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THE INFLUENCE OF PARAMETERS OF BIOMIMETIC UNDERWATER VEHICLE CONTROL SYSTEM ON THE ABILITY OF THE VEHICLE TO AVOID OBSTACLES

ABSTRACT

Autonomous underwater vehicles are vehicles that are entirely or partly independent of human decisions. In order to obtain operational independence, the vehicles have to be equipped with a specialized software that usually has many different parameters. The parameters decide about effectiveness of the software and in consequence the vehicle. The paper reports experiments performed in simulation, whose goal was to analyze the influence of selected parameters of High--level Control System of Biomimetic Underwater Vehicle on the vehicle ability to avoid obstacles.

Key words:
underwater vehicle, collision avoidance.

INTRODUCTION

Autonomous Underwater Vehicles (AUV) are vehicles that are completely or partly independent of human decisions. In order to make them autonomous, they have to be equipped with specialized software which, henceforth, is called High-Level Control System (HLCS). One task of HLCS is to move the vehicle along a desired path with collision avoidance. Whereas the navigation from a waypoint to other waypoint is a classical regulation task which can be implemented with PID controllers or others (for example, the fuzzy ones), and it simply is not a challenging task, the collision avoidance in 3D environment is not a trivial issue which often requires complex algorithms or/and advanced artificial intelligence tools.

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Each HLCS in addition to the logic of operation implemented either in the form of an algorithm or an artificial intelligence system has a number of parameters, which are decisive for HLCS effectiveness. For underwater vehicle and the collision avoidance task the following parameters are among that of crucial influence on HLCS:

- sensors (sonar, echo-sounders) range of vision;
- time interval between consecutive decisions of HLCS;
- velocity of the vehicle when avoiding collisions;
- ability to abort maneuver or performing each maneuver from the start to the end.

The above parameters have been recognized as key parameters for Biomimetic Autonomous Underwater Vehicle (BAUV) 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. For that reason the BAUV developing team made the decision to perform simulation tests with the objective to determine optimal values for the parameters before construction of the vehicle and tests in real or real-like conditions.

The above decision was dictated by finance and safety reasons. Testing the control system on real vehicle without thorough examination of its operational logic and implementation correctness in simulation conditions, the system whose task as a mind of BAUV is to independently control the vehicle without help of a human, would be a very risky move which could result in loss of the vehicle or even its destruction. What is more, tests of HLCS exclusively on BAUV would require huge financial outlays which is due to the fact that a lot of research and development work with the vehicle have to be performed in water.

The paper reports research in simulation conditions and it is organized as follows: first, short description of BAUV to be a final goal of the project is given, then, parameters analyzed during the research are outlined, next section is a presentation of results, and summary ends the paper.

BIOMIMETIC AUTONOMOUS 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).

A separate class of AUVs is a class of biomimetic vehicles, 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 BAUVs 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.

An example of ROV BAUV is the vehicle called CyberFish [1, 3, 4] constructed at the Cracow Technical University (fig. 1), which became the basis for a new vehicle 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.

Fig. 1. CyberFish [4]

According to the project assumptions the new vehicle will be AUV class and its basic task will be underwater and/or surface (by means of camera) reconnaissance. Autonomy of the vehicle means its ability to independently move along a desired path with collision avoidance. Moreover, in the certain waypoints the vehicle should also activate/deactivate devices used for reconnaissance purposes, i.e. camera, sonar, hydrophones.

The high-level control of the vehicle will be performed by HLCS [2] whose decisions, e.g. turn right, submerge, move ahead with speed 1 m/s, will be passed on to low-level control system with the aim to convert high-level decisions into commands for BAUV propellers.

Currently, HLCS is an algorithmic system designed entirely by a human--designer. It means that BAUV uses sensors to identify its momentary state and then adjusts an algorithm of operation built by the designer to the state — the designer determined behavior of BAUV in each possible identified state and what is more the designer also arbitrary defined the set of all possible states.

The algorithmic HLCS has a number of parameters affecting its effectiveness, especially in collision avoidance. The key parameters for the collision avoidance are already given in the introduction and they are as follows:

– sensor (sonar, echo-sounders) range of vision;
– time interval between consecutive decisions of HLCS;
– velocity of the vehicle when avoiding collisions;
– ability to abort maneuver or performing each maneuver from the start to the end.

