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Development of Algorithms for Approaching and Docking Underwater Vehicle with Underwater Station

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Abstract. Underwater vehicles (UV) are widely spread nowadays. Their efficient application requires accompanying base ships or net of stations for technical servicing. Fast and energy-efficient docking is one of the key requirements for trouble-free operation. In this paper authors describe the research and development of algorithms for UV control system that allows docking with underwater station. The process is divided in two steps: moving to docking zone and vehicle positioning of station. First task includes development of path regulator. The proposed one features separation of control channels for simple adjustment and gives best results when multicoupling influence is low. Second task was solved on the basis of UV mathematical model. Developed control values were tested in simulation and proved themselves to be efficient. Authors give results of coordinate changes, control force modifications and deviation of velocity and orientation angles from the required values.

1 Introduction

Underwater vehicles need periodical service and maintenance. This is usually done via ship with special equipment. In this case UV gets inside the ship through the bay in the bottom. Also there are projects where ship is substituted by submarine or underwater station. For such operations, vehicle needs to safely dock with ship or station. To solve docking task it is necessary to develop three algorithms: general control algorithm, moving algorithm and vehicle position algorithm.

2 Development of General Control Algorithm for UV Docking with Underwater Station

Analysis of existing docking systems [1-3] allowed to identify two steps of UV docking with underwater station (see Fig. 1):

1. Moving UV to docking zone with no requirements to orientation and velocity.
2. Positioning UV to station with account to orientation and velocity requirements.

Thus, general docking algorithm could be described by the following. Let UV be in arbitrary point As. Control system should move UV to station with coordinates Ad. According to orientation of the station, docking should be performed along the line L2. First step for UV is to get to point A1, that belongs to line L2. Next step is to move along the line L2 to the point A2, that is situated close to station. In A2 point control system should start positioning procedure that will result in getting UV ready to dock including correct positioning.

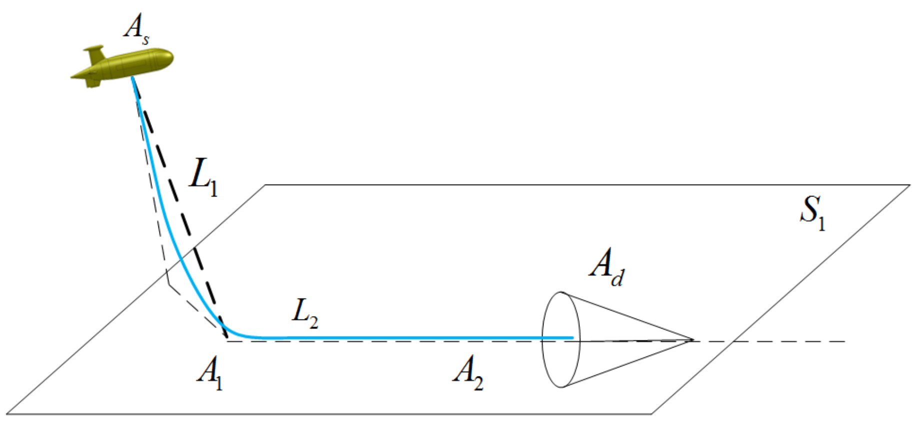

Figure 1. Path of UV according of general docking algorithm

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3 Moving UV to Docking Zone

To move UV to docking station area, it is necessary to create path regulator. Regulator should base on laws of position-path control, developed by V. Pshikhopov [4,5] but with regard to peculiarities of controlled object [6]. As it was shown earlier [6], mathematical model of UV in matrix form is:

$$\dot{\bar{Y}} = \Sigma(\bar{\theta}, \bar{X}) = \Sigma\begin{pmatrix}\Sigma_P(\bar{\theta}, \bar{X}) \\ \Sigma_\theta(\bar{\theta}, \bar{X})\end{pmatrix}$$

$$\tilde{M}\dot{\bar{X}} = \left[\bar{F}_d(\bar{P}_{\Pi\Gamma}, \bar{V}, \bar{\omega}) + \bar{F}_u(\bar{\delta}) + \bar{F}_v(G, A\ \ , R\ \ )\right] \quad (1)$$

$$T_{uyuy}\frac{d\bar{\delta}}{dt} + \bar{\delta} = \bar{\Psi}\ \ (\bar{\delta}, \bar{U})$$

