

Optimization and Synthesis of a Robot Fish Motion

Janis Viba, Semjons Cifanskis and Vladimirs Jakushevich
Riga Technical University
Latvia

1. Introduction

Inverse method algorithm for investigation of mechatronic systems in vibration technology is used for robotic systems motion control synthesis. The main difference of this method in comparison with simple analysis method is that before synthesis of a real system the optimal control task for abstract initial subsystem is solved [1 - 4]. As a result of calculations the optimal control law is found that allows to synthesize series of structural schemes for real systems based on initial subsystem. It is shown that near the optimal control excitation new structural schemes may be found in the medium of three kinds of strongly non-linear systems:

- systems with excitation as a time function;
- systems with excitation as a function of phase coordinates only;
- systems with both excitations mixed [2 - 4].

Two types of vibration devices are considered. The first one is a vibration translation machine with constant liquid or air flow excitation. The main idea is to find the optimal control law for variation of additional surface area of machine working head interacting with water or air medium. The criterion of optimization is the time required to move working head of the machine from initial position to end position. The second object of the theoretical study is a fin type propulsive device of robotic fish moving inside water. In that case the aim is to find optimal control law for variation of additional area of vibrating tail like horizontal pendulum which ensures maximal positive impulse of motion forces acting on the tail. Both problems have been solved by using the Pontryagin's maximum principle. It is shown that the optimal control action corresponds to the case of boundary values of area. One real prototype was investigated in linear water tank.

2. Translation motion system

First object with one degree of freedom x and constant water or air flow \bar{V}_0 excitation is investigated (Fig. 1., 2.). The system consists of a mass m with spring c and damper b . The main idea is to find the optimal control law for variation of additional area $S(t)$ of vibrating mass m within limits (1.):

$$S_1 \leq S(t) \leq S_2, \quad (1)$$

where S_1 - lower level of additional area of mass m ; S_2 - upper level of additional area of mass m , t - time.

The criterion of optimization is the time T required to move object from initial position to end position.

Then the differential equation for large water velocity $|V_0| \gg |\dot{x}|$ is (2):

$$m \ddot{x} = -c x - b \dot{x} - u(t) \cdot (V_0 + \dot{x})^2, \tag{2}$$

where $u(t) = S(t) \cdot k$, c - stiffness of a spring, b - damping coefficient, V_0 - constant velocity of water, $S(t)$ - area variation, $u(t)$ - control action, k - constant.

It is required to determine the control action $u = u(t)$ for displacement of a system (2) from initial position $x(t_0)$ to end position $x(t_1)$ in minimal time (criterion K) $K = T$, if area $S(t)$ has the limit (1).

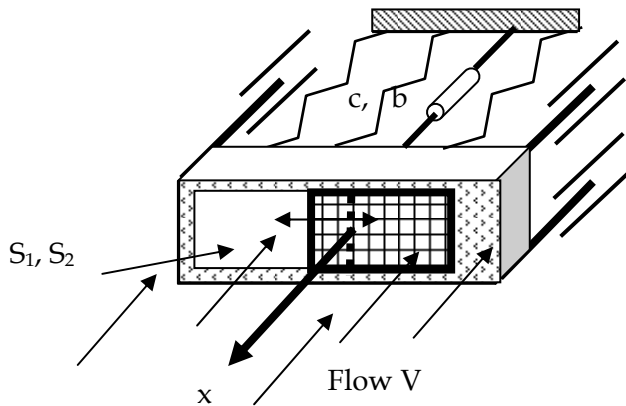


Fig. 1. Working head construction

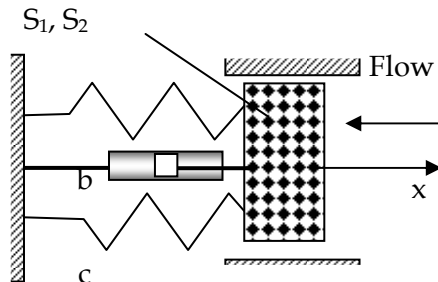


Fig. 2. Side-view of a mathematical model

2.1 Solution of optimal control problem

For solution of problem the Pontryagin’s maximum principle may be used [5 - 13]. We have

the high-speed problem $K = \int_{t_0}^{t_1} 1 \cdot dt$.

To assume $t_0=0; t_1=T$, we have $K = T$.

From the system (2), we transform $x_1 = x; \dot{x}_1 = \dot{x}_2$ or

$$\dot{x}_1 = x_2; \dot{x}_2 = \frac{1}{m} \cdot (-c x - b \dot{x} - u(t) \cdot (V_0 + \dot{x})^2)$$

and we have Hamiltonian (3):

$$H = \psi_0 + \psi_1 x_2 + \psi_2 \left(\frac{1}{m} \cdot (-c x_1 - b x_2 - u(t) \cdot (V_0 + x_2)^2) \right), \tag{3}$$

here $H = \psi \cdot X$, where (4)

$$\psi = \begin{Bmatrix} \psi_0 \\ \psi_1 \\ \psi_2 \end{Bmatrix}; X = \begin{Bmatrix} 0 \\ \dot{x}_1 \\ \dot{x}_2 \end{Bmatrix}. \tag{4}$$

Scalar product of those vector functions ψ and X in any time (function H) must be maximal. To take this maximum, control action $u(t)$ must be within limits $u(t) = u_1; u(t) = u_2$, depending only on function ψ_2 sign (5):

$$H = \max H, \tag{5}$$

if $\psi_2 \cdot (-u(t) \cdot (V_0 + x_2)^2) = \max$.

If $\psi_2 > 0, u(t) = u_1$ and if $\psi_2 < 0, u(t) = u_2$, where $u_1 = S_1 \cdot k$ and $u_2 = S_2 \cdot k$, see (1).

The examples of control action with one, two and three switch points are shown in Fig. 3. - Fig. 5.

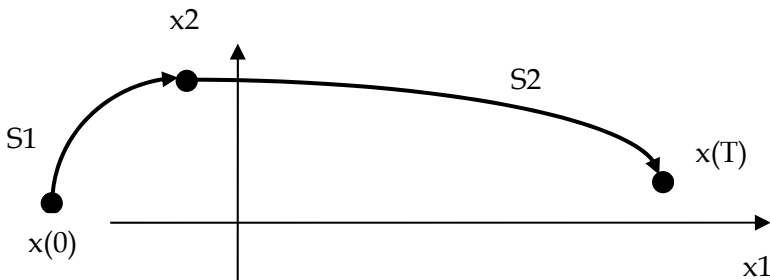


Fig. 3. Example of optimal control with one switch point

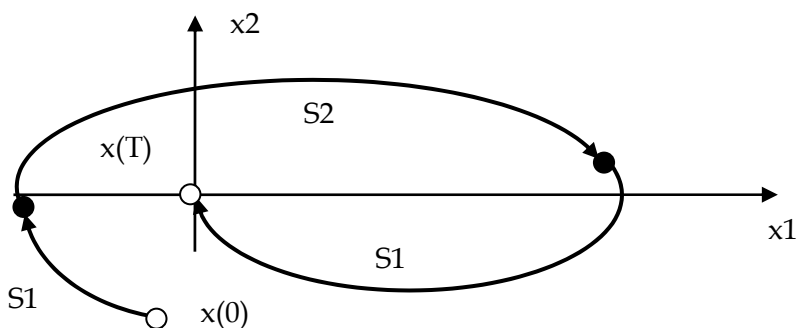


Fig. 4. Example of optimal control with two switch points in the system with damping