All the above parameters are detailed in the further part of the paper.

PARAMETERS

Range of vision

The first parameter crucial for effectiveness of HLCS is BAUV underwater range of vision by means of all available sensors. In the experiments, echo-sounders were assumed as a observation device, one looking forward, the other one looking up and the last one looking down. From the collision avoidance point of view the echo-sounder looking forward is the most important.

Of course, the most natural solution with regard to echo-sounders range of vision is to determine their maximal possible range. In this case, BAUV would be able to early detect obstacles and to appropriately react. Unfortunately, such solution may be sometimes ineffective. When an obstacle is detected, the current implementation of HLCS searches, describing it very simply, safe spaces around the vehicle, i.e. spaces without obstacles, where BAUV can be directed. The solution with maximum range of vision may sometimes lead to the situation in which there will be no clear way for the vehicle — it will be surrounded by obstacles from all sides, the obstacles will be at each direction, some closer and some further from the vehicle. For simple HLCS logic which searches safe spaces for definite courses without taking distances to obstacles into account, that is, for the logic without depth of view, it may appear that there are not any safe space and HLCS will have a problem with finding a clear way for the vehicle. Certainly, the solution to this problem is HLCS with depth of vision, that is, the system which neglects some further obstacles when maneuvering the vehicle. In practice, it means reduction of range of vision, the problem is, however, how and when the range should be reduced.

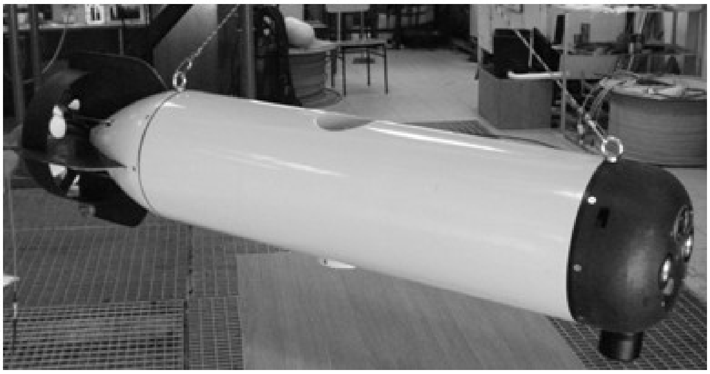

Fig. 2. ROV 'Głuptak' [5]

Time interval between consecutive decisions of HLCS

A next parameter whose influence on HLCS operation was examined during the experiments is time interval between consecutive decisions of the system. Of course, as previously, it seems that the most natural solution in this case is to maximally shorten the interval. What, however, it will mean? The consequence is that the on-board computer with HLCS will be forced to intensely process all data necessary for making decisions (e.g. data from different sensors, image data from sonar or camera which require advanced and complex processing algorithms, navigation data for SLAM and position determination) which in some situation may result in blocking the computer or at least slowing down its responses which in emergency situations may lead, in turn, to loss of the vehicle.

Excessive prolongation of the interval may have the similar effect as its shortening. In this case, HLCS may provide decisions too rarely to optimally maneuver the vehicle.

Velocity of the vehicle when avoiding collisions

Velocity of BAUV is a next key parameter for collision avoidance. It cannot be too low because it may lead to the situation in which even a weak sea current will push the vehicle from the planned path and HLCS will not be able to effectively control the vehicle. In turn, the consequence of too large velocity is the same as in the case of long interval between successive HLCS decisions, i.e. HLCS may be surprised by rapidly changing states of BAUV, and in effect, it again will not be able to successfully maneuver the vehicle. Certainly, the velocity should be adjusted to the interval between decisions — high velocity should be combined with more frequent decisions and vice versa.

