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Turning maneuver of biomimetic underwater vehicle

Abstract

Biomimetic underwater vehicle equipped with two side fins and one tail fin can perform a turning maneuver in many ways using for that purpose a suitable setting of its fins. In order to select the most effective variant of the turning maneuver a number of tests with a real vehicle were performed. The paper presents the tests themselves as well as their results.

Keywords: biomimetic underwater vehicle, maneuverability.

1. Introduction

In order to carry out tasks entrusted to underwater robots, the latter have to be able to move in an indicated direction. To do so, the ability to perform the turning maneuver is necessary. In the case of Biomimetic Underwater Vehicle (BUV) that is being built within the project no. DOBR-BIO4/033/13015/2013, entitled „Autonomous underwater vehicles with silent undulating propulsion for underwater reconnaissance" financed by polish National Center of Research and Development, there exist a lot of different variants of the turning maneuver. For the BUV equipped with two side fins and one tail fin, each variant corresponds to other setting of the fins. Due to high requirements imposed on the maneuverability of BUV, an appropriate selection of a turning maneuver variant is a key issue for effectiveness of the vehicle. In order to determine the most effective variant in terms of BUV maneuverability, the experiments were performed during which various fin settings were tested. The current paper presents the experiments themselves and the results that were accomplished. The first part of the paper is a short presentation of BUV being built, the second part is a description of the experiments, the next third part is an analysis of the results, and the last part is a summary.

2. Biomimetic underwater vehicle

The underwater vehicles often and often replace the human in performing various tasks, e.g. underwater monitoring and reconnaissance, underwater works. The most often, Remotely Operated Vehicles (ROV), that is the vehicles controlled by a human, are in use. However, increasingly, autonomous underwater vehicles (AUV) also appear, which act entirely independently of human or there are modes in which they have to cope without help from operator (e.g. breaking communication with the operator).

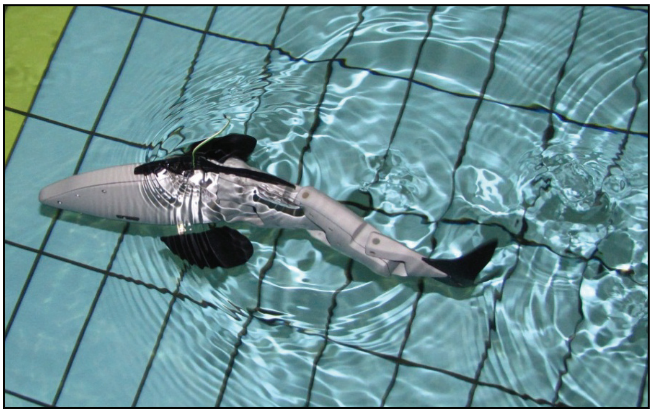

Fig. 1. CyberFish

A separate class of UVs is a class of BUVs, which by appearance or/and behavior resemble living organisms like fishes or seals. As the preliminary experiments shown, the potential advantage of such vehicles compared to vehicles with traditional screw propeller may be:

- a greater energetic effectiveness which may prolong duration of their mission,
- lower level of noise which during the experiments was generated by their propulsion.

Both above-mentioned features of BUVs are very important for military purpose vehicles, especially when they are used for underwater and/or surface reconnaissance. Lower consumption of energy allows smaller batteries to be used on vehicle board which in consequence reduces dimensions of vehicles. This, in turn, makes them harder to detect which is crucial factor during military operations. Undulating propulsion, when generates less noise, also hinders detection of the vehicle, first, because the vehicle is more silent, and second, due to different acoustic characteristic of sound generated by the undulating propulsion compared to commonly used screw propulsion.

