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Laboratory stand for research on mini CyberSeal

Abstract

In recent times, we may notice some new designs of underwater vehicles, which imitate living underwater organisms, e.g. a fish, a seal, a turtle, etc. These vehicles are called biomimetic. They are driven by undulating propulsion, imitating wavy motion of fins, which were created during many years of evolution. In the paper, a laboratory stand for research on Biomimetic Underwater Vehicle (BUV) called mini CyberSeal is presented. The main objectives of the stand is to investigate future construction of BUV imitating a seal (made in scale) and to test different control algorithms for this BUV. At the beginning of the paper, an introduction to the research area and a structure of the laboratory stand is described in general, and then in the following section all elements of the stand are presented in details. At the end of the paper, an initial research on mini CyberSeal and a schedule of the future research are inserted.

Keywords: biomimetic underwater vehicle, undulating propulsion.

1. Introduction

In the recent years, a dynamical development of underwater robotics has been noticed. One of the latest innovative constructions in this field are autonomous biomimetic underwater vehicles (BUVs) [1][3][4]. They imitate underwater living organisms, e.g. fishes, marine mammals, etc. They can imitate both the construction and kinematics of motion. BUVs are driven by undulating propulsion imitating real fins, e.g. of a fish – Fig. 1.

In the Fig. 1, we can see CyberFish ver. 5 designed and built in Cracow University of Technology in cooperation with Polish Naval Academy. This underwater vehicle is equipped with an artificial tail fin for generating main thrust in a longitudinal axis of symmetry and moment of force relative to a vertical axis of symmetry. The tail is a main propulsion acting in a horizontal surface. Moreover, the CyberFish is equipped with side fins for generating additional thrust in a longitudinal axis of symmetry and moment of force relative to a transverse axis of symmetry. The side fins are responsible for motion in both horizontal and vertical surfaces. The depth control is additionally supported by an artificial swim bladder similar to a fish bladder. The bladder is used to control buoyancy and usually it works as a ballast tank, which can increase or decrease a total mass of the vehicle by pumping water into or outside the tank.

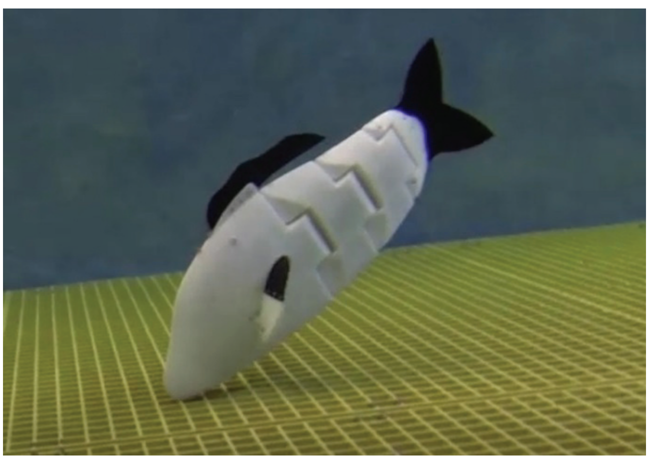

Fig. 1. BUV CyberFish ver. 5 in a swimming pool [2]

The CyberFishes ver. 1 to 5 were designed and built to demonstrate the operation of a new technology of biomimetic underwater vehicle with undulating propulsion. The additional goal of building CyberFishes was to developed new undulating propulsion. Achieved results of the BUVs operation (in comparison with Remotely Operated Vehicle ROV with similar dimensions) in terms of a maneuverability, an energy efficiency and a generated hydroacoustic signature contributed to the next research on more functional BUV, equipped with commercial sensors and equipment – Fig. 2. The next BUV was named ABPP. Two constructions of ABPP were designed and built within Polish development project [5] carried out by the consortium consisted of the following scientific and industrial partners: Polish Naval Academy AMW – the leader, Cracow University of Technology PK, Industrial Institute of Automatics and Measurement PIAP and Forkos Company.