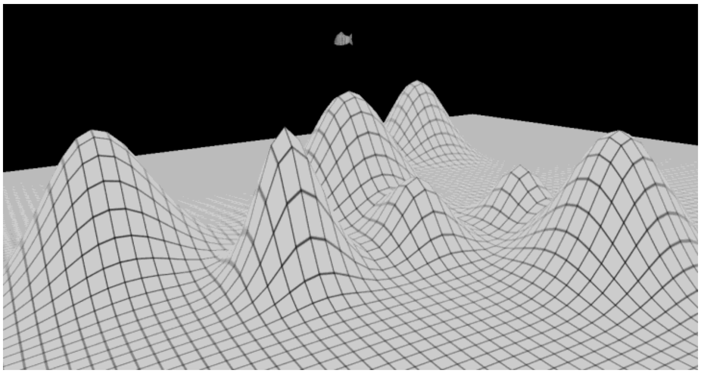

Fig. 3. Virtual sea environment used in experiments [own work]

Ability to abort maneuver or performing each maneuver from the start to the end

The last parameter whose influence on BAUV effectiveness to avoid collisions was tested in the experiments presented in the paper is the way of controlling BAUV by means of consecutive maneuvers. Generally, there are three possible approaches, in this case. The first is the lack of possibility to interrupt maneuvers which are already started which means that if, for example, the decision is made to turn right at 30 degrees, this maneuver cannot be interrupted by other maneuver caused by change of external conditions. The second approach means, in turn, that each maneuver can be interrupted by other maneuver. It is also possible the combined approach which forbids interruption of started maneuver in typical situations or when the vehicle is safe and which allows HLCS to change maneuver in an emergency situation.

At first glance, it seems that the most natural solution or even the only possible solution is possibility to interrupt each maneuver. During each maneuver, circumstances may appear which may suggest to change previous decisions and in consequence alteration of the maneuver. Unfortunately, such solution may lead to frequent decision changes and in effect to chaos in decision making. For example, it may turn out, that input data to HLCS in each control loop will change so that respond of the system for each input data in the form of maneuver will be completely different. In such a case, inertia of the vehicle will lead either to lack of noticeable maneuver or to sequence of maneuvers with hardly predictable effect.

In turn, lack of possibility to interrupt maneuvers may result in high inertia of BAUV, i.e. if the vehicle makes deep turn at 180 degrees, even a drastic change of external conditions cannot change this maneuver, the turn has to be completed and next maneuver can be started only after completion of the previous maneuver. Such an approach seems to be dangerous for BAUV, however, it also seems that the number of situations in which HLCS will sudden have to make emergency decisions will take place very rarely. In such situations and only in such situations, BAUV should have possibility to change maneuver, the problem is, however, how to identify such situations.

EXPERIMENTS

Conditions of experiments

The experiments whose objective was to analyze the influence of parameters described above on effectiveness of BAUV to avoid collisions took place in simulation conditions. In order to design simulation model of BAUV, ROV 'Głuptak' (torpedo-shape vehicle, fig. 2) [5] with oscillation in horizontal plane was used which made it possible to mimic BAUV with the most characteristic feature, i.e. with its undulating propulsion. Moreover, in order to visually evaluate operation of HLCS and BAUV during collision avoidance for different values of parameters, the experiments were carried out in virtual sea environment with obstacles (fig. 3). The size of the environment was 100 x 100 meters, whereas its depth amounted to 20 meters.

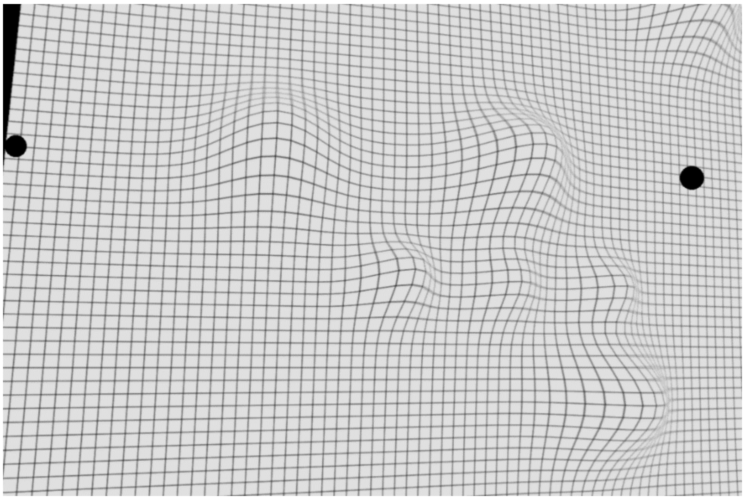

Fig. 4. Starting and destination points (black circles in the image) [own work]

