SYNTHESIS OF UNDERWATER ROBOT'S ADAPTIVE VELOCITY CONTROL SYSTEM

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Abstract: Self-tuning underwater robot's control system at the stepwise varies of its velocity is syntheses in this paper. This control system based on variable-structure system which working in sliding mode and allow to carry out self-tuning of a control system without directly measuring current parameters of the control object. Investigation of developed control system was carry out, which showed efficacy its control system. *Copyright © 2000 IFAC*

Keywords: self – tuning control, sliding mode, robust control, velocity control, nonlinear control system.

1. INTRODUCTION

Recently are applied to performance of various underwater works all underwater robots (UR) wider which should precisely move on complex space trajectories. The quality of performance of this task is determined by properties of UR's control systems. In turn UR represents complex nonlinear multi-connected dynamic object with uncertain and variable parameters, that considerably complicates synthesis of a control system, which should provide qualitative control of UR during its functioning.

Set of kinds of UR's control systems now is developed, among which the large interest suffices represent what are constructed on the basis of systems with variable structure and work in a sliding mode. The basic advantage of such systems is the independence of control process of dynamic properties of the control object. But the grave drawback to the systems is that they are synthesized for extreme operation condition and thus have a low speed of response in more favorable operation modes. In order to improve the efficiency of the system, adaptive control algorithms may be used which help increasing a speed of system response under simple operation conditions without loss of zero-overshoot mode. One of such algorithms is offered in works (Dyda and Filaretov, 1993; Filaretov and Lebedev, 1998). Its advantage consists that it allows to carry out self-tuning of a control system without direct measurement of the current parameters of control object, being based only on an indirect estimation of a condition of all system as a whole. However, in work (Filaretov and Lebedev, 1998) the synthesis of a UR's control system only for a mode of the approach to some object is considered, when the robot's velocity decreases from some meaning up to zero. If the program speed of UR's movement varies arbitrary, but is stepwise fashion, it is required to synthesize and to use the new control law.

2. PROBLEM DEFINITION

Thus, in given paper is put and solve the task of synthesis of such system with variable structure for control of UR's spatial motion, in which for maintenance of the maximal speed of course of a sliding mode the automatic self-tuning of parameters of regulators is entered at stepwise varies of program signal of this robot's velocity. Thus, by analogy to work (Filaretov and Lebedev, 1998), it is offered to use a method of decomposition, according to which all UR's control system is broken into a control system of its space situation, six independent control systems of velocity on each of six degrees of freedom and six adaptive thruster's control systems, ensuring moving on it to six degrees of freedom.

3. DYNAMIC BEFAVIOR OF UR

If to apply an adaptive UD thruster's control system, developed in (Filaretov et al., 1998), dynamics can be described these thruster by the differential equations of the first order with constant coefficients.

By executing the mentioned above decomposition, we shall consider a task of synthesis of a control system of one linear UR's degree of freedom. The dynamics of UR's movement on one degree of freedom can be described by the following system of the differential equations:

$$T_d \dot{\tau}_d + \tau_d = K_d u, \qquad (1)$$

$$m\dot{v} + F_v + f = \tau_d, \qquad (2)$$

where T_d is the time constant of the thruster; τ is the thrust delivered by the thruster; K_d is the gain factor; u is the control signal for the degree of freedom; m is the apparent mass of the robot; F_v is the viscosity friction force; v is the linear velocity for the degree of freedom; f is the external disturbances including hydrostatic and Coriolis forces. The equation (1) describes thruster's dynamics with a self-tuning regulator (Filaretov et al., 1998), and equation (2) – UR's dynamics of its linear movement on one of coordinates. For simplicity, in the equation (2) the linear dependence of force of viscous friction on UR's velocity is used. It has a place at rather small velocity of this movement (Kuafe, 1985). However, will below be shown, that the regulator synthesized for the specified linear dependence, can be successfully used and in that case, when this dependence is square-law. For UR's rotary degrees of freedom of the equation of dynamics will be similar (1) and (2), only equation (2) should describe not linear, and rotary movement.

4. SYNTHESIS OF ADAPTIVE VELOCITY CONTROLLER

It is convenient to present system (1), (2) as one differential equation of the second order:

$$T_d m\ddot{v} + (T_d d + m)\dot{v} + dv + f + T_d \dot{f} = K_d u. \qquad (3)$$

The equation (3) we shall copy concerning a error $e = v_d - v$ that the program signal v_d is step. After necessary transformations we shall receive:

$$\ddot{e} + \frac{T_d d + m}{T_d m}\dot{e} + \frac{d}{T_d m}e = \frac{d}{T_d m}v_d - \frac{K_d u + f + \dot{f}}{T_d m}. \qquad (4)$$

Using the equation (4), we shall solve a task of synthesis of a control system of one UR's linear degree of freedom. For other degrees of freedom this task is solved similarly.

