\ {}^2_{65} - {}^2_{66}\ {}^2_{55}}{{}_{56}\ {}_{66}\left({}_{55}\ {}_{66} - {}_{56}\ {}_{65}\right)} x_3;$$
$$f_6(x_3) = \left(\frac{{}_{65}\ {}_{66}\ {}^2_{55} - {}_{55}\ {}_{56}\ {}^2_{65}}{{}_{56}\ {}_{66}\left({}_{55}\ {}_{66} - {}_{56}\ {}_{65}\right)} - \pm^2_3 \right) x_3.$$
$${}_5 \quad \frac{{}_{55}}{{}_{56}} \quad 0, \quad {}_6 \quad \frac{{}_{65}}{{}_{66}} > 0$$

Consequently the equations of the observer is formed

$$\dot{w}_3(t) = -\left[\left(\frac{{}_{33}}{{}_{34}}\right)^2 + \pm_2^2 + \frac{{}_{43}\ {}_{33}}{{}_{44}\ {}_{34}} + \left(\frac{{}_{43}}{{}_{44}}\right)^2\right] x_2 +$$

$$+\left(\frac{{}_{33}}{{}_{34}} + \frac{{}_{43}}{{}_{44}}\right)\left(w_3 + a_2 u_2 - g\cos x_5\right) + w_4;$$

$$\dot{w}_4(t) = \left(\frac{{}_{43}\ {}_{33}^{\,2}}{{}_{44}\ {}_{34}^{\,2}} + \frac{{}_{33}\ {}_{43}^{\,2}}{{}_{34}\ {}_{44}^{\,2}}\right) x_2 + \left(\frac{{}_{33}\ {}_{43}}{{}_{44}\ {}_{34}}\right)\left(g\cos x_5 - a_2 u_2 - w_3\right) +$$

$$+\pm_2^2\left(a_2 u_2 - g\cos x_5\right).$$

$${}_5(\,)\quad \left(\frac{{}_{55}}{{}_{56}}\right)^2 \quad {}_3^2 \quad \frac{{}_{65}\ {}_{55}}{{}_{66}\ {}_{56}} \quad \left(\frac{{}_{65}}{{}_{66}}\right)^2 \quad {}_3 \quad \frac{{}_{55}}{{}_{56}} \quad \frac{{}_{65}}{{}_{66}}\left({}_5 \quad {}_3 u_3\right) \quad w_6;$$

[redacted]