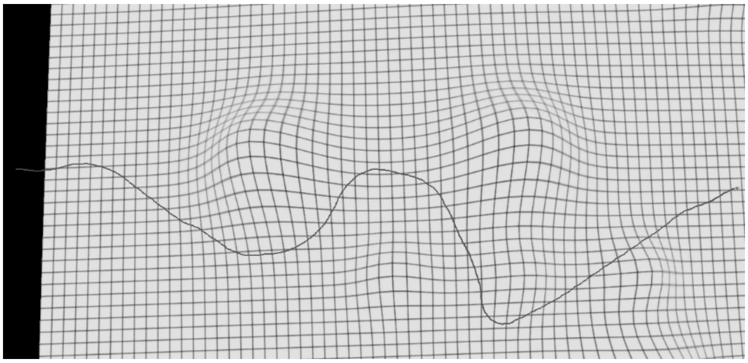

Fig. 5. Path of BAUV for rage of vision 20 meters [own work]

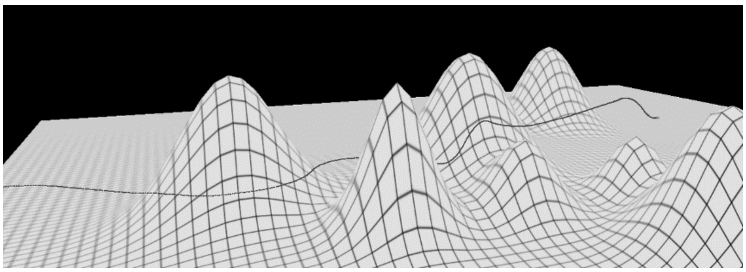

Fig. 6. Path of BAUV for rage of vision 20 meters —
other point of observation [own work]

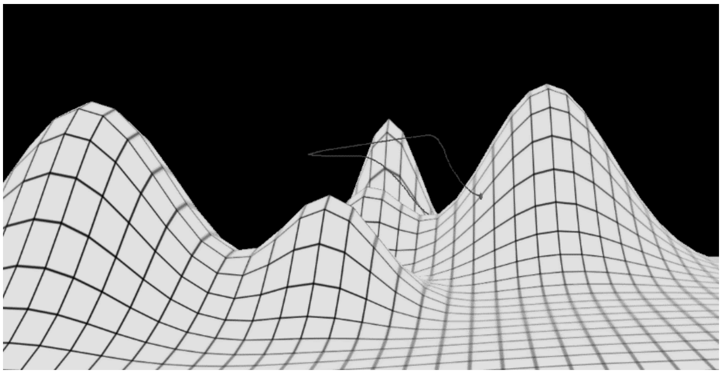

Fig. 7. Path of BAUV for rage of vision 20 meters — projection along axis *Y* [own work]

In the experiments, BAUV was controlled by algorithmic HLCS which was a result of long-lasting implementation works of designing team. To achieve the main research goal, the decision was made to analyze behavior of BAUV when moving between two points of the environment. Location of starting and destination point was selected in the way which forced BAUV to perform different maneuvers, frequent change of movement direction or depth was necessary to reach the destination — starting point was located in point (40, 0, 15) (*X* axis goes 'up', *Y* axis goes 'right' — other than standard orientation of coordinate system), whereas destination point was located in point (40, 60, 15) (fig. 4).

Results — range of vision

All the research were divided into four stages, in each stage a different parameter was tested. In the first stage, echo-sounder range of vision was examined for three different values: 10, 15, 20 meters. At this stage, the following values of the remaining parameters were applied: interval between decisions — 0.2 sec (it is minimum possible value due to HLCS implementation), velocity when avoiding collisions — 0.5 m/s (this value was assumed to be minimum velocity of the vehicle, except 0 m/s), interruption of maneuvers — not allowed.

Results of the tests are presented in figures 5–10 and they show that:

1. Longer range equal to 15–20 meters yields better results than the range 10 meters.
2. Paths for range 15 m and 20 m were very similar.

For the range equal to 10 m, BAUV hit twice an obstacle which activated the maneuver responsible for obviation of obstacle. In the first case, the vehicle changed depth whereas in the second one first it moved back and then it also changed depth.

Collisions with obstacles were generally caused by too late detection of obstacles which, in turn, were caused by velocity of BAUV along with its inertia. Maneuvers used by BAUV when collision with obstacle is detected are an example of emergency maneuvers which are allowed to interrupt other standard maneuvers.

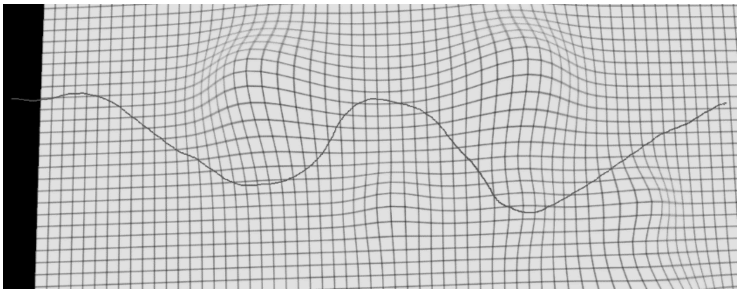

Fig. 8. Path of BAUV for rage of vision 15 meters [own work]

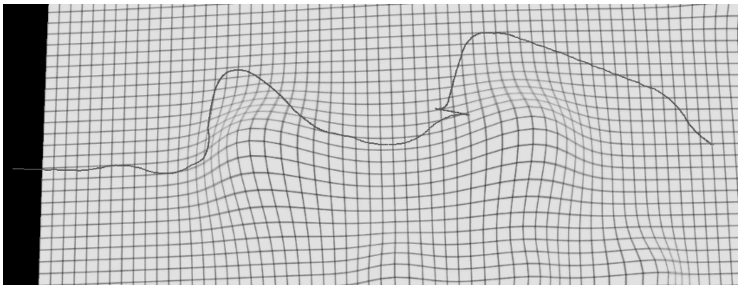

Fig. 9. Path of BAUV for rage of vision 10 meters [own work]

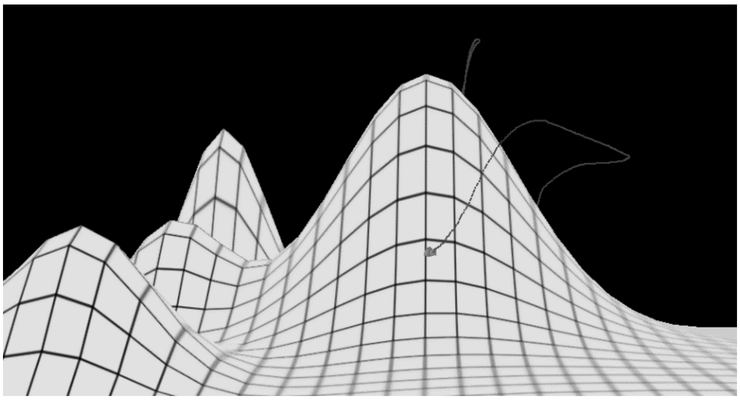

Fig. 10. Path of BAUV for rage of vision 10 meters — projection along axis Y [own work]

Because the tests reported in this section demonstrated higher effectiveness of HLCS with a longer range of vision, in further experiments the range 20 meters was applied.

Results — interval between decisions

The objective of the second stage of the research was to test the influence of the interval between successive HLCS decisions on effectiveness of the system. The following values of interval were tested: 0.4, 1 sec (value 0.2 was examined in previous stage). The remaining parameters had this time the following values: range of vision — 20 m (value selected in the previous stage), velocity of BAUV — 0.5 m/s, interrupting maneuvers — not allowed. Results of the tests are presented in figures 11–15.

In this case the experiments showed that:

1. Interval 0.2 s yields better results than longer intervals.
2. For longer intervals, BAUV later detected obstacles and later made decisions to avoid them which resulted in collisions.

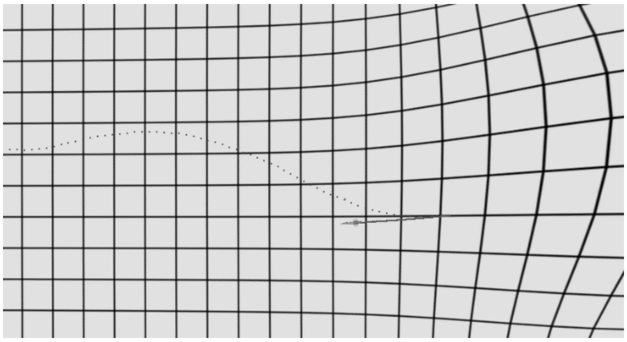

Fig. 11. Hitting the obstacle and moving back maneuver for interval 0.4 s [own work]

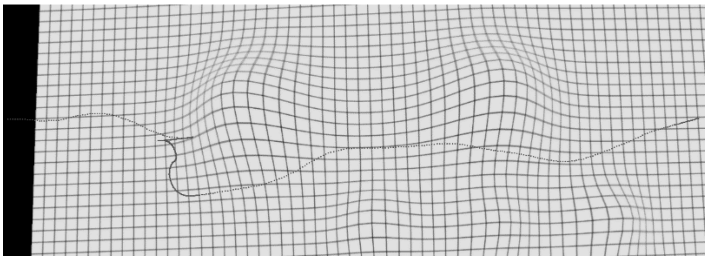

Fig. 12. The whole path of BAUV for interval 0.4 s [own work]

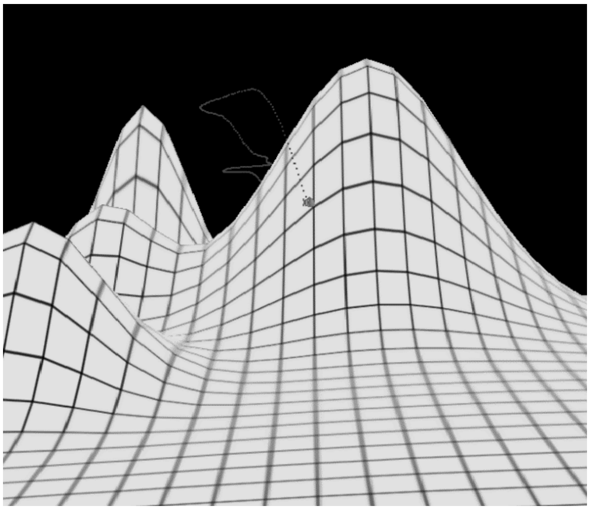

Fig. 13. Path of BAUV for interval 0.4 s — projection along axis *Y* [own work]

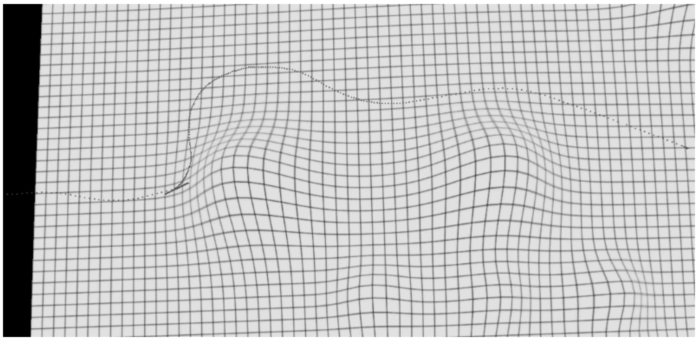

Fig. 14. Path of BAUV for interval 1 s [own work]

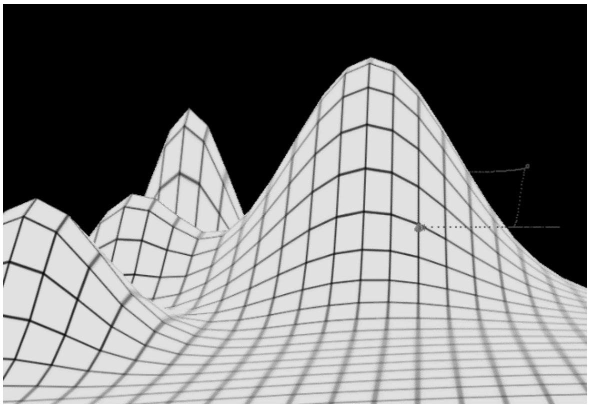

Fig. 15. Path of BAUV for interval 1 s — projection along axis *Y* [own work]

In effect of research reported in this section, the decision was made to apply interval 0.2 s in further tests.

Results — vehicle velocity

The third stage of experiments was devoted to tests on vehicle march velocity which should be applied by BAUV when avoiding collisions. Since in previous experiments value 0.5 m/s was used, the next value which selected for examination was 1 m/s. Earlier, 0.5 m/s was assumed to be minimal allowed velocity of the vehicle and for that reason lower velocities were not tested. Greater velocities than 1m/s were not also tested because it was assumed that such velocities may be difficult to achieve by vehicle with undulating propulsion, and even if they would be achievable consumption of energy in such a case would be so high that they would not be used as march velocities. Results of the tests in the third stage are presented in figures 16–18.

Results showed that velocity 1 m/s applied when BAUV avoid collisions (distance from vehicle to the nearest obstacle is below a threshold) is too high. For that velocity, the vehicle was not able to avoid obstacle detected before, its inertia was too high to prevent collision. In consequence of such result, in the last stage of experiments velocity equal to 0.5 m/s was used as a march velocity during maneuvering close to obstacles.

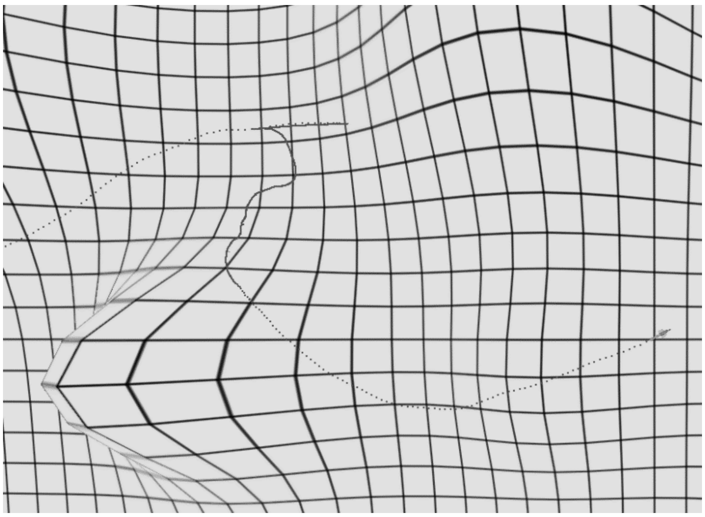

Fig. 16. Path for velocity 1 m/s — hitting the obstacle and obviation maneuver [own work]

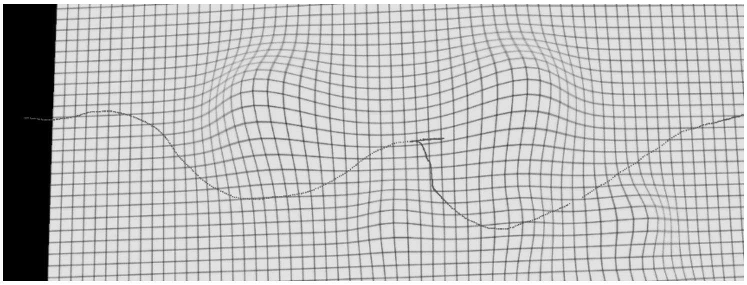

Fig. 17. The whole path for velocity 1 m/s [own work]

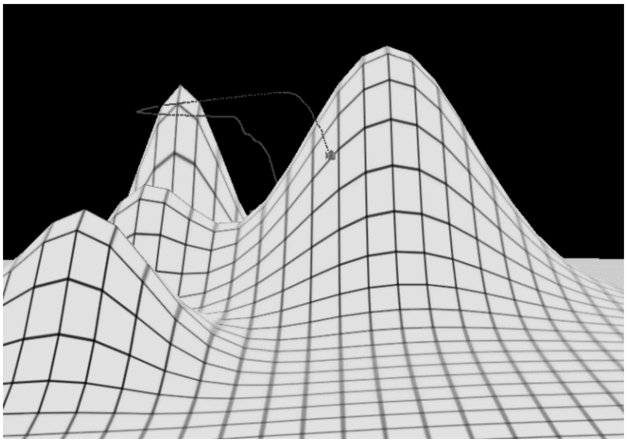

Fig. 18. Path for velocity 1 m/s — projection along axis *Y* [own work]

Results — interruption of maneuvers

The last element of HLCS was variant of the system in which interruption of maneuvers and their replacement with other maneuvers is allowed (variant without permission for interrupting maneuvers was tested in all prior experiments). Results of the tests in this stage are depicted in figures 19–20.