where $T_{\text{иу}}$ and $\bar{\Psi}(\bar{\delta}, \bar{U})$ – diagonal matrix of time constants ИУ and vector of non-linear functions of right side of equations of actuation devices; $\bar{\delta}$ – vector of control actions for UV, formed by actuation devices; $\bar{U}$ – control vector, formed by UV control system; где x – m-vector of internal coordinates; M – $(m\times m)$-matrix of UV mass and inertial parameters; $F_u(x, Y, \delta, l)$ – m-vector of control forces and force moments; $F_d(x, Y, l)$ – m-vector of UV non-linear dynamics elements; F_v – m-vector of immeasurable external disturbances; $Y = (P, \Theta)^T$ – n-vector of position P and orientation Θ in body axis system; $n\leq 6$; $\sum(\Theta, x)$ – n-vector of kinematic links; $\sum_p(\Theta, x)$ – vector of linear velocities in body axis system; $\sum_\Theta(\Theta, x)$ – vector of angular velocities in body axis system.

For the abovementioned model (1) the closed-loop system equation will be:

$$\ddot{\Psi}_{tr} + T_1\dot{\Psi}_{tr} + T_2\Psi = 0$$
$$\dot{\Psi}_{ck} + T_3\Psi_{ck} = 0 \quad (2)$$

$$\Psi_{tr} = A_1P + A_2\Theta + A_3$$
$$\Psi_{ck} = A_4V + A_5 \quad (3)$$

where:

$$A_1 = \begin{bmatrix}0 & 0 & 0\\ 0 & k_y & 0\end{bmatrix}, A_2 = \begin{bmatrix}1 & 0 & 0\\ 0 & 1 & 0\end{bmatrix}, A_3 = \begin{bmatrix}-\varphi^* \\ -k_{y\text{з}}H\end{bmatrix}$$

$$P = \begin{bmatrix}x\\ y\\ z\end{bmatrix}, \Theta = \begin{bmatrix}\varphi\\ \psi\\ \gamma\end{bmatrix}, A_3 = \begin{bmatrix}\phi_{\text{з}}\\ -k_{y\text{з}}H\end{bmatrix},$$

$$\varphi = tg(z - z^* / x - x^*) - tg(V_z / V_x),$$

$$\mathrm{A}_4 = \begin{bmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 1\end{bmatrix}, A_5 = \begin{bmatrix}V_x - V_x^*\\ V_y - V_y^*\\ V_z - V_z^*\end{bmatrix}.$$

Vector $\left|V_x^* V_y^* V_z^*\right|^T$ – is a vector for setting required UV velocity. It should be noted that $V_y^* = V_z^* = 0$ due to specificity of object [6].

Substitution of (3) into equation (2) with regard to UV mathematical model (1) gives the following expression for control:

$$F_u = -M\begin{bmatrix}A_4 & 0\\ A_1A' & A_2A_w\end{bmatrix}\begin{bmatrix}T_3\Psi_{cr}\\ A_1\dot{A}'V + A_2\dot{A}_wW + T_2\Psi_{tr} + T_1\dot{\Psi}_{tr}\end{bmatrix}$$
(4)

Proposed approach to path regulator synthesis differs in separation of control channels thus simplifying regulator adjustment. Movement is decomposed in horizontal and vertical planes. This is usual logic [3] of mobile object control, so it simplifies implementation of the algorithm into existing systems. It stands to mention, that separation of control channels and movement decomposition results in loosing of proposed algorithms to position-path ones in case of complex movement where multicoupling influence is high.

4 Positioning UV to Station

On the basis of mathematical model (1) lets set a requirement for changing of UV coordinate:

$$\Psi_{tr} = A_1Y + A_2 \quad (5)$$

Behavior of closed-loop system will be:

$$\dot{\Psi} + T_2\Psi = 0, \quad (6)$$

where $\Psi = \dot{\Psi}_{tr} + T_1\Psi_{tr} = A_1RX + T_1(A_1Y + A_0)$;

$$A_0 = \begin{bmatrix}-x_d\\ -y_d\\ -z_d\\ -\phi_d\\ \psi_d\end{bmatrix} \quad (7)$$

Substitution of (5) into equation (6) with regard to UV mathematical model (1) gives the following control value:

$$F_u = -F_d - MR^{-1}A_1^{-1}(A_1\dot{R}X + T_1A_1RX + T_2\Psi), \quad (8)$$

5 Computer Simulation of Proposed Algorithms

Computer simulation was also performed for algorithms (4) – moving UV to underwater station zone with no requirements to orientation and velocity. Results are shown on Fig. 2-4.