Fig. 2. One of the BUVs built within the project „Autonomous underwater vehicles with silent undulating propulsion for underwater reconnaissance"

An example of ROV BUV is the vehicle called CyberFish [1, 7, 8] constructed at the Cracow Technical University (Fig. 1), which became the basis for a new vehicle [2-6] designed within the project no. DOBR-BIO4/033/13015/2013, entitled „Autonomous underwater vehicles with silent undulating propulsion for underwater reconnaissance" financed by polish National Center of Research and Development and depicted in Fig .2. The new BUV is equipped with a number of devices and sensors used for underwater and surface navigation (VN200 – inertial system integrated with GPS, magnetic compass), for collision avoidance (three echo sounders), and for surface and underwater reconnaissance (two cameras and sonar). To move the vehicle, the propulsion is used with two fins located symmetrically on both sides of the vehicle, in its front compartment, and one tail fin. Controlling the vehicle by means of the fins is performed by an appropriate setting of fin parameters affecting their operation. The parameters of the fins are as follows:

1. Neutral position (N) – zero position of fin, the fin moves up and down from the neutral position;
2. Amplitude of movement (A);
3. Frequency of movement (F).

In order to generate a desirable behavior of BUV, that is, to move it forward with a fixed speed, to turn left/right, to submerge/emerge, it is necessary to appropriately set the above parameters. In the following parts of the paper the experiments are reported whose objective was to determine the most effective fin settings for turning maneuver of the vehicle.

3. Experiments on turning maneuver

One of the tasks during constructing BUV was to determine the way in which the vehicle should turn. After initial analysis of vehicle behavior for different fin settings we noticed that there are three different turning modes which give the chance of effective turn meant here as possibly the most quick turn.

The first mode, that is mode no. 1, imitates operation of canoeist equipped with an oar and a rudder. In this mode the tail fin operates like a rudder, which means that it moves to the maximum position in the direction of the turn. In other words, operation of the tail fin in this mode can be specified as follows: *N* = maximum fin position left or right, *A*=0, *F*=0. Operation of side fins corresponds to the work of the oar. The fin on the turn side is set vertically down and as the tail fin it is motionless (*N*=–90, *A*=0, F=0), whereas the fin on the other side moves with a fixed frequency and amplitude around the neutral point set horizontally back (*N*=0, *A* and *F* – parameters of turn).

In the second turning mode, mode no. 2, the side fin which in the mode no. 1 is set vertically is arranged horizontally, which means the following parameters: *N*=0, *A*=0, *F*=0. The remaining fins work as in the mode no. 1. The objective of the mode no. 2 is not to slow down the vehicle during the turning maneuver as much as in the mode no. 1. Initial analysis of vehicle operation while turning according to the mode no. 1 showed that deactivating two fins (tail fin and one side fin) and setting one fin in the breaking position (vertically down) results in significant slowing down the vehicle and in effect making the turning maneuver difficult. For that reason, the decision was made to apply in the experiments “less breaking” variant of the mode no. 1 with motionless side fin set in the position neutral to motion of the vehicle, that is, horizontally along the vehicle hull.

Fig. 3. BUV on tests on pool

The third turning mode, mode no. 3, was originally designed for turning maneuver performed in a place, that is, in the situation when speed of the vehicle is equal early to zero meters per second. After initial tests with the turning modes no. 1 and 2 which revealed that deactivating two out of three fins of BUV during turning maneuver always results in considerable slowing down the vehicle, the decision was made that the mode no. 3 can also be successfully used as a standard turning mode of BUV. In this mode, the tail fin works as in modes no. 1 and 2, that is, it is motionless and maximally moved in the direction of the turn, whereas side fins work in opposite direction, the fin operating on the vehicle side in which the turn is to be performed pushes the vehicle backward (*N*=180, *A* and *F* – parameters of the mode), whereas the other fin pushes it forward (*N*=0, *A* and *F* – parameters of the mode).