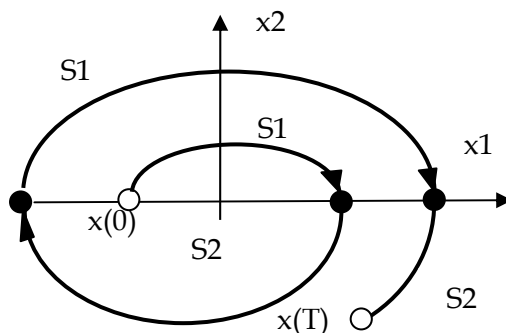


Fig. 5. Example of optimal control with three switch points in the task of system excitation

2.2 Theoretical synthesis of control action

For realizing of optimal control actions (in general case) system of one degree of freedom needs a feedback system with two adapters: one to measure a displacement and another one to measure a velocity. There is a simple case of control existing with only one adapter when directions of motion are changed (Fig. 5) [3]. It means that control action is like negative dry friction and switch points are along zero velocity line. In this case equation of motion is (6):

$$m \cdot \ddot{x} = -c \cdot x - b \cdot \dot{x} - \left[k \cdot (V_0 + \dot{x})^2 \cdot A_1 \cdot \left(0,5 - 0,5 \cdot \frac{\dot{x}}{|\dot{x}|} \right) \right] - \left[k \cdot (V_0 + \dot{x})^2 \cdot A_2 \cdot \left(0,5 + 0,5 \cdot \frac{\dot{x}}{|\dot{x}|} \right) \right], \quad (6)$$

where m – mass; c , b , k , V_0 – constants. Examples of modeling are shown in Fig. 6. – Fig. 9.

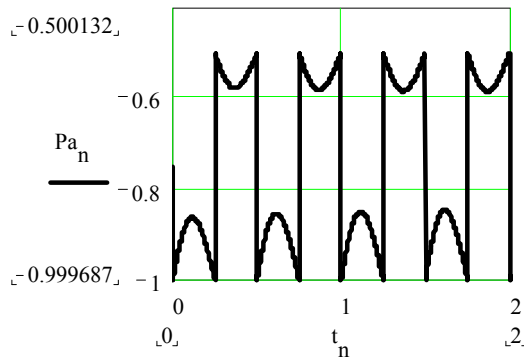


Fig. 6. Full control action in time domain

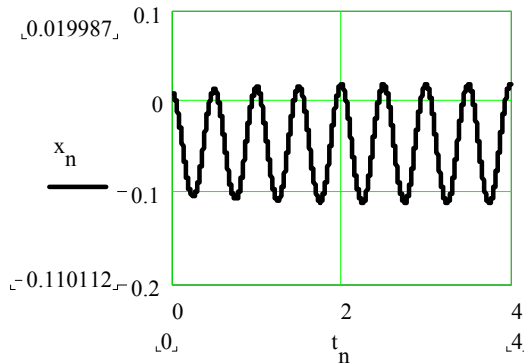


Fig. 7. Displacement in time domain

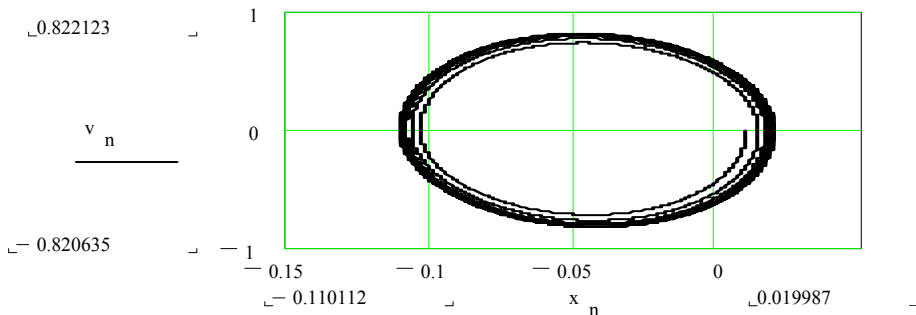


Fig. 8. Motion in phase plane starting from inside of limit cycle

A search for the case with more than one limit cycle was investigated in a very complicated system with linear and cubic restoring force, linear and cubic resistance force and dry friction. It was found that for a system with non-periodic excitation (like constant velocity of water or air flow) more than one limit cycles exist (Fig. 10., 11.).

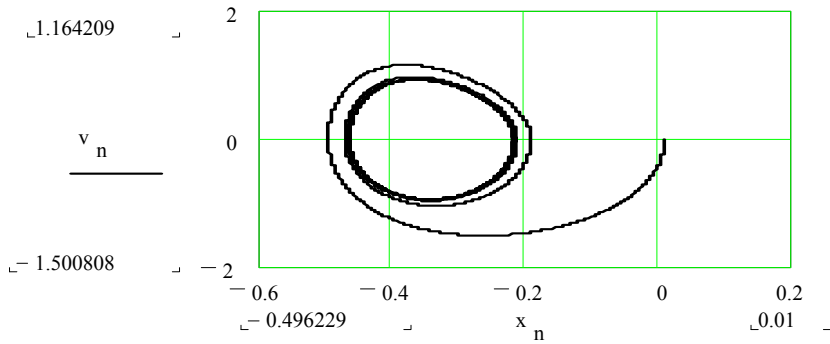


Fig. 9. Motion with initial conditions outside of limit cycle

$$\begin{bmatrix} x_0 \\ v_0 \end{bmatrix} := \begin{bmatrix} 0.09 \\ 0 \end{bmatrix}$$

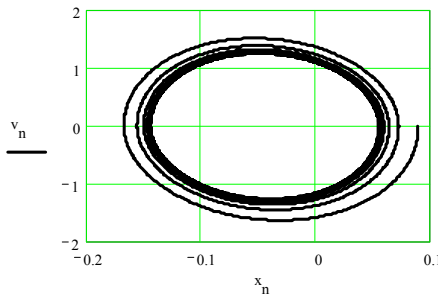


Fig. 10. Motion in phase plane for small limit cycle

$$\begin{bmatrix} x_0 \\ v_0 \end{bmatrix} := \begin{bmatrix} 9 \\ -0 \end{bmatrix}$$

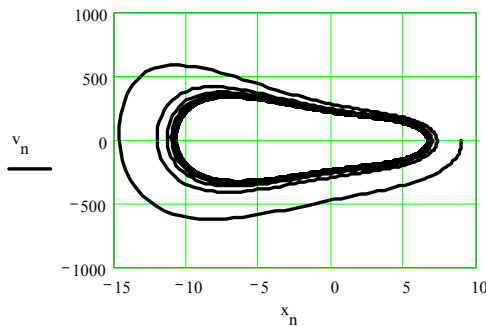


Fig. 11. Motion for large limit cycle

2.3 Synthesis of a real system with rotating blades

Scheme of a system includes main mass of the object, spring and viscous damper (Fig. 12). Part of mass with blades does not rotate. Second part of main mass like blades rotates around fixed axis inside body. Blades have symmetric areas A_1 and A_2 .