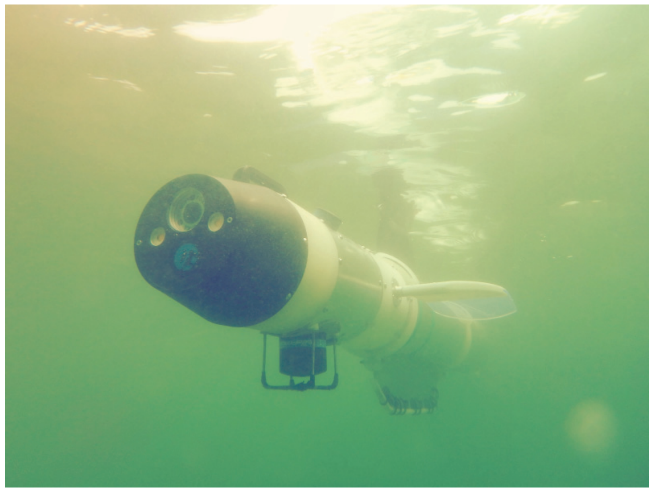

Fig. 2. BUV ABPP2 during the sea trials

The main objective of this project was to build heterogeneous torpedo-shaped BUVs with undulating propulsion for selected scenarios of underwater mission. The vehicle were equipped with sensors and equipment for surface and underwater navigation and communication, for obstacle detection and for registration of sonar and video images. Moreover, the ABPPs were enriched in software for autonomous control along desired trajectory with obstacle avoidance and registration of sonar and video signals. The final demonstration of the vehicles operation was conducted with success in April 2017.

Currently, the work on BUVs is continued in the project which was started in European Defense Agency [6]. The project is carried out by the consortium consisted of the mentioned above Polish partners and also Bundeswehr Technical Center for Ships and Naval Weapons WTD 71 in Eckernförde, Germany. The main objective of the project is to build BUVs similar to real inhabitants of underwater environment, prepared for their swarm operation. One of the BUVs will imitates a fish and other will imitates a seal.

This paper describes the laboratory stand designed and built in Polish Naval Academy for performing tests on new design of the BUV named mini CyberSeal – Fig. 3. This new vehicle is a physical model made in scale of the larger vehicle, which will imitates a seal. The laboratory stand of the mini CyberSeal has two main goals. The first goal is to examine a propulsion system of the vehicle, consisted of two tail fins and two side fins. The second goal is to test different control algorithm for mini CyberSeal, which will be useful for larger CyberSeal currently under construction. Thanks to such an approach, the research focused on autonomy of CyberSeal is carried out before the final construction will be finished.

As it was showed above, the research on BUVs are consistent and are developing in the direction of autonomous vehicles cooperating in a swarm. This development requires many different research focused on control algorithms, starting with low-level control and providing to semi– or fully–autonomous behaviors at the end of the research. Many of the research will be performed using the described in the paper laboratory stand.

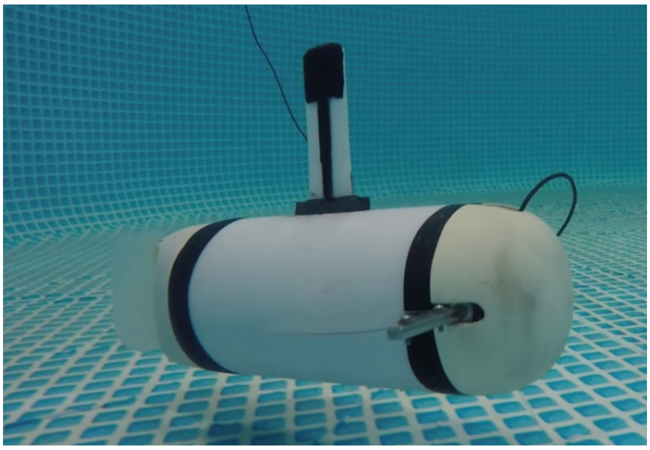

Fig. 3. BUV mini CyberSeal ver. 2 in a swimming pool

In the next section, the general structure of the laboratory stand for research on mini CyberSeal was presented. