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IMPLEMENTATION OF UNDERWATER GLIDER AND IDENTIFICATION OF ITS PARAMETERS

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Graphical abstract

Abstract

This paper is part of a series that describe the development and setup of intelligent underwater vehicle. Here we focus on the implementation tests for the identification of the actuating device parameters. An energy efficient type of glider is chosen with its block diagram presented. The assembled model is placed in a mini pool for movement tests with the objective of setting up the motors and pump. When put in neutral, its immersion and surfacing position show that there is interdependent between pump operation time, ballast bag maze, displacement of weight and glider attitude angle. These dependencies are described by linear equations and coefficients which are then identified.

Keywords: Glider; underwater vehicle; control system; identification of parameters

1.0 INTRODUCTION

Over recent years, the explorations of the underwater world are greatly boosted by robots. Either semi or fully automatic, these vehicles gather data from points that are not reachable by men. Built for high and low temperature, great pressure and other extreme conditions, they are limited only by the energy source and control algorithms. Problems of their improvement draw the attention of many scientists. In order to increase autonomous operating time and reduce the difficulties faced by the underwater vehicles (UV), some researchers had developed a new UV control system [1, 2], including mathematical models, path planning, movement and docking methods [3, 4, 5]. The system successfully passed the simulator tests for above water [6, 7]. Now the task is to conduct underwater tests, and make a vehicle for it. One of the popular types of underwater vehicles is a glider that allows to extend autonomous mission duration due to special, energy efficient design, compared to other vehicle types [8]. The main feature of the glider is its ability to change buoyancy and center of gravity during operation. This provides necessary forces for glider movement underwater. In this paper we will describe the glider itself and conduct experiments for identification of its parameters.

2.0 DEVELOPMENT OF THE GLIDER

From the bird's eye view the glider consists of a hull with sensors and actuating devices and control system in which motion control, path planning, mathematical model, etc. are implemented. To form the solid understanding of the glider, it is foreground and background, we will briefly describe the control system before coming to the hardware.

2.1 Intelligent Control System

The structure of the intellectual control system of AUV is shown in Figure 1. One of its core components is intelligent planning subsystem based on Bionic neural network [1]. It is designed to safely navigate the glider to the required point on the surface or underwater by automatic generation of the path that allows to bypass stationary and mobile obstacles at a required speed.

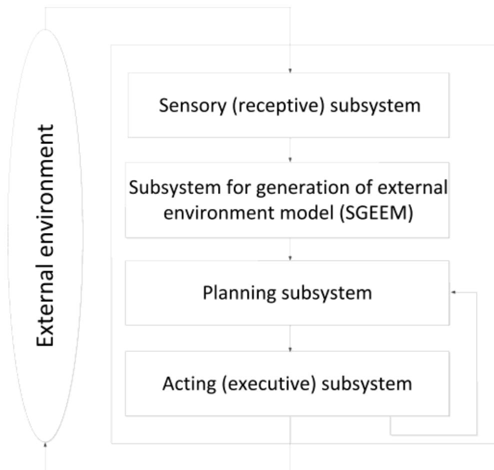

Figure 1 Structure of intellectual control system of AUV

Following the course set by the planner, the glider constantly perceives current information regarding the state of the environment using on-board sonar (OBS). On the basis of this information, intelligent control system (ICS) constructs a three-dimensional model of the environment. If there is an obstacle in front of the glider, ICS transforms its location into the states of the corresponding elements of three-dimensional neural network. Excitation waves in neural network generate a set of options on how to move around the obstacle, and Hopfield network, connected to it, chooses the best way to avoid the obstacle. After the completion of the avoiding maneuver, the glider returns to its given course.

Sensory subsystem is a board OBS that reads environment data. SGEEM provides conversion of the data into the internal model. The planning subsystem is implemented in the form of a multilayered neural network shown in Figure 2.