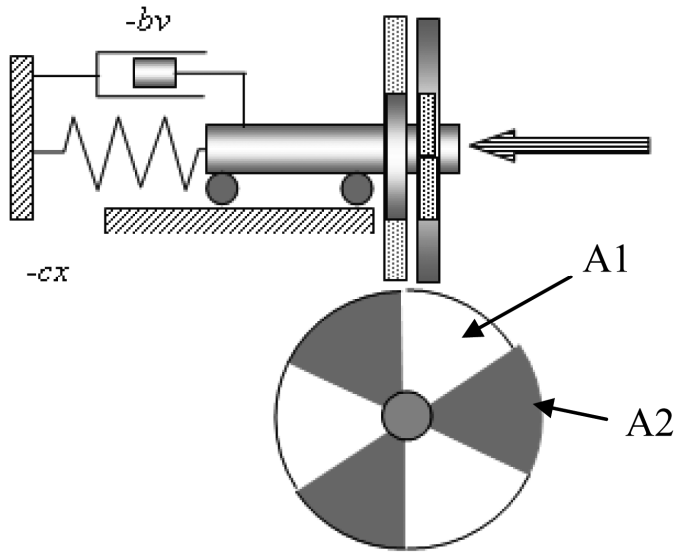


Fig. 12. System with rotating blades

Results of investigation are shown in Fig. 13. - Fig. 14.

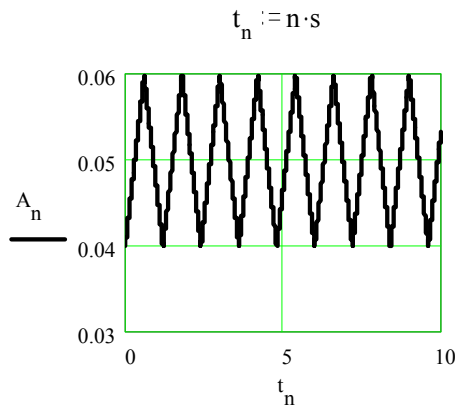


Fig. 13. Area change function in time domain when blades rotate with constant angular velocity ω

Investigation shows that system is very stable because of air excitation and damping forces depending from velocity squared.

$$\frac{\sqrt{\frac{c}{m}}}{\omega} = 1$$

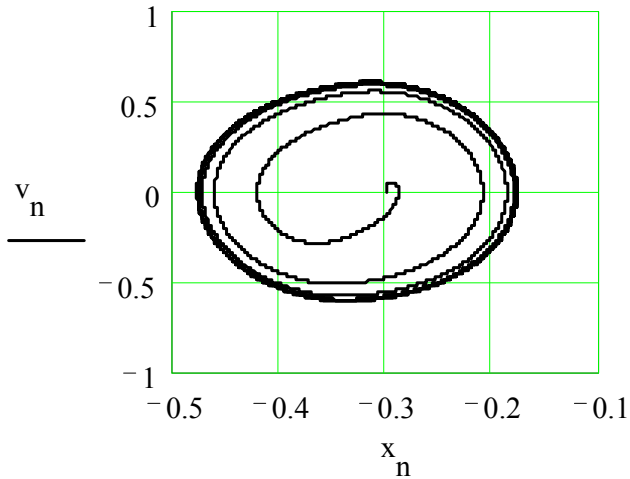


Fig. 14. Motion in phase plane for parameters close to the first resonance

2.4 Synthesis of real system inside tube with variable hole area - A

Adaptive control where analyzed by next area exchange functions $f1(A)$ (Fig. 15, 16.):

$$f1(A) = A2 \cdot \left(1 + a \cdot \frac{v \cdot x}{|v \cdot x|}\right),$$

where $A2$, a - constants, v , x - velocity and coordinate of moving mass $m2$.

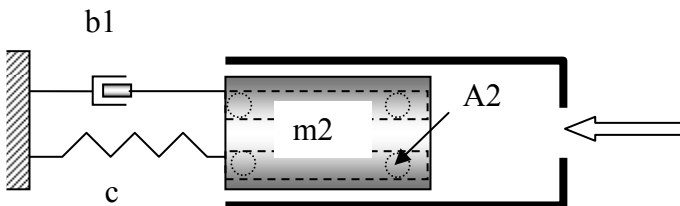


Fig. 15. Synthesis of system inside tube

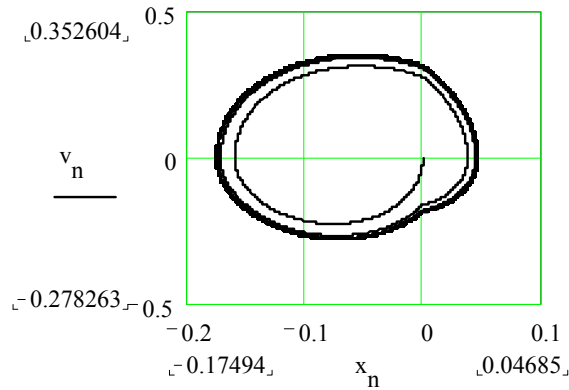


Fig. 16. Motion in phase plane

It is shown that adaptive systems are also very stable because of water or air excitation and damping forces depending from velocity squared.

In order to get values of parameters in equations, experiments were made in the wind tunnel. It should be noted that the air flow is similar to the water flow, with one main difference in the density. It is therefore convenient to perform synthesis algorithm experiments done with air flow in the wind tunnel. Experimental results obtained in the wind tunnel to some extent may be used to analyze water flow excitation in robot fish prototypes. Using “Armfield” subsonic wind tunnel several additional results were obtained. For example, drag forces, acting on different shapes of bodies, were measured and drag coefficients were calculated by formula $F_d = C_d \cdot S \cdot \frac{\rho \cdot V^2}{2}$, where ρ - density, V - flow velocity, S - specific area, C_d - drag coefficient. These coefficients depend on bodie’s geometry, orientation relative to flow, and non-dimensional Reynolds number.



Fig. 17. Subsonic wind tunnel used for experiments at Mechanics Institute of Riga TU

All experiments were done at constant air flow velocity in the range of 10 – 20 m/s. This corresponds to Re value of about 40 000.

Drag coefficient for a plate perpendicular to the flow depends on plate's length and chord ratio. For standard plates C_d it is about 1.2. For infinitely long plates C_d reaches the value of 2. For a cone $C_d = 0,5$; for a cylinder along the flow - about 0,81; for both cylinder and cone in one direction - 0,32. All these forms can be used for robot fish main body form designing, (together with the tail) in real robot fish models (see part 3.4, where cone and cylinder were used). Depth control of prototypes was provided by two front control wings (see part 3.4).

Parameters of subsonic wind tunnel were as follows: length 2.98m, width 0.8m., height 1.83m. Variable speed motor drive unit downstream of the working section permits stepless control of airspeed between 0 and 26 ms⁻¹. Experiments prove that air flow excitation is very efficient.

3. Investigation of a rotating system

The second object of the theoretical study is a fin type propulsive device of robotic fish moving inside water. The aim of the study is to find out optimal control law for variation of additional area of vibrating tail like horizontal pendulum, which ensures maximal positive impulse of motion forces components acting on a tail parallel to x axis (Fig.18).

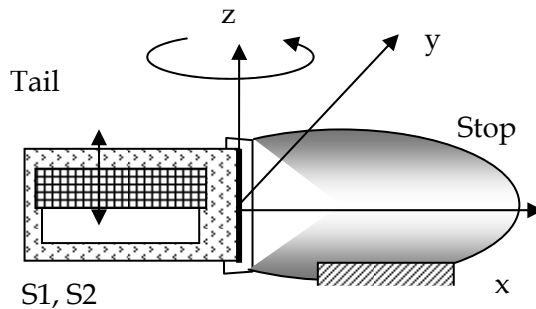


Fig. 18. Side-view of a robot fish tail like horizontal pendulum

Problem has been solved by using Pontryagin's maximum principle. It is shown that optimal control action corresponds to the case of boundary values of area.

Mathematical model of a system consists of rigid straight flat tail moving around pivot (Fig. 18.,19.). Area of the tail may be changed by control actions. For excitation of the motion a moment $M(t, \varphi, \omega)$ around pivot must be added, where $\omega = d\varphi/dt$ - angular velocity of a rigid tail. To improve performance of a system additional rotational spring with stiffness c may be added (Fig. 19.).

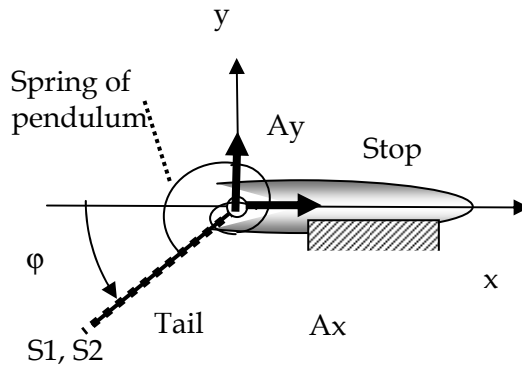


Fig. 19. Top-view of a robot fish tail like horizontal pendulum. Simplified model with fixed pivot A

The principal task described in this report is to find optimal control law for variation of additional area $B(t)$ of vibrating tail within limits (7):

$$B_1 \leq B(t) \leq B_2, \tag{7}$$

where B_1 - lower level of additional area of a tail; B_2 - upper level of additional area of a tail, t - time.

The criterion of optimization is full reaction Ax^* impulse in pivot, acting to a hull (indirect reaction to a tail) which is required to move an object from one stop - initial position ($\varphi_{max}, \dot{\varphi} = 0$) to another stop - end position ($\varphi_{min}, \dot{\varphi} = 0$) in time $T(8)$.

$$K = - \int_0^T Ax^* \cdot dt, \tag{8}$$

Differential equation of motion of the system with one degree of freedom (including a change of angular momentum around fixed point A) is (9):

$$J_A \ddot{\varphi} = M(t, \varphi, \dot{\varphi}) - c \cdot \varphi - k_t \cdot B \cdot \text{sign}(\dot{\varphi} \cdot \varphi) \cdot \int_0^L (\dot{\varphi} \cdot \xi)^2 \cdot \xi \cdot d\xi. \tag{9}$$

Here J_A - moment of inertia of the tail around pivot point; $\ddot{\varphi}$ - angular acceleration of a rigid straight tail; $M(t, \varphi, \dot{\varphi})$ - excitation moment of the drive; c - angular stiffness; k_t - constant coefficient; B - area; $(\int_0^L (\dot{\varphi} \cdot \xi)^2 \cdot \xi \cdot d\xi)$ - component of the moment of resistance force expressed as an integral along tail direction; $\dot{\varphi}$ - angular velocity; L - length of the tail.

From the principle of the motion of mass center C it follows (10):

$$m \cdot \left(\dot{\varphi}^2 \cdot \frac{L}{2} \cdot \cos \varphi + \ddot{\varphi} \cdot \frac{L}{2} \cdot \sin \varphi \right) = Ax - k_i \cdot B \cdot \sin(\varphi) \cdot \text{sign}(\varphi \cdot \dot{\varphi}) \cdot \left(\int_0^L (\dot{\varphi} \cdot \xi)^2 \cdot d\xi \right) \quad (10)$$

After integration from equations (9) and (10) we have (11, 12):

$$\ddot{\varphi} = \frac{1}{J_A} \cdot \left[M(t, \varphi, \dot{\varphi}) - c \cdot \varphi - k_i \cdot B \cdot \text{sign}(\dot{\varphi}) \cdot \dot{\varphi}^2 \cdot \frac{L^4}{4} \right]. \quad (11)$$

$$Ax = m \cdot \left\{ \dot{\varphi}^2 \cdot \frac{L}{2} \cdot \cos(\varphi) + \frac{1}{J_A} \cdot \left[M(t, \varphi, \dot{\varphi}) - c \cdot \varphi - k_i \cdot B \cdot \text{sign}(\dot{\varphi}) \cdot \dot{\varphi}^2 \cdot \frac{L^4}{4} \right] \cdot \frac{L}{2} \cdot \sin(\varphi) \right\} + k_i \cdot B \cdot \sin(\varphi) \cdot \text{sign}(\varphi \cdot \dot{\varphi}) \cdot \dot{\varphi}^2 \cdot \frac{L^3}{3}. \quad (12)$$

Then the criterion of optimization (full impulse) is:

$$K = - \int_0^T \left(m \cdot \left\{ \dot{\varphi}^2 \cdot \frac{L}{2} \cdot \cos(\varphi) + \frac{1}{J_A} \cdot \left[M(t, \varphi, \dot{\varphi}) - c \cdot \varphi - k_i \cdot B \cdot \text{sign}(\dot{\varphi}) \cdot \dot{\varphi}^2 \cdot \frac{L^4}{4} \right] \cdot \frac{L}{2} \cdot \sin(\varphi) \right\} + k_i \cdot B \cdot \sin(\varphi) \cdot \text{sign}(\varphi \cdot \dot{\varphi}) \cdot \dot{\varphi}^2 \cdot \frac{L^3}{3} \right) \cdot dt, \quad (13)$$

Equations (13) will be used to solve the optimization problem.

