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SMALL ROV TO DETECTION AND IDENTIFICATION OF DANGEROUS UNDERWATER OBJECTS

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Abstract: A small unmanned underwater vehicle (UUV) to inspection of an undersea space is presented in the paper. Its behavior is controlled by a trained pilot. Correct detection and identification of targets depends on vehicle’s precise displacement along a predefined route. Nowadays, the UUVs are equipped with an automatic control system to execute some basic maneuvers without constant human interventions. Hence, in the paper, an autopilot assuring an appropriate vehicle’s movement is described. Selected results of computer simulations illustrating a quality of the underwater mission are inserted.

Keywords: - underwater vehile, autopilot, modelling, simulation.

1. INTRODUCTION

A described system to detection and identification of dangerous objects located in the underwater space is a floating platform designed and built basis on a special kind of the UUV, called remotely operated vehicle (ROV). It is equipped with a comprehensive set of devices and sensors to achieve a high quality of operational work. The set mounted on the vehicle’s body consists of: lamps and TV cameras, a scanning sonar, an inertial navigation unit, a doppler velocity log, a transponder/responder for hydroacoustic navigation and a manipulator (see Fig. 1).

The ROV operates in crab-wise manner in four degrees of freedom (DOF) with small roll and pitch angles that can be neglected during normal operations. Its behaviour is controlled by a trained pilot located on a board of the mother-ship or an offshore structure. A typical mission of detection and identification of dangerous objects consists of two phase. The first one, called a transition phase, is a displacement to a target area from a launch point. During the second phase, called detection phase, a searched object is found by the pilot. A pilot’s work is supported by a computer which provides required information, integrating sonar and cameras images with data from a navigation system and other sensors (see Fig. 2 and Fig. 3).

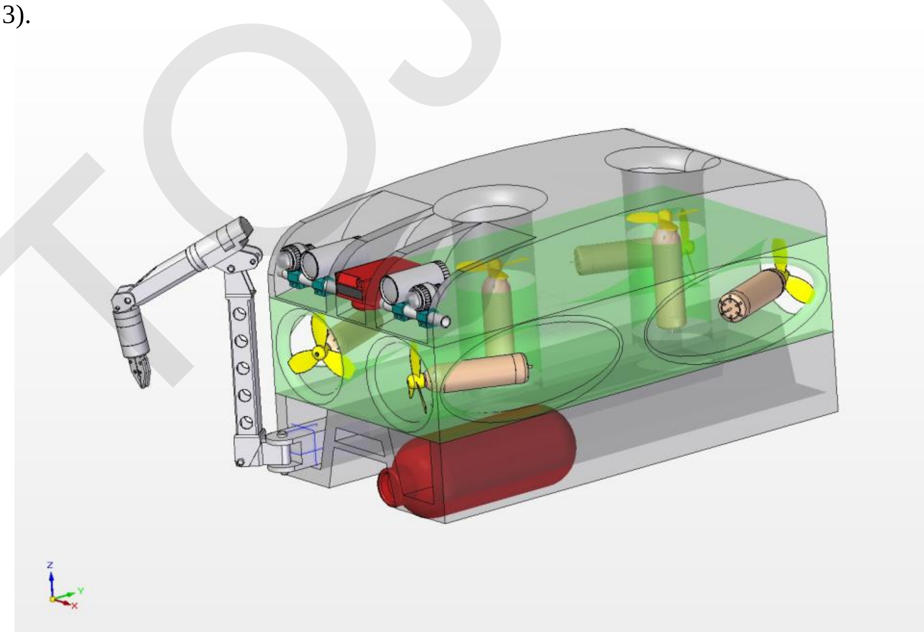


Figure 1. Virtual vision of ROV.

To execute some basic manoeuvres without a constant pilot’s supervision, contemporary ROVs are often and often equipped with an automatic control system. An interesting review of classical and modern techniques useful to steering of the UUVs vehicles has been provided in Craven *et al.*, 1998. Automatic control of such underwater apparatus is a difficult problem due to their nonlinear dynamics. Moreover, the dynamics can change according to the alteration of configuration to be suited to the mission. Hence, an autopilot, responsible for keeping desired positions and orientations of the ROV during the transition phase, should be flexible and self-adapting to varying motion conditions.