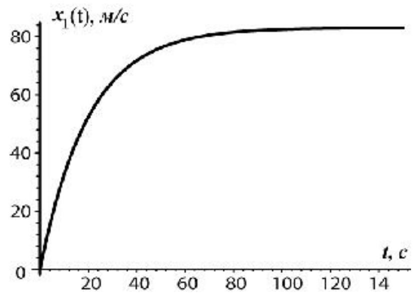


Fig. 1 Transient process relatively horizontal speed V_x

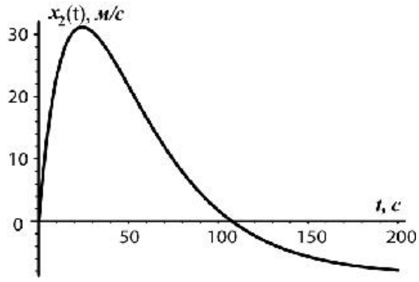


Fig. 2 Transient process relatively vertical speed V_y

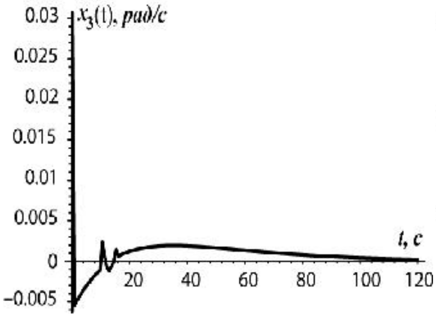


Fig. 3 Transient process relatively angular speed μ_z

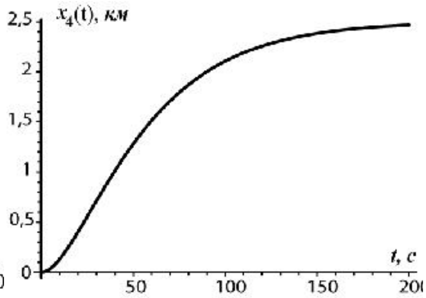


Fig. 4 Transient process relatively flight height H

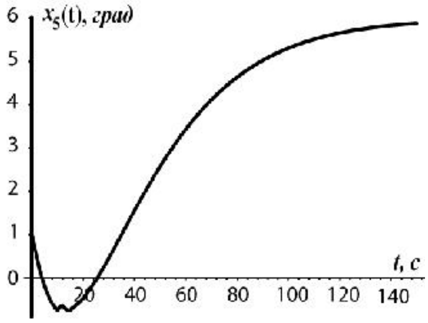


Fig. 5 Transient process relatively pitch angular speed g

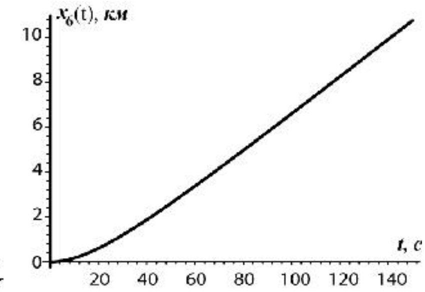


Fig. 6 Transient process relatively flight distance X

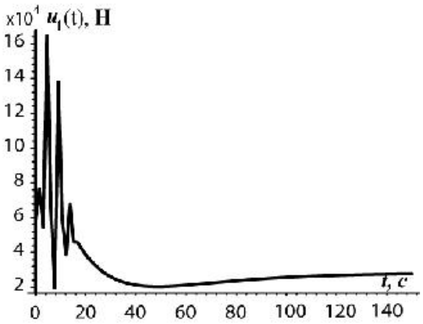


Fig. 7 Transient process relatively control u_1

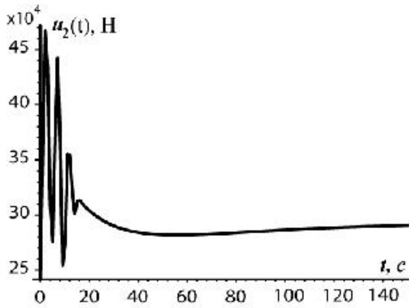


Fig. 8 Transient process relatively control u_2

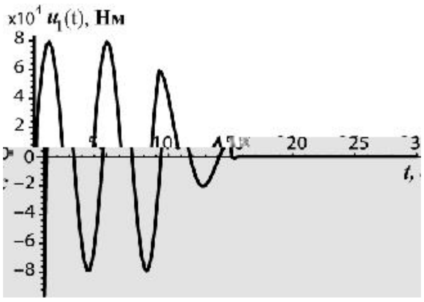


Fig. 9 Transient process relatively control u_3

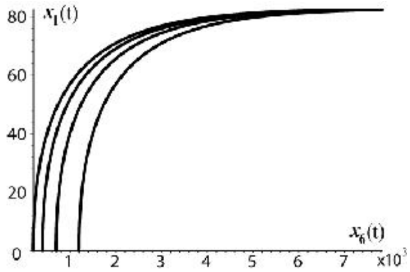


Fig. 10 Projection of system phase trajectory on surface $x_1(t)\,\&\,x_6(t)$

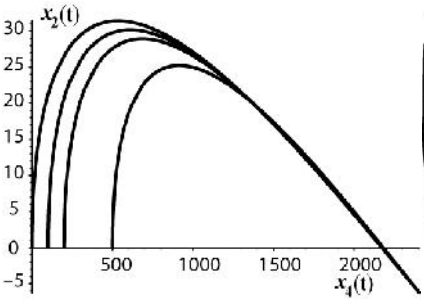


Fig. 11 Projection of system phase trajectory on surface $x_2(t)\,\&\,x_4(t)$

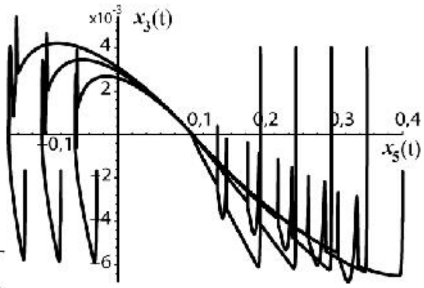
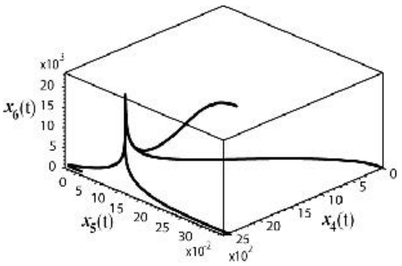


Fig. 12 Projection of system phase trajectory on surface $x_3(t)\,\&\,x_5(t)$