3.1 Task of optimization

Solution of optimal control problem for a system with one degree of freedom (11) by using the Pontryagin's maximum principle includes following steps [8 - 13]:

1. Formulation of a criterion of optimization (13):

$$K = - \int_0^T Ax \cdot dt.$$

2. Transformation of the equation (9) and equation (13) in the three first order equations with new variables φ_0 , φ_1 and φ_2 (phase coordinates):

$$\varphi_0 = (-1) \cdot \left[m \cdot \left\{ \varphi_2^2 \cdot \frac{L}{2} \cdot \cos(\varphi_1) + \frac{1}{J_A} \cdot \left[M(t, \varphi_1, \varphi_2) - c \cdot \varphi_1 - k_i \cdot B \cdot \text{sign}(\varphi_2) \cdot \varphi_2^2 \cdot \frac{L^4}{4} \right] \cdot \frac{L}{2} \cdot \sin(\varphi_1) \right\} + k_i \cdot B \cdot \sin(\varphi_1) \cdot \text{sign}(\varphi_1 \cdot \varphi_2) \cdot \varphi_2^2 \cdot \frac{L^3}{3}, \right]$$

$$\dot{\varphi}_1 = \varphi_2;$$

$$\dot{\varphi}_2 = \frac{1}{J_A} \cdot \left[M(t, \varphi_1, \varphi_2) - c \cdot \varphi_1 - k_i \cdot B \cdot \text{sign}(\varphi_2) \cdot \varphi_2^2 \cdot \frac{L^4}{4} \right] \quad (14)$$

According to procedure of Pontryagin's maximum principle, Hamiltonian (H) is [9 -12]:

$$H = \psi_0 \cdot (-1) \cdot \left[\begin{aligned} & m \cdot \varphi_2^2 \cdot \frac{L}{2} \cdot \cos(\varphi_1) + \frac{1}{J_A} \cdot [M(t, \varphi_1, \varphi_2) - c \cdot \varphi_1 - \\ & -k_t \cdot B \cdot \text{sign}(\varphi_2) \cdot \varphi_2^2 \cdot \frac{L^4}{4}] \cdot \frac{L}{2} \cdot \sin(\varphi_1) \Big\} + \\ & + k_t \cdot B \cdot \sin(\varphi_1) \cdot \text{sign}(\varphi_1 \cdot \varphi_2) \cdot \varphi_2^2 \cdot \frac{L^3}{3} \end{aligned} \right] + \tag{15}$$

$$+ \psi_1 \cdot \varphi_2 + \psi_2 \cdot \frac{1}{J_A} \cdot \left[M(t, \varphi_1, \varphi_2) - c \cdot \varphi_1 - k_t \cdot B \cdot \text{sign}(\varphi_2) \cdot \varphi_2^2 \cdot \frac{L^4}{4} \right].$$

here $H = \psi \cdot \Phi$, where (10, 11)

$$\psi = \left\{ \begin{aligned} & \psi_0 \\ & \psi_1 \\ & \psi_2 \end{aligned} \right\}; \tag{16}$$

$$\Phi = \left\{ \begin{aligned} & \Phi_0 \\ & \Phi_1 \\ & \Phi_2 \end{aligned} \right\}, \tag{17}$$

Φ_0, Φ_1, Φ_2 - right side of system equations (14).

For functions Φ_0, Φ_1, Φ_2 calculations are following differential equations [9 - 12]:

$$\dot{\Phi}_0 = -\frac{\partial H}{\partial \phi_0}; \quad \dot{\Phi}_1 = -\frac{\partial H}{\partial \phi_1}; \quad \dot{\Phi}_2 = -\frac{\partial H}{\partial \phi_2}, \tag{18}$$

where left side is the derivation in time t : $\dot{\Phi}_{0,1,2} = \frac{d\Phi_{0,1,2}}{dt}$.

From equations (15) and (18) we get nonlinear system of differential equations to find functions ψ_0, ψ_1, ψ_2 . Solution of such system is out of the scope of this report because it depends from unknown moment $M(t, \varphi, \omega)$. But some conclusions and recommendations may be given from Hamiltonian if excitation moment $M(t, \varphi, \omega)$ does not depend from phase coordinates $\varphi = \varphi_1, \omega = \varphi_2$:

$$M = M(t).$$

In this case scalar product of two last vector functions ψ and Φ in any time (Hamiltonian H [11]) must be maximal (supremum - in this linear B case) [8 - 12]. To have such maximum (supremum), control action $B(t)$ must be within limits $B(t) = B_1; B(t) = B_2$, depending only from the *sign* of a function (19) or (20):

$$\text{sign} \left(\begin{array}{l} \psi_0 \cdot \left[\frac{m}{J_A} \cdot \left[k_t \cdot 1 \cdot \text{sign}(\varphi_2) \cdot \frac{L^5}{4} \right] \cdot \frac{1}{2} \cdot \sin(\varphi_1) + k_t \cdot 1 \cdot \sin(\varphi_1) \cdot \text{sign}(\varphi_1 \cdot \varphi_2) \cdot \frac{L^3}{3} \right] + \\ + \psi_2 \cdot \frac{1}{J_A} \cdot \left[-k_t \cdot 1 \cdot \text{sign}(\varphi_2) \cdot \frac{L^4}{4} \right] \end{array} \right) \geq 0, \quad (19)$$

$$B = B2;$$

$$\text{sign} \left(\begin{array}{l} \psi_0 \cdot \left[\frac{m}{J_A} \cdot \left[k_t \cdot 1 \cdot \text{sign}(\varphi_2) \cdot \frac{L^5}{4} \right] \cdot \frac{1}{2} \cdot \sin(\varphi_1) + k_t \cdot 1 \cdot \sin(\varphi_1) \cdot \text{sign}(\varphi_1 \cdot \varphi_2) \cdot \frac{L^3}{3} \right] + \\ + \psi_2 \cdot \frac{1}{J_A} \cdot \left[-k_t \cdot 1 \cdot \text{sign}(\varphi_2) \cdot \frac{L^4}{4} \right] \end{array} \right) \leq 0. \quad (20)$$

$$B = B1;$$

From inequalities (19) and (20) in real system synthesis following quasi-optimal control action may be recommended (21):

$$B = [B2 \cdot (0,5 - 0,5 \cdot \text{sign}(\varphi_1 \cdot \varphi_2)) + B1 \cdot (0,5 + 0,5 \cdot \text{sign}(\varphi_1 \cdot \varphi_2))],$$

or

$$B = [B2 \cdot (0,5 - 0,5 \cdot \text{sign}(\varphi \cdot \dot{\varphi})) + B1 \cdot (0,5 + 0,5 \cdot \text{sign}(\varphi \cdot \dot{\varphi}))]. \quad (21)$$

3.2 Synthesis of mixed system with time-harmonic excitation and area adaptive control

In the case of time-harmonic excitation moment M in time domain is (see equations (9) and (11)):

$$M(t) = M0 \cdot \sin(k \cdot t).$$

Results of modeling are shown in Fig. 20. – 25. Comments about graphics are given under all Fig. 20. – 25.