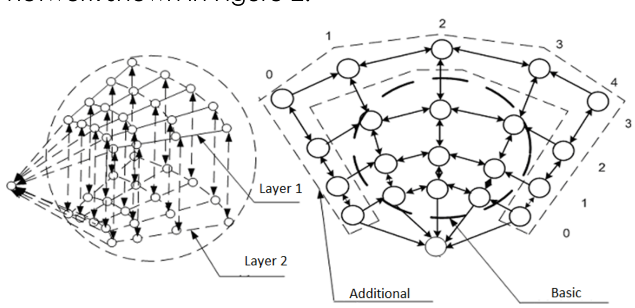

Figure 2 Structure of a multi-layered control neural network

The right side of the figure shows the relations of the neurons at the horizontal layer, and the left side show the connection of the neurons between the different layers. Each main neuron has a correspondent topological element in external environment through its model. If, at some moment in time, this area is available for movement, SGEEM switches on the corresponding neuron into commutation with the closest neurons. If this area is marked as blocked, the neuron blocks it, and if the area is finished (goal) the neuron generates an excitation wave. If the goal point is beyond the perception area, an additional neuron, pointing in the direction of the goal, switches on. In Figure 2, Hopfield neural network is marked by circles, connected to all neurons in the network. This network is responsible for choosing the glider direction in every elementary step of motion.

The main operation principle of the 3D neural network is as follows:

1. Determine the address of the cell with the goals. This cell has a goal bite that extends to the left, right, forward, backward (inside the layer) and up and down (between the layers). Then elements, corresponding to the blocked areas of the environment (areas with obstacles) are cleared.
2. These actions continue until the first bite appears in the vertical layer, connected to the Hopfield neural network.
3. This bite is marked by the Hopfield neural network that determines the required horizontal and vertical deviation angles of the glider.
4. After the elementary step is finished, arrays of goals and obstacles are updated and the algorithm starts over form step 1.

These steps continue until the arrival of the glider to the goal point of the external environment.

Motion Control Level is based on the AUV position-trajectory control method [5, 11, 12]. Among the advantages of such approach is independence of estimator from controller that provides high and stable performance [13].

2.2 Mathematical Model

The mathematical model of the glider is used by the control system for the generation of the precise path around the obstacles and to generate reaction on the external disturbances. Coordinate systems describing the mathematical model of the glider are shown in Figure 3. The terrestrial system $O^0X^0Y^0Z^0$ is a fixed external coordinate system. The mobile system OXYZ is referenced in the point of application of the buoyancy force acting on the underwater vehicle.

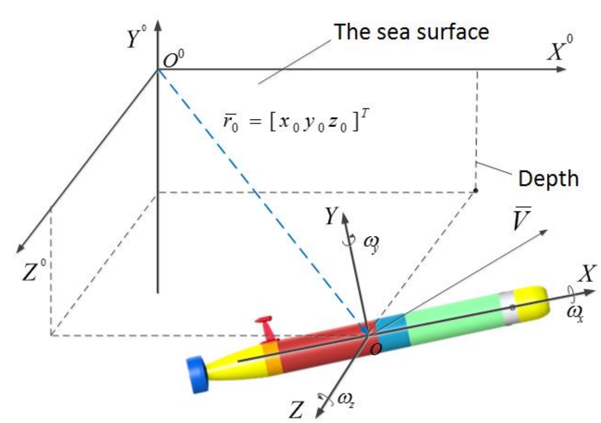

Figure 3 Coordinate systems K(OX^0 Y^0 Z^0) and K(OX Y Z)

Model itself is based on the solid body equations and can be presented in the vector-matrix form:

$$\dot{Y} = \Sigma(\overline{\Theta}, \bar{X}) = \Sigma\begin{pmatrix}\Sigma_P(\overline{\Theta}, \bar{X})\\ \Sigma_\Theta(\overline{\Theta}, \bar{X})\end{pmatrix} \tag{1}$$

$$\tilde{M}\dot{\bar{X}} = \bar{F}_d(\bar{P}, \bar{V}, \bar{\omega}) + \bar{F}_u(\bar{\delta}) + \bar{F}_v(G, A_p, R_g) \tag{2}$$

$$T_{uy}\frac{d\bar{\delta}}{dt} + \bar{\delta} = \overline{\Psi}_{uy}(\bar{\delta}, \bar{U}) \tag{3}$$

where T_{uy} is the diagonal matrix of time constants of the actuating devices (AD); $\overline{\Psi}_{uy}(\bar{\delta}, \bar{U})$ is the vector of nonlinear functions of the AD equation right-hand sides; $\bar{\delta}$ is the vector of the control actions for UV elements, formed by AD; $\bar{U}$ is the control vector, formed by UV control system; *m* is the vector of internal coordinates (state coordinates); *M* (*m*×*m*) is the matrix of mass and inertia parameters that include mass, moment of inertia, added masses of underwater vehicle; $F_u(x, Y, \delta, l)$ is the *m*-vector of control forces and moments and *l* is the vector of construction parameters; $F_d(x, Y, l)$ is the *m*-vector of nonlinear elements of UV dynamics; F_v is the *m*-vector of measureable and non-measureable external disturbances; $Y = (P, \Theta)^T$ is the *n*-vector of position *P* and orientation *Θ* (output coordinates) in body coordinate system in respect of reference coordinate system; $\Sigma(\Theta, x)$ is the *n*-vector of kinematic links; $\Sigma_p(\Theta, x)$ is the vector of linear velocities in in body coordinate system in respect of reference coordinate system; $\Sigma_\Theta(\Theta, x)$ is the vector of angular velocities in in body coordinate system in respect of reference coordinate system.