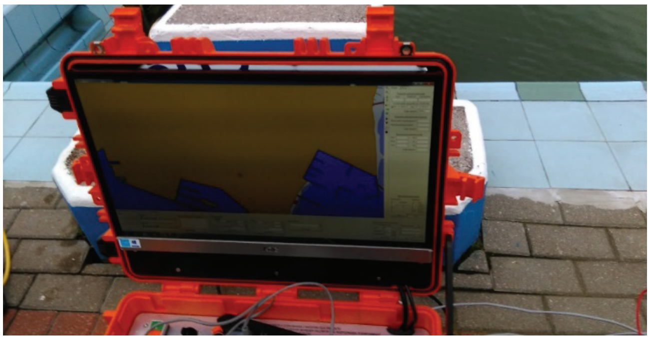

Fig. 4. Control station desk used during tests on pool

Generally, the initial tests showed that each turning mode in which the tail fin and one of the side fins stand still inevitably leads to slowing down the vehicle practically to the speed equal to 0 m/s. In consequence, the decision was made that the vehicle during the turning maneuver will always stop in place, perform the turn, and then continue movement to the previously fixed direction. Of course, there were also attempts to determine turning modes in which the vehicle would not level off its speed. Unfortunately, the attempts failed. It appeared that BUV can either move forward or turn almost in a place.

The main cause of that state of affairs is construction of the tail fin which maximum neutral point *N* that allows the fin to oscillate around that point is rotated 20 degrees from the hull axis. What is more, maximum amplitude *A* is equal, in this case, to a next 20 degrees. It is generally too little for the tail fin, when moving, to be a significant source of the turn.

Finally, the decision was made that the three modes described above would be the only turning modes of the BUV put to the optimization test. In the tests, different values of amplitudes *A* and frequencies *F* were examined, neutral points *N* had constant values assigned which were characteristic for each mode. The main evaluation criterion of all tested variants of the turning maneuvers was angular velocity of BUV.

All the tests were conducted on the open pool of Sport Club “Fleet” in Gdynia (Fig. 3). Each variant of turning maneuver was tested once. Each of them differed from other variants in the mode applied (*N* fixed) and in parameters of moving fins (*A* and *F*). In a single test, the vehicle moving forward was first accelerated to its maximum speed and then turning maneuver was run (left or right, depending on the conditions).

Throughout the tests, the vehicle worked always in a remotely operated mode, that is, all commands arriving to it came from manipulator of Control Station Desk (Fig. 4) and were transferred to the vehicle via a cable fastened to it. Measurements of vehicle course were performed by means of inertial system VN200 installed on BUV board, whereas angular velocity of the vehicle was determined according to the following simple formula:

$$\omega = \frac{\left|KR_K^W - KR_P^W\right|}{T^W}$$

where KR_K^W i KR_P^W is a final and initial vehicle course at the very start of turning maneuver, respectively (these courses were not the same for all tested variants, the parameter of interest in the tests was, however, the change of the course in time, not course itself), whereas T^W is the duration of the turn, from the initial course to the final course. For all tested variants, the change of course always ranged from 90 deg – 270 deg.

In the tests, the following values of *A* and *F* were examined:

- *A* = 20, 30, 40, 50 degrees;
- *F* = 1, 2, 3, 4 Hz.

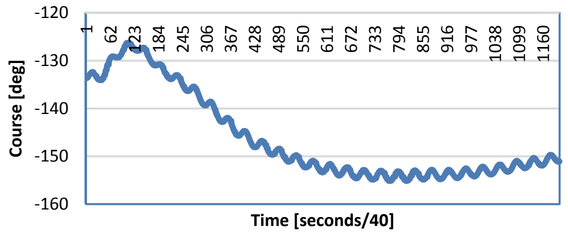

Fig. 5. Course change for mode no. 1 with parameters: *F*=1Hz, *A* = 50 deg

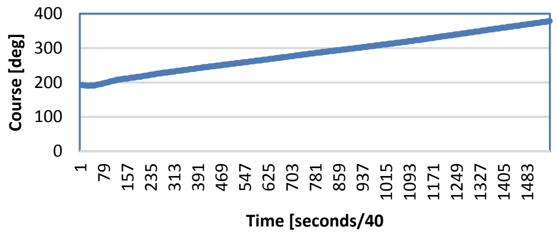

Fig. 6. Course change for mode no. 1 with parameters: *F*=2Hz, *A* = 40 deg

4. Results of the tests

Diagrams with changes of course in time for example five tested variants are displayed in Fig. 5-9, whereas final results (angular velocities *ω*) are inserted in Tab. 1-3. Generally, all the figures and tables show that the most quick turning mode for the BUV is mode no. 3. In most variants of that mode, angular velocities are almost twice higher than for other tested modes. The greatest angular velocity for that mode was achieved for variant with *F*=2 Hz and *A*=40° and it is equal to 10.098 deg/s. Meanwhile, the best results for modes no. 1 and 2 are the following: 5.6 deg/s and 5.02 deg/s, respectively. As mentioned above, it is almost twice less than for the mode no. 3.