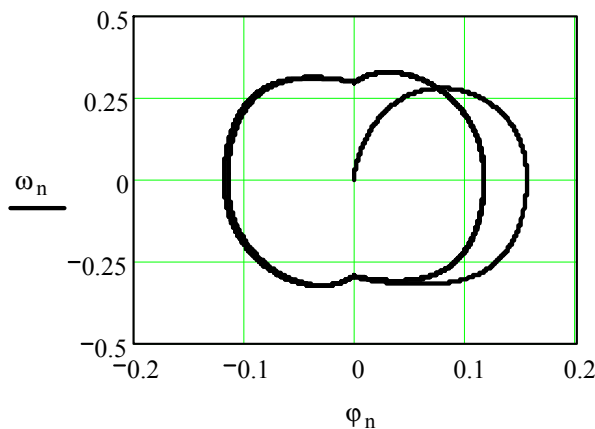


Fig. 20. Tail angular motion in the phase plane – angular velocity as function of angle

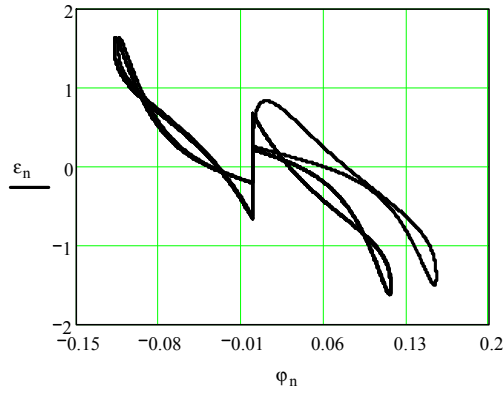


Fig. 21. Angular acceleration of the tail as function of angle. At the end of transition process graph is symmetric

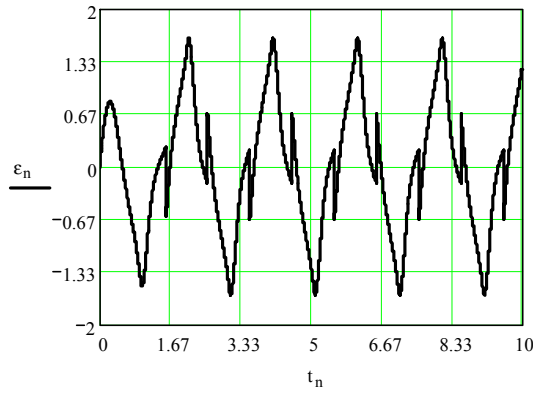


Fig. 22. Angular acceleration $\epsilon = \ddot{\phi}$ of a tail in time domain (see equation (9)). Practically angular acceleration of the tail reaches steady-state cycle after one oscillation

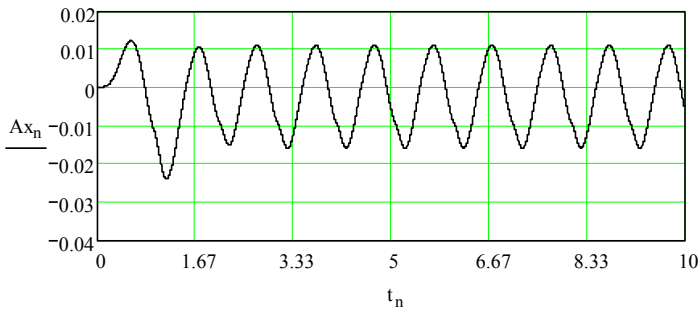


Fig. 23. Impulse $Ax(t)$ in time domain (see equation (12)). Impulse is non-symmetric against zero level (non-symmetry is negative)

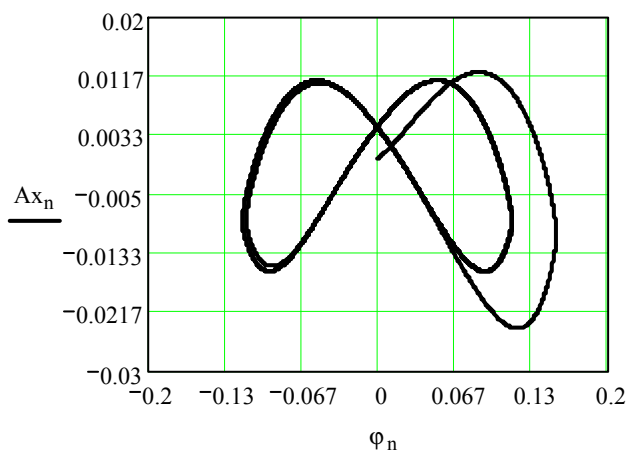


Fig. 24. Impulse $Ax(t)$ as a function of angle φ .
Impulse is non-symmetric against zero level (non-symmetry is negative)

$$IAx_n := \sum_n Ax_n$$

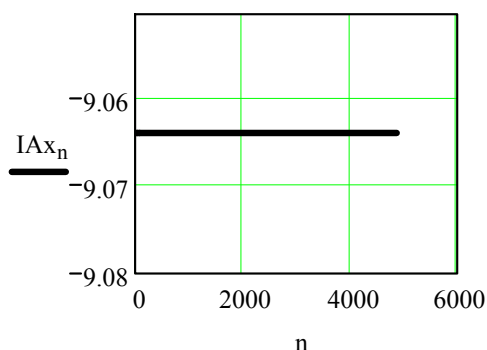


Fig. 25. Negative mean value of $Ax(t)$ in time domain.
Force of pivot to push a hull (necessary for robotic fish motion)

3.3 Synthesis of a system with adaptive excitation and adaptive area control

In a case of adaptive excitation a moment M may be used as the function of angular velocity in the form [3, 4]:

$$M(t) = M0 \cdot \text{sign}(\omega).$$

Results of modeling are shown in Fig. 26. – 31. Comments about graphics are given under all Fig. 26. – 31.

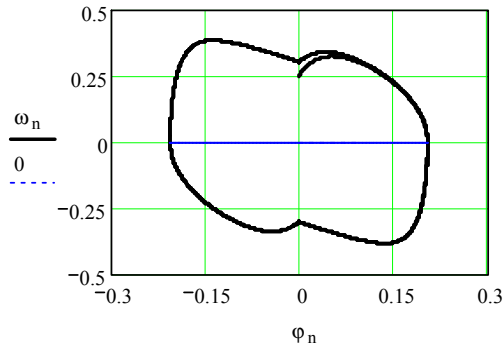


Fig. 26. Tail angular motion in phase plane - angular velocity as the function of angle. Due to large water resistance the transition process is very short. Adaptive excitation is more efficient than harmonic excitation (see Fig.20.)