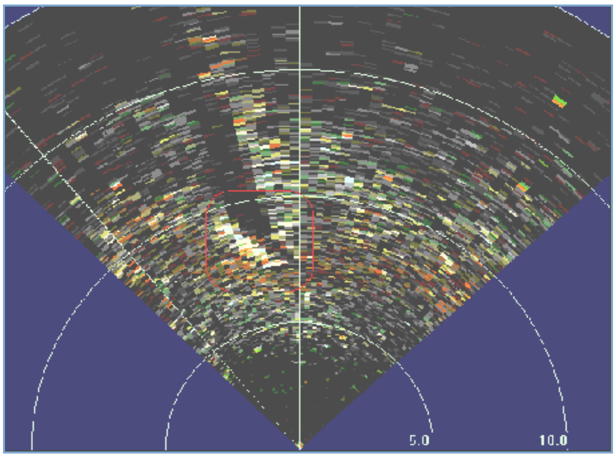


Figure 2. Screen display with sonar image.

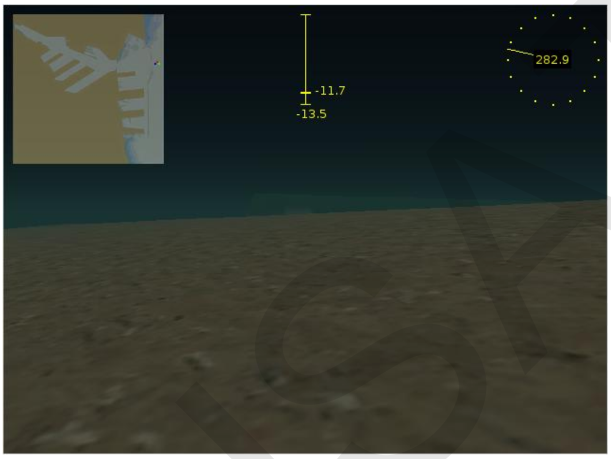


Figure 3. Screen display with TV image and navigation data.

2. EQUATIONS OF MOTION

A general motion of the underwater vehicle of six DOFs describes the following vectors (Fossen, 1994; Fossen, 2011) :

$$\begin{aligned} \boldsymbol{\eta} &= [x, y, z, \phi, \theta, \psi]^T \\ \mathbf{v} &= [u, v, w, p, q, r]^T \\ \boldsymbol{\tau} &= [X, Y, Z, K, M, N]^T \end{aligned} \qquad (1)$$

where:

$\boldsymbol{\eta}$	–	position and orientation vector in the inertial frame;
x, y, z	–	coordinates of position;
ϕ, θ, ψ	–	coordinates of orientation (Euler angles);
$\mathbf{v}$	–	linear and angular velocity vector with coordinates in the body-fixed frame;
u, v, w	–	linear velocities along longitudinal, transversal and vertical axes;
p, q, r	–	angular velocities about longitudinal, transversal and vertical axes;
$\boldsymbol{\tau}$	–	vector of forces and moments acting on the vehicle in the body-fixed frame;
X, Y, Z	–	forces along longitudinal, transversal and vertical axes;
K, M, N	–	moments about longitudinal, transversal and vertical axes.

Nonlinear dynamical and kinematical equations of motion in the body-fixed frame can be expressed as:

$$\begin{aligned} \mathbf{M}\dot{\mathbf{v}} + \mathbf{C}(\mathbf{v})\mathbf{v} + \mathbf{D}(\mathbf{v})\mathbf{v} + \mathbf{g}(\boldsymbol{\eta}) &= \boldsymbol{\tau} \\ \dot{\boldsymbol{\eta}} &= \mathbf{J}(\boldsymbol{\eta})\mathbf{v} \end{aligned} \qquad (2)$$

where:

$\mathbf{M}$	–	inertia matrix (including added mass);
$\mathbf{C}(\mathbf{v})$	–	matrix of Coriolis and centripetal terms (including added mass);
$\mathbf{D}(\mathbf{v})$	–	hydrodynamic damping and lift matrix;
$\mathbf{g}(\boldsymbol{\eta})$	–	vector of gravitational forces and moments;
$\mathbf{J}(\boldsymbol{\eta})$	–	velocity transformation matrix between the body fixed and the inertial frames.

3. ADAPTIVE ALGORITHM OF CONTROL

The algorithm of control worked out basis on a simplified ROV model proposed in Fossen, 1994:

$$\mathbf{M}_d \dot{\mathbf{v}} + \mathbf{D}_d(\mathbf{v})\mathbf{v} = \boldsymbol{\tau} \tag{3}$$

where all kinematics and dynamics cross-coupling terms are neglected, so $\mathbf{M}_d$ and $\mathbf{D}_d(\mathbf{v})$ are diagonal matrices. Uncertainties in the above model are compensated by a control system.