As it already was specified earlier, in the given work the mode of step change of program UR's velocity is considered, in order to prevent occurrence of a static error it, as show researches, can be rather large and failure of a sliding mode as against the control law offered in work (Filaretov and Lebedev, 1998), it is necessary to use control of a kind:

$$u = k_{u1} \mid e \mid g(s) + k_{u2}\tau_d,$$

here k_{u1}, k_{u2} are the gain factors of the velocity controller, g(s) is the relay function:

$$g(s) = \begin{cases} 1, \text{ if } s > \Delta s \\ 1, \text{ if} > -\Delta s \text{ and } \dot{s} > 0 \\ -1, \text{ if } s < \Delta s \text{ and } \dot{s} < 0 \\ -1, \text{ if } s < -\Delta s, \end{cases}$$

Δs is the width of hysteresis loop, s is the value calculated from the formula:

$$s = \dot{e} + Ce,$$

here C is the slope of switching line of a variable-structure system on the phase plane. And it is necessary to observe the following condition:

$$k_{u1} \mid e \mid > \mid \frac{\dot{f}}{m} + (\frac{2d \mid v \mid}{m} - C)Ce \mid \frac{T_d}{K_d},$$

$$k_{u2} = 1 / K_d.$$

Equation (4) in view of control law (5) and ratio (6) can be copied as:

$$\ddot{e} + \frac{d}{m}\dot{e} + \frac{\dot{f}}{m} + \frac{K_d k_{u1}}{T_d m} g(s) \mid e \mid = 0.$$

The analysis of the equation (7) shows, that at use of the control law (5) in system completely there is no static error on velocity, therefore parameter of sliding will be real to provide affinity of a sliding line to degenerating trajectory. It makes possible application offered in works (Dyda and Filaretov, 1993; Filaretov and Lebedev, 1998) of algorithm of self-adjustment of regulators and for considered system.

As already it was marked above, the control law (5) was synthesized in the assumption that has a place linear dependence of force of viscous friction on UR's velocity, i.e. at small velocity of its movement. However, in many cases UR is gone with velocities, at which the square-law dependence of force of viscous friction on UR's velocity of movement is observed.

In this case, UR's movement dynamics on one linear degree of freedom will be described already by system of the equations of a kind:

$$T_d \dot{\tau}_d + \tau_d = K_d u, \qquad (8)$$

$$m\dot{v} + dv\,|\,v\,| + f = \tau_d. \qquad (9)$$

We shall present system (8), (9) as one differential equation of the second degree:

$$\ddot{e} + \frac{2T_d d\,|\,v_d - e\,| + m}{T_d m}\dot{e} + \frac{d\,|\,v_d - e\,|}{T_d m}e =$$

$$= \frac{d\,|\,v_d - e\,|}{T_d m}v_d - \frac{K_d}{T_d m}u + \frac{f + T_d \dot{f}}{T_d m}. \qquad (10)$$

By substituting in the equation (10) earlier entered the control law (5), in view of a ratio (6) we shall receive:

$$\ddot{e} + \frac{2d\,|\,v_d - e\,|}{m}\dot{e} + \frac{K_d k_{u1} g(s)}{T_d m}|\,e\,| + \frac{\dot{f}}{m} = 0. \quad (11)$$

As was specified earlier, primary factor adversely influencing self-tuning, is the static error arising during functioning of system. The analysis of the equation (11) shows, that the control (5) completely removes this error in system (8), (9). Therefore at use of the control law (5) in system (11) self-tuning of a controller also will be provided, that confirm results of the carried out mathematical modeling.

5. SIMULATION RESULTS

For research of the synthesized control system the modeling was carried out at the following parameters of control object and controllers: m_{min} = 700 kg; m_{max} = 1500 kg; d_{min} = 500 $N \cdot c^2 \cdot m^{-2}$; d_{max} = 1000 $N \cdot c^2 \cdot m^{-2}$; T_d = 0.1 c^{-1}; K_d = 50; k_{u1} = 100; k_{u2} = 0.02.