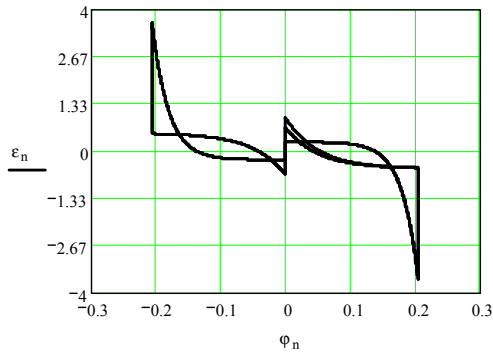


Fig. 27. Angular acceleration of a tail as the function of angle. At the end of transition process graph is more symmetric than the graph shown in Fig. 22

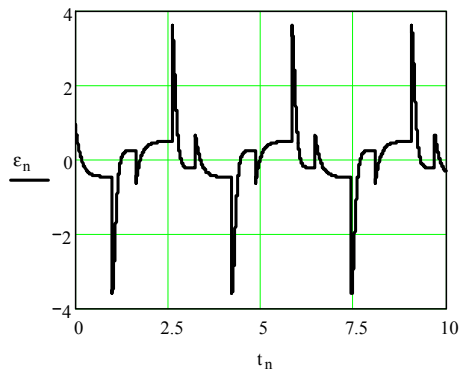


Fig. 28. Angular acceleration $\epsilon = \ddot{\phi}$ of a tail in time domain (see equation (9)). Typically angular acceleration of the tail reaches steady-state cycle after half oscillation

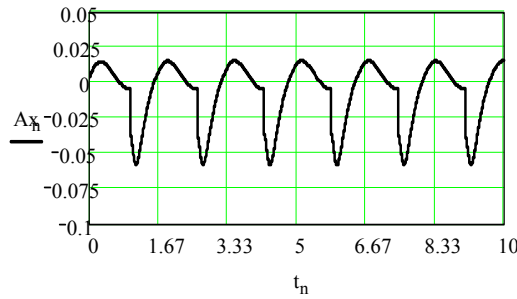


Fig. 29. Impulse $Ax(t)$ in time domain (see equation (12)). Impulse is non-symmetric against zero level (non-symmetry is negative)

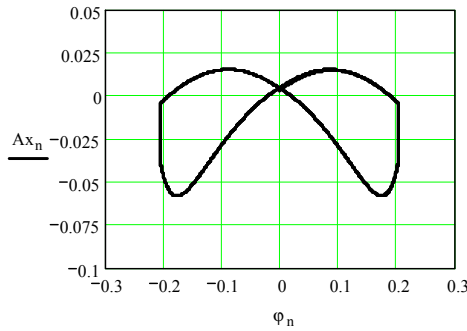


Fig. 30. Impulse $Ax(t)$ as a function of angle φ

Impulse is non-symmetric against zero level (non-symmetry is negative), it means that criterion of optimization (8) is positive and force of pivot pushes fish hull to the right.

$$IAx_n := \sum_n Ax_n$$

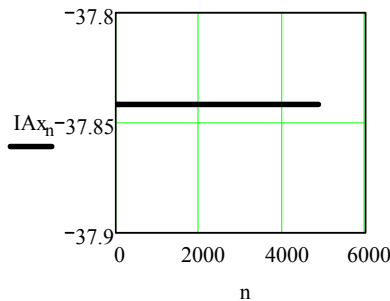


Fig. 31. Negative mean value of $Ax(t)$ in time domain. Force of pivot to push fish hull to the right (in order to have robotic fish motions to the right). This graph shows that adaptive excitation of a moment is about four times more efficient than harmonic excitation (see Fig. 25.)

3.4 Robot fish model

A prototype of robot fish for experimental investigations was made (Fig. 32, 33). This prototype was investigated in a linear water tank with different aims, for example: - find maximal motion velocity depending on the power pack capacity; - find minimal propulsion force, depending on the system parameters.

Additionally this prototype was investigated in a large storage lake with autonomy power pack and distance control system, moving in real under water conditions with waves (Fig. 34.). The results of the theoretical and experimental investigation may be used for inventions of new robotic systems. The new ideas of synthesising robotic systems in Latvia can be found in [15 - 23].



Fig. 32. Top-view of prototype

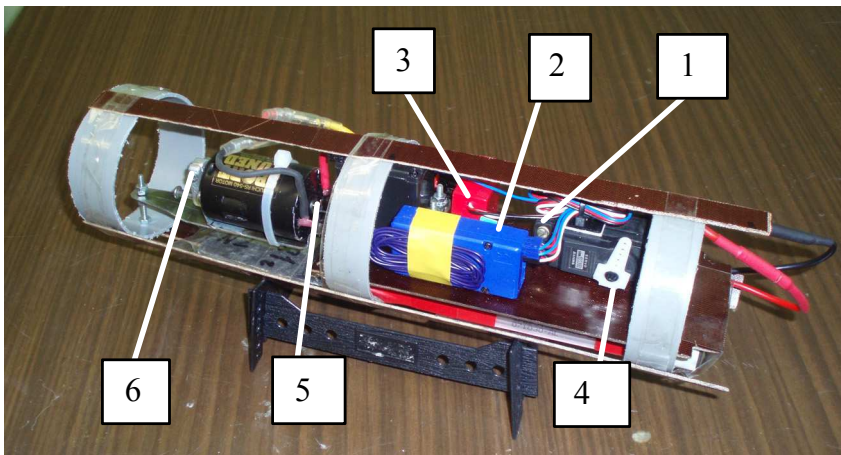


Fig. 33. Inside prototype there are: microcontroller 1; three actuators (for level 4, direction 5 and velocity 6 control); power supply 2 and radio signal detector 3)



Fig. 34. Prototype was investigated in a large storage lake with autonomy power pack and distance control system, moving in real under water conditions with waves

4. Conclusion

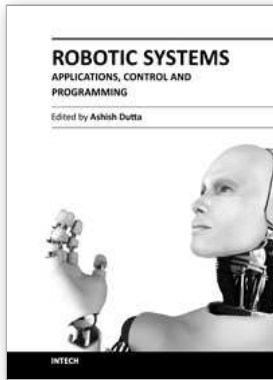
Motion of robotic systems vibration by simplified interaction with water or air flow can be described by rather simple equations for motion analysis. That allows to solve mathematical problem of area control optimization and to give information for new systems synthesis. Control (or change) of object area under water or in air allows to create very efficient mechatronic systems. For realization of such systems adapters and controllers must be used. For this reason very simple control action have solutions with use of sign functions. Examples of synthesis of real mechatronic systems are given. As one example of synthesis is a system with time-harmonic moment excitation of the tail in the pivot. The second example of synthesis is a system with adaptive force moment excitation as the function of phase coordinates. In both systems area change (from maximal to minimal values) has control action as the function of phase coordinates. It is shown that real controlled systems vibration motion is very stable.

5. References

- [1] E. Lavendelis: Synthesis of optimal vibro machines. Zinatne, Riga, (1970). (in Russian).
- [2] E. Lavendelis and J. Viba: Individuality of Optimal Synthesis of vibro impact systems. Book: Vibrotechnics". Kaunas. Vol. 3 (20), (1973). (in Russian).
- [3] J. Viba: Optimization and synthesis of vibro impact systems. Zinatne, Riga, (1988). (in Russian).
- [4] E. Lavendelis and J. Viba: Methods of optimal synthesis of strongly non – linear (impact) systems. Scientific Proceedings of Riga Technical University. Mechanics. Volume 24. Riga (2007).
- [5] http://en.wikipedia.org/wiki/Lev_Pontryagin. (2008).