The expression (3) for motion in four DOFs, (surge, sway, heave and yaw), takes a form (Garus, 2007):

$$\begin{aligned} m_X \dot{u} + d_X |u| u &= \tau_X \\ m_Y \dot{v} + d_Y |v| v &= \tau_Y \\ m_Z \dot{w} + d_Z |w| w &= \tau_Z \\ m_N \dot{r} + d_N |r| r &= \tau_N \end{aligned} \tag{4}$$

Define the following vectors $\boldsymbol{\tau} = [\tau_X, \tau_Y, \tau_Z, \tau_N]^T$ and $\mathbf{p} = [m_X, d_X, m_Y, d_Y, m_Z, d_Z, m_N, d_N]^T$ the expression (4) can be written as:

$$\boldsymbol{\tau} = \mathbf{Y}(\mathbf{v}, \dot{\mathbf{v}})\mathbf{p} \tag{5}$$

where $\mathbf{Y}(\mathbf{v}, \dot{\mathbf{v}})$ is a known matrix of measured signals, usually referred as the regressor matrix, (for more details see Spong *et al.*, 1998), and has the form:

$$\mathbf{Y}(\mathbf{v}, \dot{\mathbf{v}}) = \begin{bmatrix} \dot{u} & |u|u & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \dot{v} & |v|v & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \dot{w} & |w|w & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \dot{r} & |r|r \end{bmatrix} \tag{6}$$

A structure of the proposed control system is depicted in Fig. 4.

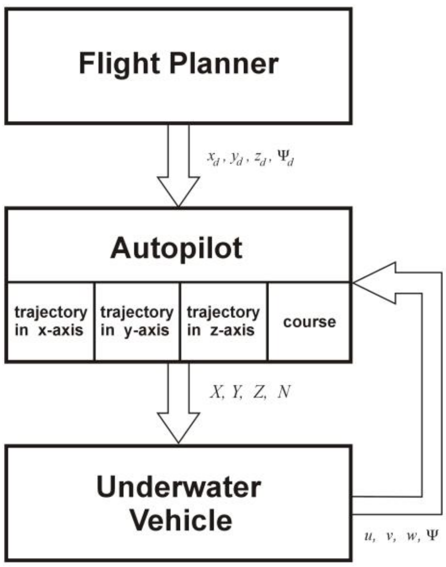


Figure 4. Block diagram showing structure of control system.

4. SIMULATION STUDY

Numerical simulations have been made to confirm validity of the proposed control algorithm under the following assumptions:

1. the ROV can move with varying linear velocities *u*, *v*, *w* and angular velocity *r*;
2. its velocities *u*, *v*, *w*, *r* and coordinates of position *x*, *y*, *z* and heading ψ are measurable;
3. the desired route is given by means of set of way-points $\{(x_{di}, y_{di}, z_{di})\}$;
4. segments of the predefined route between two successive way-points are defined as smooth and bounded curves;
5. the command signal $\boldsymbol{\tau}$ consists of four components: $\tau_1 = \tau_X = X$, $\tau_2 = \tau_Y = Y$, $\tau_3 = \tau_Z = Z$ and $\tau_4 = \tau_N = N$ calculated from the control law (5).

A regulation problem has been examined under interaction of environmental disturbances, i.e. a sea current. To simulate such influence on vehicle's motion its velocity V_c was assumed to be slowly varying and having a fixed direction. For computer simulations the disturbance was calculated by using the 1st order Gauss-Markov process (Song *et al.*, 2003):

$$\dot{V}_c + \mu V_c = \omega \tag{11}$$

where ω is a Gaussian white noise, $\mu \geq 0$ is a constant and $0 \leq V_c(t) \leq V_{c\max}$.