More details regarding the mathematical model can be found in paper [4].

2.3 Hull and Its Components

The developed hardware was intended for research of UV movement, identification of mathematical model parameters, verification of the proposed algorithms for glider control and control methods for underwater vehicles.

The glider has the following functions:

- movement in automatic mode [5],
- remote controlled movement [6].

Structure and equipment layout were proposed aiming on the minimization of weight of the glider (see Figure 4).

Important module in underwater glider is buoyancy change mechanism (BCM). BCM is intended for redistribution of the vehicle internal volume and mass and allows the control of glider buoyancy. According to buoyancy sign, this provides the glider immersion or surfacing [9, 10].

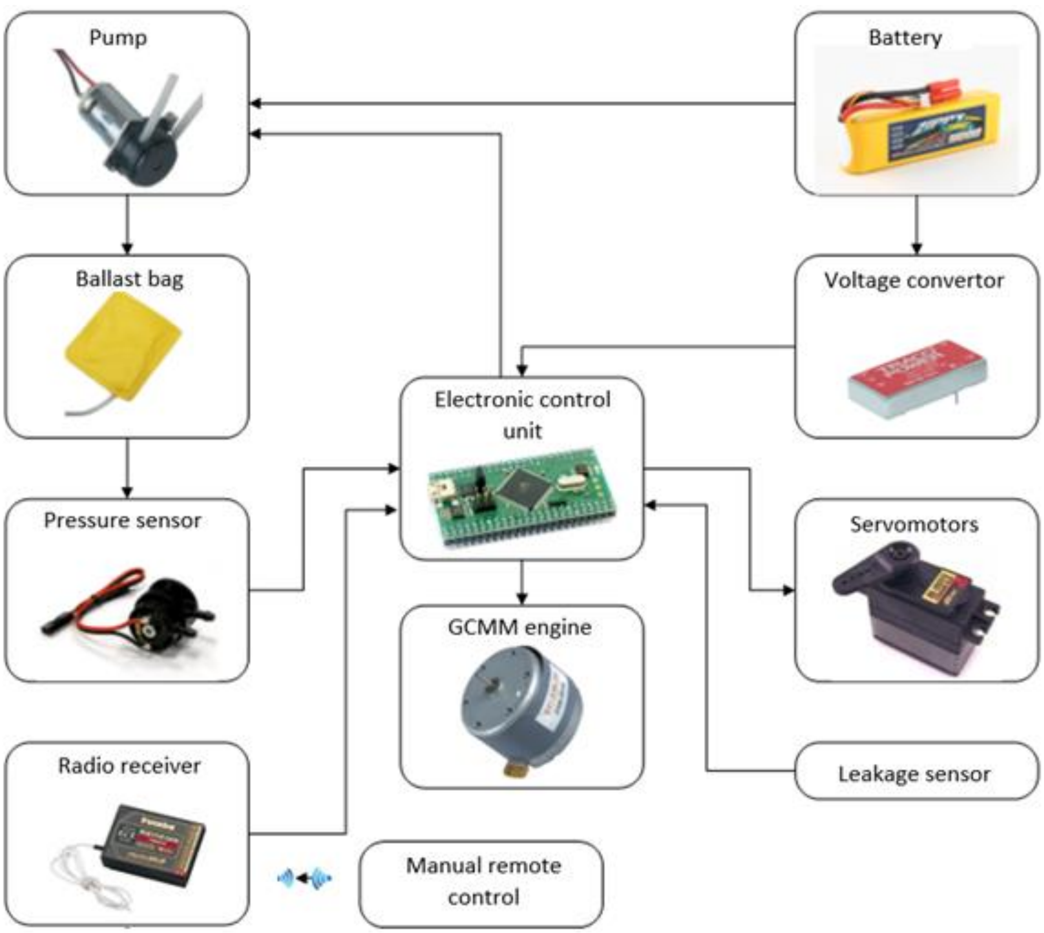

Figure 4 Block diagram of the glider

In this paper, BCM consists of electrical pump and ballast bag. The pump operates in two directions: injection and ejection of water into and out of the bag. Ballast is the seawater that comes to the pump through the leak-proof path. The amount of water in the bag is controlled via the calibrated pressure sensor.