- [6] http://en.wikipedia.org/wiki/Pontryagin%27s_maximum_principle.(February (2008)).
- [7] http://en.wikipedia.org/wiki/Hamiltonian_%28control_theory%29. (2007).
- [8] V.G. Boltyanskii, R.V. Gamkrelidze and L. S. Pontryagin: On the Theory of Optimum Processes (In Russian), *Dokl. AN SSSR*, 110, No. 1, 7-10 (1956).
- [9] L. S. Pontryagin, V.G. Boltyanskii, R.V.Gamkrelidze and E.F. Mischenko: (Fizmatgiz). *The Mathematical Theory of Optimal Processes*, Moscow (1961).
- [10] L.S. Pontryagin, V.G. Boltyanskii, R.V. Gamkrelidze, and E.F. Mishchenko: *The Mathematical Theory of Optimal Processes*, Wiley-Interscience, New York. (1962).
- [11] V. G. Boltyanskii: *Mathematical Methods of Optimal Control*, Nauka, Moscow. (1966).
- [12] V.G. Boltyanskii: Mathematical methods of optimal control: Authorized translation form the Russian. Translator K.N. Trirgoff. Balskrishnan-Neustadt series. New York. Holt, Rinehart and Winston. (1971).
- [13] E.B. Lee and L. Markus: *Foundations of Optimal Control Theory*, Moscow: Nauka, (1972). (in Russian). 14. Sonneborn, L., and F. Van Vleck (1965): *The Bang-Bang Principle for Linear Control Systems*, SIAM J. Control 2, 151-159.
- [14] http://en.wikipedia.org/wiki/Bang-bang_control. (2008).
- [15] Patent LV 13928, Republic of Latvia, Int.Cl. B25 D9/00, B25 D11/00. Method for control of operation condition of one-mass vibromachine on elastic suspension / J. Viba, V. Beresnevich, M. Eiduks, L. Shtals, E. Kovals, G. Kulikovskis. - Applied on 03.03.2009, application P-09-38; published on 20.09.2009 // Patenti un preču zīmes, 2009, No. 9, p. 1209 - 1210.
- [16] Patent LV 14033, Republic of Latvia, Int.Cl. B63 H 1/00. Method for tractive force forming in fin propulsive device / J. Viba, V. Beresnevich, S. Cifanskis, G. Kulikovskis, M. Kruusmaa, W. Megill, J.-G. Fontaine, P. Fiorini. - Applied on 04.09.2009, application P-09-151; published on 20.02.2010 // Patenti un preču zīmes, 2010, No. 2, p. 203.
- [17] Patent LV 14034, Republic of Latvia, Int.Cl. B63 H1/00. Hydrodynamic fin-type vibration propulsive device / S. Cifanskis, J. Viba, V. Jakushevich, O. Kononova, J.-G. Fontaine, W. Megill. - Applied on 29.09.2009, application P-09-160; published 20.02.2010 // Patenti un preču zīmes, 2010, No. 2, p. 203.
- [18] Patent LV 14054, Republic of Latvia, Int.Cl. B63 H1/00. Fin of hydrodynamic vibration propulsive device / S. Cifanskis, J. Viba, V. Jakushevich, V. Beresnevich, O. Kononova, G. Kulikovskis. - Applied on 15.10.2009, application P-09-174; published 20.03.2010 // Patenti un preču zīmes, 2010, No. 3, p. 428.
- [19] Patent LV 14055, Republic of Latvia, Int.Cl. B63 H1/00. Method for control of operating condition of hydrodynamic fin-type vibration propulsive device / J. Viba, S. Cifanskis, V. Jakushevich, O. Kononova, J.-G. Fontaine, E. Kovals. - Applied on 02.11.2009, application P-09-191; published 20.03.2010 // Patenti un preču zīmes, 2010, No. 3, p. 428.
- [20] Patent LV 14076, Republic of Latvia, Int.Cl. B63 H1/00. Hydrodynamic fin-type vibration propulsive device / S. Cifanskis, J. Viba, V. Jakushevich, O. Kononova, M. Kruusmaa, G. Kulikovskis. - Applied on 24.11.2009, application P-09-205; published 20.04.2010 // Patenti un preču zīmes, 2010, No. 4, p. 631.

- [21] Patent LV 14077, Republic of Latvia, Int.Cl. B63 H 1/00. Method for adjustment of operation condition of fin-type vibration propulsive device / S. Cifanskis, V. Beresnevich, J. Viba, V. Yakushevich, J.-G. Fontaine, G. Kulikovskis. – Applied on 10.12.2009, application P-09-219; published on 20.04.2010 // Patenti un preču zīmes, 2010, No. 4, p. 631.
- [22] Patent LV 14175, Republic of Latvia, Int.Cl. B63 H 1/00. Method for adjustment of operation condition of fin-type vibration propulsive device / S. Cifanskis, J. Viba, V. Beresnevich, V. Jakushevich, M. Listak, T. Salumäe. – Applied on 28.04.2010, application P-10-63; published 20.10.2010 // Patenti un preču zīmes, 2010, No. 10, p. 1515 – 1516.
- [23] Patent LV 14237, Republic of Latvia, Int.Cl. B63 H1/00. Hydrodynamic fin-type vibration propulsive device / S. Cifanskis, J. Viba, V. Beresnevich, V. Jakushevich, J.-G. Fontaine, W. Megill. – Applied on 07.10.2010, application P-10-141; published 20.02.2011 // Patenti un preču zīmes, 2011, No. 2, p. 188.



Robotic Systems - Applications, Control and Programming

Edited by Dr. Ashish Dutta

ISBN 978-953-307-941-7

Hard cover, 628 pages

Publisher InTech

Published online 03, February, 2012

Published in print edition February, 2012

This book brings together some of the latest research in robot applications, control, modeling, sensors and algorithms. Consisting of three main sections, the first section of the book has a focus on robotic surgery, rehabilitation, self-assembly, while the second section offers an insight into the area of control with discussions on exoskeleton control and robot learning among others. The third section is on vision and ultrasonic sensors which is followed by a series of chapters which include a focus on the programming of intelligent service robots and systems adaptations.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Janis Viba, Semjons Cifanskis and Vladimirs Jakushevich (2012). Optimization and Synthesis of a Robot Fish Motion, *Robotic Systems - Applications, Control and Programming*, Dr. Ashish Dutta (Ed.), ISBN: 978-953-307-941-7, InTech, Available from: <http://www.intechopen.com/books/robotic-systems-applications-control-and-programming/optimization-and-synthesis-of-robot-fish-motion>

INTECH

open science | open minds

InTech Europe

University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

© 2012 The Author(s). Licensee IntechOpen. This is an open access article distributed under the terms of the [Creative Commons Attribution 3.0 License](#), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.