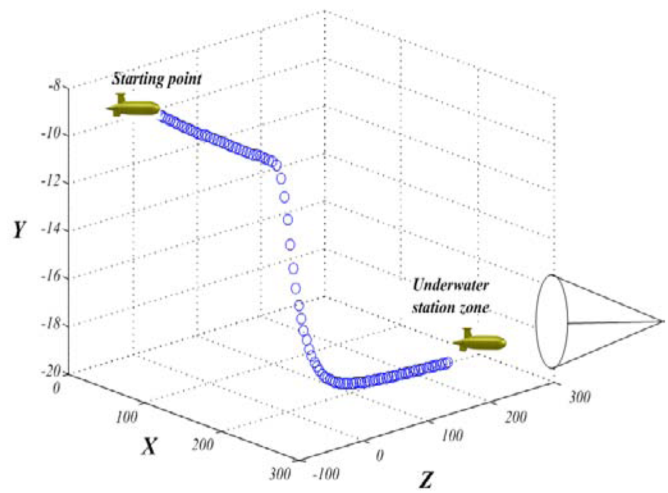

Figure 2. Path of UV motion to underwater station zone

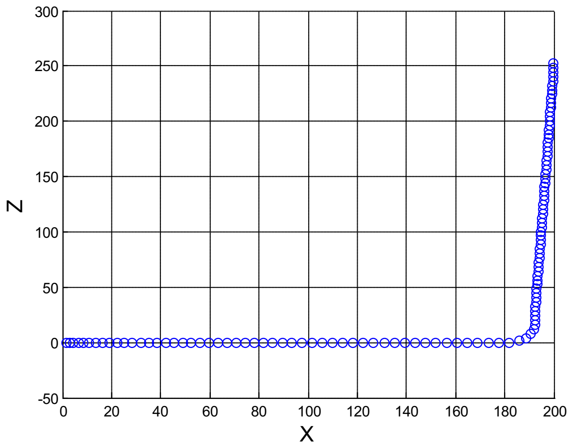

Figure 3. Path of UV motion to underwater station zone (top view)

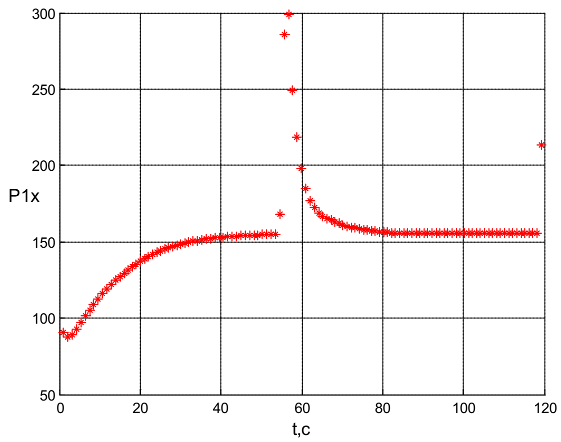

Figure 4. Change of control force P_{1x}

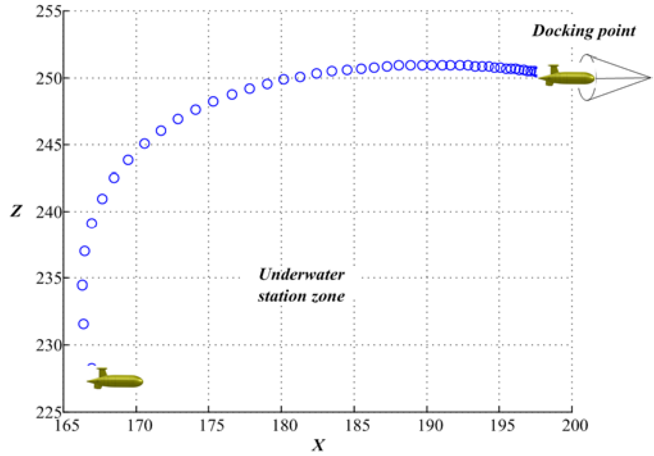

Figure 5. UV motion path when docking

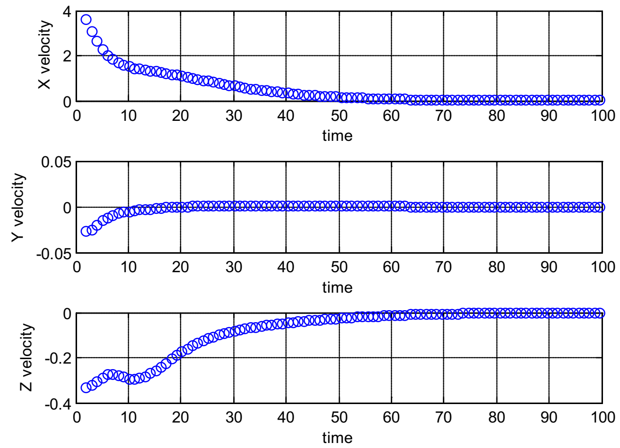

Figure 6. Deviation of velocity from the required value while docking

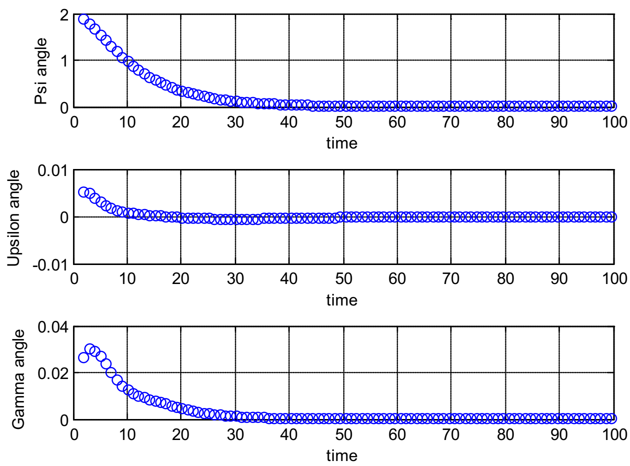

Figure 7. Deviation of orientation angles from the required value while docking

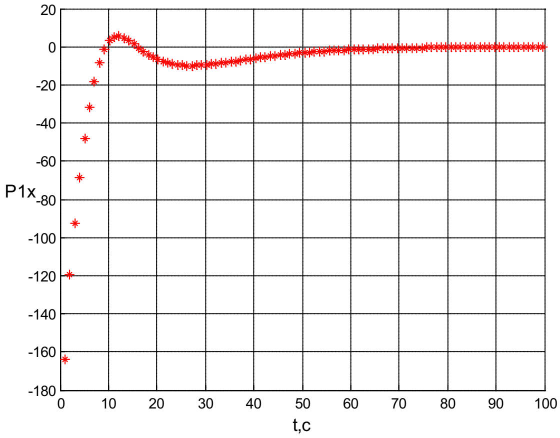

Figure 8. Change of control force P_{1x}

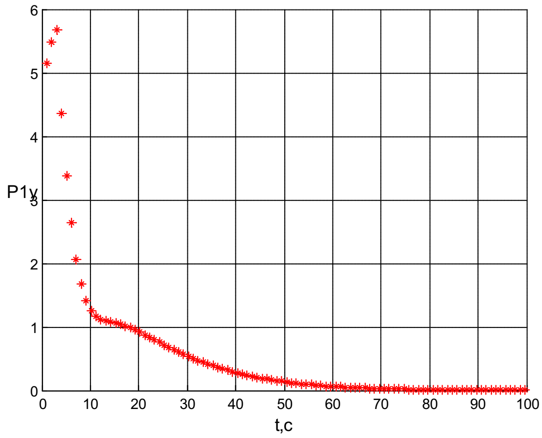

Figure 9. Change of control force P_{1y}

6 Conclusion

Paper presents UV control algorithms for approaching the underwater station and docking with it. The task is important as underwater vehicles periodically need service and maintenance. Developed algorithms handle two sub processes: moving and positioning. Moving from point to station was accomplished with path regulator, based on Pshikhopov's position path control theory, but with regard to peculiarities of controlled object. New control simplifies implementation of the algorithm into existing systems and performs its best when multicoupling influence is not high. Positioning control value was also given. Developed algorithms were tested in simulator where underwater vehicle successfully docked the station. Review of experiment results include vehicle path in XYZ coordinates, forces and angles of thrusts. The analysis of deviation of UV actual speed and position from the required one showed high efficiency of developed control. Next task is to define a criterion for switching between the algorithms (4) and (8).

Acknowledgements

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