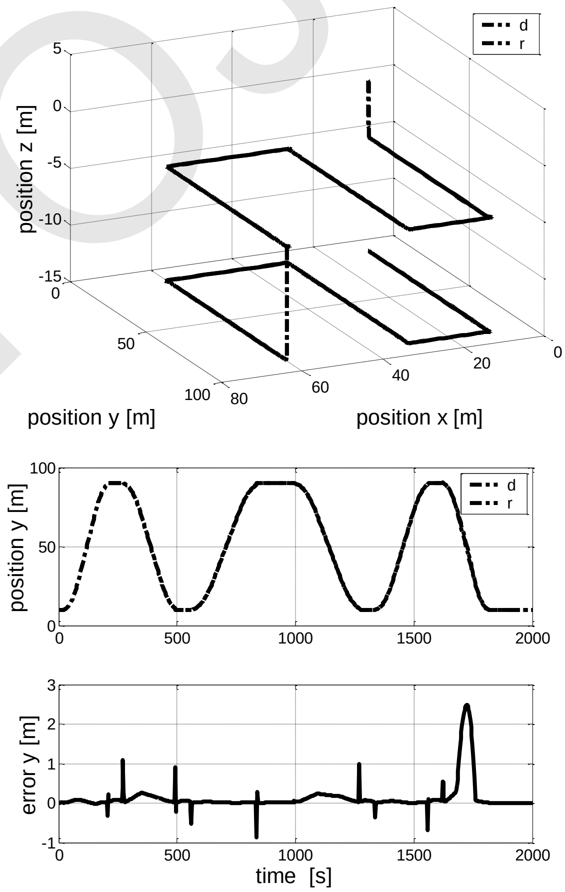
Some results of simulations are depicted in Fig. 5. The case study showed that the proposed adaptive algorithm enhanced good quality of movement along the desired route.

5. CONCLUSIONS

This paper has described the using of the adaptive algorithm for control of positions and orientations of the remotely operated vehicle designed to detection and recognition of dangerous targets in the underwater space.

It can be concluded from the obtained results that the proposed approach provides the automatic control system being robust and having good performance.

Another advantage of the discussed control system is its flexibility with regard to the change of dynamic properties of the ROV according to the alteration of configuration to be suited to the mission.



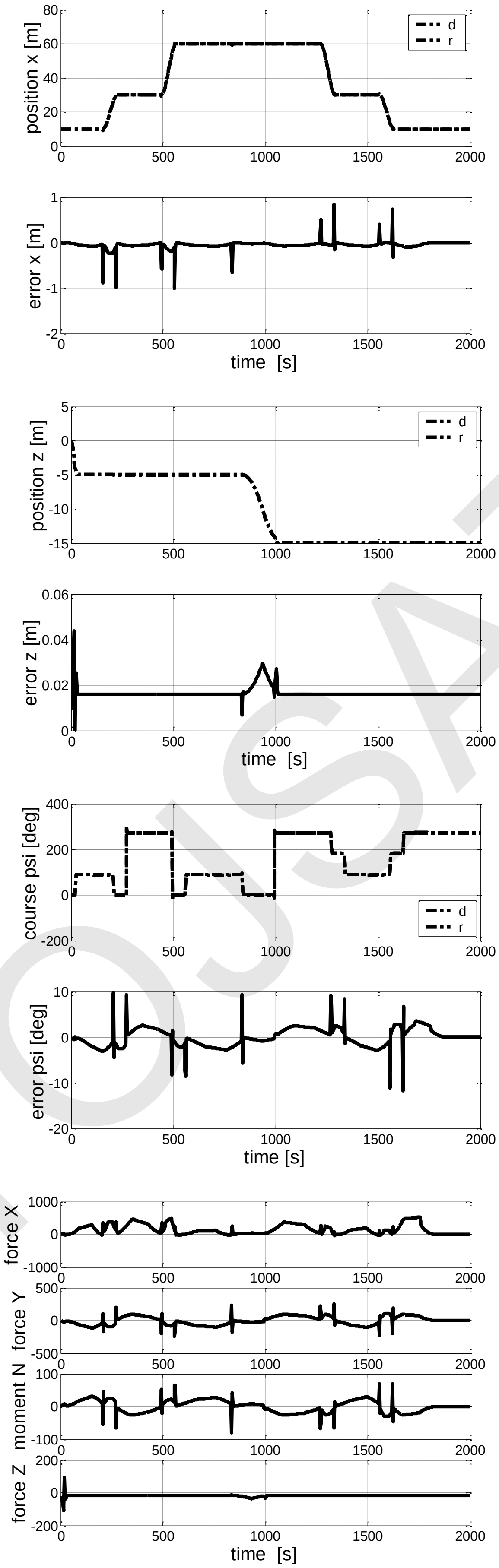


Figure 5. Results of track-keeping control: desired (d) and real (r) path in 3D space (upper plot), *x*-, *y*-, *z*-position and error of position (2nd ÷ 4th plots), course and error of course (5th plot), commands (low plot).

6. ACKNOWLEDGMENT

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