At modeling on an input of system the step signal equal vd = -1 m/c moved. The maximal value of parameter μ (Dyda and Filaretov, 1993; Filaretov and Lebedev, 1998), determined on the formula:

$$\mu = \frac{t_{u+}}{t_{u+} + t_{u-}}$$

where t_{u+} - time of movement of system on a piece hyperbola near to a line of sliding, t_{u-} - the time of movement of system on a parabola near to a line of sliding, and estimating affinity of a line of sliding to degenerated trajectory of system at the current unknown parameters of control object, was accepted equal μ_{max} = 0,9. The modeling was carried out that force of viscous friction and UR's velocity are connected by square-law dependence, i.e. the system (8), (9) was used.

On fig.1 the change of parameter μ is shown at self-tuning of a controller. The curves 1 and 2 correspond to systems with parameters $d = d_{min}$, $m = m_{min}$ and $d = d_{max}$, $m = m_{max}$, accordingly. From this figure it is visible, that at self-tuning irrespective of control object's parameters, parameter μ invariable achieves value μ_{max}, i.e. the system most close approaches to degenerated trajectory and has the greatest possible meaning C, and consequently, and speed of movement in a sliding mode. It is shown in a fig. 2 and fig. 3.

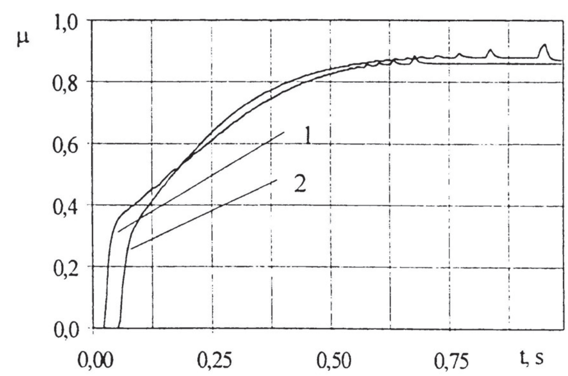

Fig. 1. Time variation of parameter μ during of self – tuning process

In a fig. 2 the process of change of coefficient C, describing an inclination of a line of sliding of system with variable structure is shown. The curves 1 and 2 correspond to systems with parameters $d = d_{min}$, $m = m_{min}$ and $d = d_{max}$, $m = m_{max}$, accordingly. From this figure it is visible, that the system is adjusted on various values C at various parameters of control object ($C \approx 8$ in first and $C \approx 5$ in the second cases), thus parameter of sliding achieves the same beforehand given maximal value.

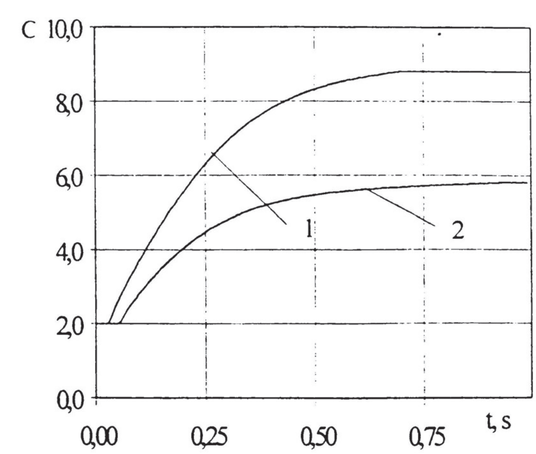

Fig. 2. Time variation of slope C during of self-tuning process

In a fig. 3 the transitive process of error in a researched degree of freedom is shown. The curves 1 and 2 correspond to systems with parameters $d = d_{min}$, $m = m_{min}$ and $d = d_{max}$, $m = m_{max}$, accordingly. From this figure it is visible, that use of self-adjustment can increase speed of course of a sliding mode, that will allow essentially to increase efficiency of systems with variable structure at control of UR.

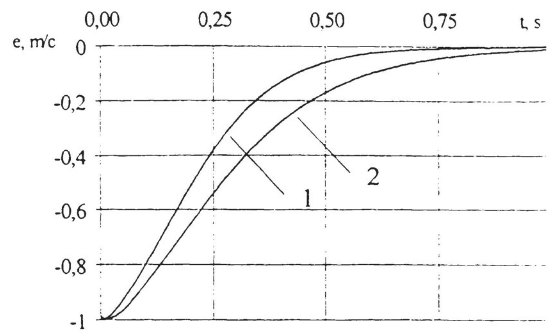

Fig. 3. Transitive process of an error at use of self-tuning controller

CONCLUSIONS

Thus, in article the new control law of the separate channel of UR's velocity was developed which allows to apply self-tuning at step entrance influences. The mathematical modeling of the received control system was carried out which has confirmed serviceability and high efficiency of the given control law both at linear, and at square-law dependence of viscous friction's factor on UR's velocity in water environment.

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