Gravity center modification mechanism (GCMM) is where the electric motor rotates the shaft with the weight (battery on the platform) clockwise and counterclockwise. Thus, weight moves from the glider tail to the nose and the glider center of gravity changes accordingly.

Other components of the block diagram are: servomotor, that allows to control the yaw rudder, leakage sensor for alarm on hull decompression and water penetration into the underwater vehicle and electrical power system that consists of battery and voltage converter for low-voltage electric circuits.

Radio communication system consists of remote control device and radio receiver. It is intended for sending commands to the underwater vehicle by the operator from the remote site and getting its status.

Glider subsystems are managed by electronic controller unit (ECU).

The main element of the ECU is a microcontroller with the following functions [3]:

- receive and process navigation data from satellite positioning system (when glider is on the water surface) and inertial navigation,
- monitoring of the pressure sensor in the ballast bag and leakage sensor,
- processing remote control data from the radio receiver and generation of controlling actions for actuating mechanisms,
- glider control in automatic mode using the provided control method,
- control of glider actuating device using corresponding drivers.

The navigation system is not presented in Figure 4. For the tests in this paper it was unnecessary and therefore substituted by the spacer with similar weight. It will be added for future experiments.

3.0 IMPLEMENTATION AND SET UP EXPERIMENTAL

The following requirements were set for glider construction: equal distribution of mass along the glider length (with absence of ballast bag and with weight in central position); length of connecting conduction tracks should not exceed the limits, specified by the equipment make; ease of assembling, adjusting, servicing and replacement of the system elements;

The block diagram of the control system prototype is is shown in Figure 5. MCU is a micro control unit, INS – Inertial Navigation System, USBL – ultrashort navigation system. The following equipment is used: on-board computer Intel Atom N270 (1.6 GHz, 512 kB L2 cache, FSB 533 MHz); actuators microcontrollers AVR-CRUMB2560, ATmega2560; Doppler log RD instruments

ExplorerDVL; navigation system Companav 2; communication system based on Evo Logic S2C R 48/78 USBL Acoustic Modem. For the detailed description see paper [2].

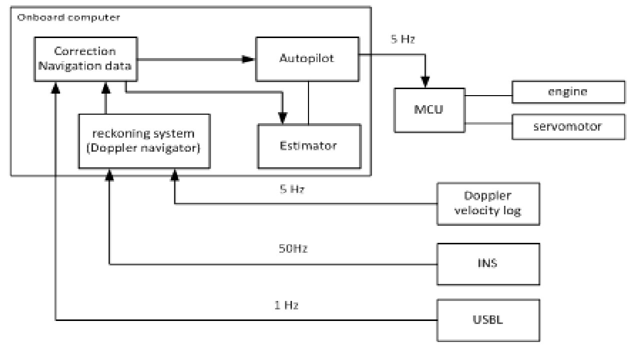

Figure 5 Block diagram of control system prototype

The next system elements were used:

- hull – radio-controlled submarine “Neptune sb-1”,
- engine for gravity center modification mechanism – commutator motor EG-530AD2B,
- pump – Seaking 180L,
- servomotor – HS-7955TG.

For improvement of hydrodynamic properties of the glider, the hydrodynamic surfaces, was calculated using Numeca software [14]. The glider is shown in the Fig. 6.

Figure 6 Glider prototype

Before being applied in real-life experiments, the control system successfully passed the simulator test [15].

The experiment was conducted in 3 steps. At first, the glider was placed in the laboratory pool with its weight in neutral position and attitude angle should be 0. Then, in step 2, the weight was moved to the nose and pump started to inject the water into the ballast bag. Commands were send using a remote control. In step 3 the weight was moved to the tail and pump ejects water out of the ballast bag. Four parameters namely pump operation time, ballast bag mass, displacement of weight and attitude angle that were constantly changed throughout the experiment, and were recorded for further processing.

In Figure 7 the glider with the weight is in neutral position. Waterline is parallel to the glider hull.