Trajectories of BAUV obtained in this case differ from the ones presented in section 3.2 for range of vision equal to 20 meters that is for the variant of HLCS without interrupting maneuvers. In both cases BAUV did not hit the obstacle, however, trajectory presented in section 3.2 seems to be closer to the optimal one, that is, the one which carries a lower risk of collision. It is due to a greater 'smoothness' of that trajectory — it does not have deep turns of BAUV. Figure 19 shows that in the first section of the trajectory, BAUV had problems with selecting further direction of movement — the vehicle changed decision a number of times. The effect was that the final maneuver avoiding obstacle was carried out at a short distance from the obstacle. It may mean that for a shorter initial distance of BAUV to obstacle, the vehicle could make the final decision too late to prevent collision.

Finally, after comparison of BAUV trajectories for two variants of HLCS the decision was made that in the future vehicle the variant without interruption of maneuvers will be applied.

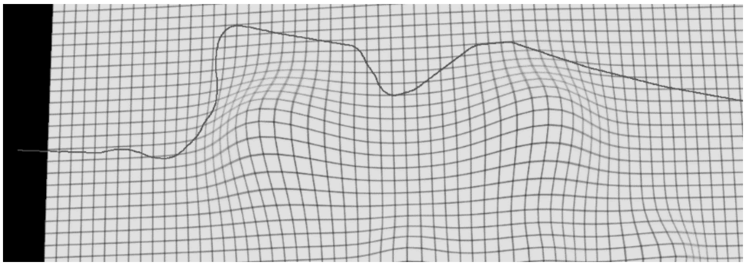

Fig. 19. Path of BAUV for the HLCS variant with interruption of maneuvers [own work]

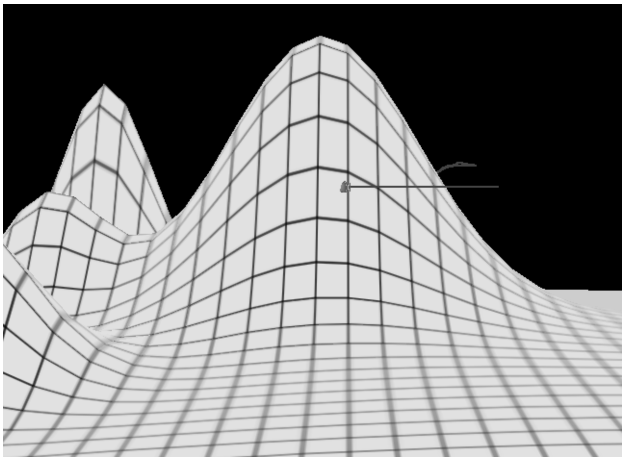

Fig. 20. Path of BAUV for the HLCS variant with interruption of maneuvers — projection along axis Y [own work]

SUMMARY

The paper reports research whose objective was to analyze the influence of selected HLCS parameters on the ability of BAUV to avoid collisions. As a result of mentioned research values of parameters were determined which enable the vehicle to safely navigate near the underwater obstacles. The following values of parameters were found to be optimal:

1. Range of vision = 20 meters.
2. Interval between HLCS decisions = 0.2 sec.
3. Velocity of BAUV when close to obstacles = 0.5 m/s.

Interruption of maneuvers = not allowed.

Acknoledgements

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'.

The environment designed to display computer simulations implemented by dr Krzysztof Naus (fig. 3–20) was used in n the course of the investigations.

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ANALIZA WPŁYWU PARAMETRÓW SYSTEMU STEROWANIA BIOMIMETYCZNYM POJAZDEM PODWODNYM NA ZDOLNOŚĆ POJAZDU DO OMIJANIA PRZESZKÓD

STRESZCZENIE

Autonomiczne pojazdy podwodne są to pojazdy całkowicie lub częściowo niezależne od decyzji człowieka. W celu uzyskania samodzielności działania muszą zostać wyposażone w specjalizowane oprogramowanie, które zazwyczaj ma wiele różnych parametrów. Decydują one o skuteczności oprogramowania i w konsekwencji pojazdu podwodnego. W artykule zaprezentowano badania symulacyjne, których celem była analiza wpływu wybranych parametrów wysokopoziomowego systemu sterowania biomimetycznym pojazdem podwodnym na jego zdolność do omijania przeszkód.

Słowa kluczowe:
autonomiczne pojazdy podwodne, unikanie kolizji.