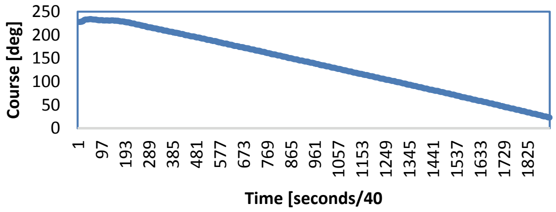

Fig. 7. Course change for mode no. 2 with parameters: F=2Hz, A = 40 deg

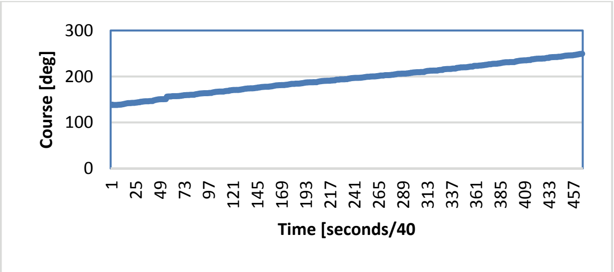

Fig. 7. Course change for mode no. 2 with parameters: *F*=2Hz, *A* = 40 deg

Taking the fact into consideration that in all the modes the vehicle, while turning, always slowed down at a similar level, the mode no. 3 can be regarded as the most effective out of all tested modes. The consequence of that is acceptance of that mode as the only turning mode in the future experiments with BUV.

Tab. 1. Angular velocities for mode no. 1 (deg/s)

A/*F*	1 Hz	2 Hz	3 Hz	4 Hz
20°		4.03256	3.5654	3.821597
30°		4.124351	3.446571	3.76345
40°		5.02054	4.605653	3.801306
50°	0.59			

Tab. 2. Angular velocities for mode no. 2 (deg/s)

A/*F*	1 Hz	2 Hz	3 Hz	4 Hz
20°		4.82124	5.601441	4.947428
30°		4.76864	4.252077	4.50263
40°		4.460239	4.378898	5.074513
50°	0.8654			

Tab. 3. Angular velocities for mode no. 3 (deg/s)

A/*F*	2 Hz	3 Hz
20°	8.5467	7.2376
30°	8.95456	8.6543
40°	10.098	8.8408

5. Summary

The paper presents one stage of the experiments with Biomimetic Underwater Vehicle whose general objective is to construct the vehicle able to perform all tasks specified in operational scenarios defined in the project. The goal of the experiments presented in the paper was to determine the most effective turning mode for the vehicle in terms of turning speed. In the experiments, three different turning modes were tested, each implementing a different turning pattern. For each mode, a number of variants were also examined, each with different parameter setting of moving fins. The experiments were carried out on the swimming pool for the vehicle controlled via Control Station Desk and the cable fastened to the vehicle.

The experiments showed that the most effective turning mode is the mode in which the tail fin of the vehicle operates like a canoe rudder, that is, it is motionless and set to its maximum left or right positon, whereas both side fins work in opposite direction, that is, one pushes the vehicle forward and the other one backward. Angular velocity of BUV achieved for the best mode is about 10 deg/s. As the result of the experiments, the turning mode for the vehicle was finally selected – it is the most effective mode from the experiments reported in the paper.

The research presented in the paper were founded by Polish National Center of Research and Development within the project no. DOBR-BIO4/033/13015/2013, entitled „Autonomous underwater vehicles with silent undulating propulsion for underwater reconnaissance".

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