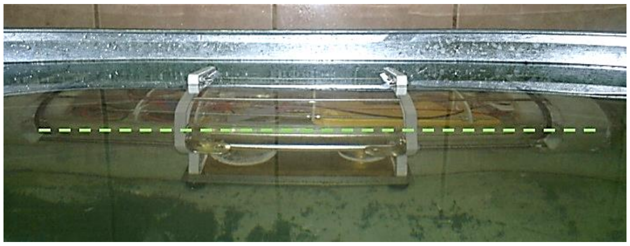

Figure 7 Glider with weight in neutral position

In Figure 8 the glider is shown with the weight, moved to the nose. This position is used for immersion. At the same time, the ballast bag is being filled with water and glider moves forward.

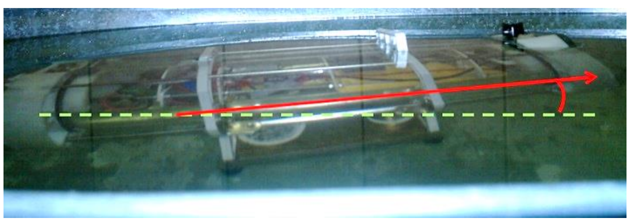

Figure 8 Glider with weight near the nose

In Figure 9 the weight was moved close to the glider tail. In this position the glider surfaces along with ejection of water from the ballast bag. During the surfacing the glider also moves forward.

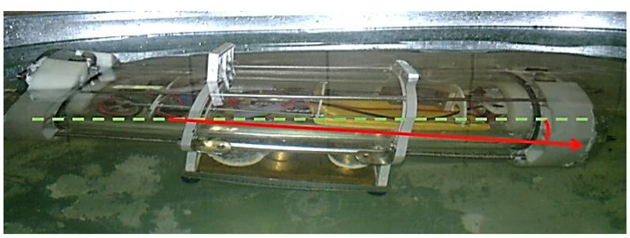

Figure 9 Glider with weight near the tail

The proposed design showed good results during the test. There was no leakage, BCM and GCMM allowed to change the attitude angle in the required range of values. The remote control showed good performance, but the conditions of operation were favourable.

4.0 RESULTS AND DISCUSSION

To create the regulator for the control system and adjust its coefficients it is necessary to determine operation dependencies of the actuating devices.

For the pump, it is connection between time of operation and mass of the ballast bag. The experiment data is provided in Table 1.

Table 1 Dependence of ballast bag mass from pump operation time

Pump operation time, s	Ballast bag mass, g
0	0
5	8.5
10	42.5
15	85
20	127.5
25	170
30	212.5

Injection and ejection operation showed the same values because it was almost at the surface position of the glider. When it was immersed deeper, water pressure will be addressed by the additional coefficient.

The linear model is the following: $f(x) = k \times p_1 x + p_2$, where coefficients (with 95% confidence limit) are:

k = 1 (future pressure coefficient),

p_1 = 0.08333 (0.08333, 0.08333),

p_2 = −3.045e-15 (−8.413e-15, 2.323e-15).

Research of movable gravity center should provide connection between position of the weight and position of the glider in the water. Results are presented in Table 2.

Table 2 Dependence of attitude angle from the position of movable gravity center

Displacement of weight from the neutral glider position, sm.	Attitude angle, °
−2.5	−10
−2	−8
−1.5	−6
−1	−4
−0.5	−2
0	0
0.5	2
1	4
1.5	6
2	8
2.5	10

Linear model will be the following [7]: $f(x) = a\sin(x-\pi) + b(x-10)^2 + c$, where coefficients (with 95% confidence limit) are:

a = −0.1889 (−1.261, 0.8828);

b = −0.195 (−0.2205, −0.1695);

c = 19.99 (17.35, 22.62).

Now these equations with identified coefficients will be put in mathematical models of the glider inside the control system and allow precision control of the glider immersion and surfacing for the upcoming underwater tests.

5.0 CONCLUSION

The proposed glider design passed preliminary underwater tests. The number of components, their makes and models (except navigation module) were chosen in order to minimize vehicle weight and thus improve autonomous operating time. However, future tests may affect the structure if reliability requirements are not met.

The proposed mechanisms for change of buoyancy and change of gravity center worked well in the laboratory pool. The collected data will be used for configuration of the control system.

After the development and installation of on-board self-diagnostic module we plan to conduct experiments in a larger pool and in the sea in order to measure the efficiency of the developed underwater vehicle and compared with to state-of-art solutions.

Acknowledgement

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