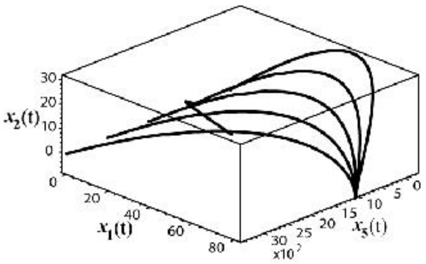


Fig. 13 Phase portrait in space $x_4(t), x_5(t), x_6(t)$

Fig. 14 Phase portrait in space $x_5(t),\ x_1(t),\ x_2(t)$

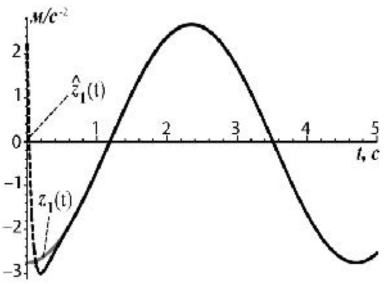


Fig. 15 Transient process relatively disturbance $z_1(t)$ *and its estimation*

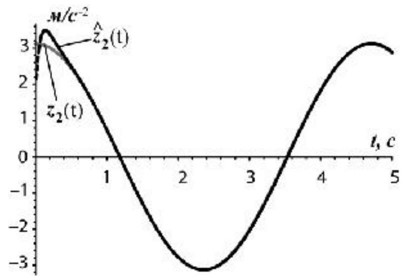


Fig. 16 Transient process relatively $z_2(t)$ *and its estimation*

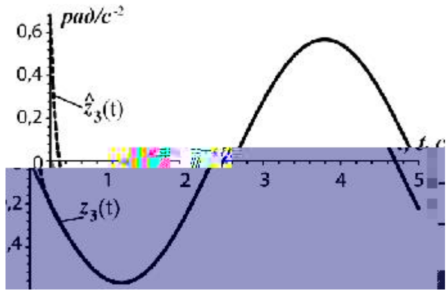


Fig. 17 Transient process relatively $z_3(t)$ *and its evaluation*

5. Conclusion

This work is described the synergistic approach to problem of synthesis of effective correlated control laws of longitudinal motion SA under sea wave conditions, particularly in taking off process from water surface.

In conducting the simulation showed that the SA's longitudinal motion control objectives are achieved and using synthesized control laws can significantly improve motion performance: decreasing pitch angle oscillation, angular rate fluctuations and SA's gravity center oscillation. The observers estimate the unobserved disturbances with high measurement accuracy (fig.15-fig.17).

Thus, using synergetic control theory enable to create new classes of SA's motion control systems.

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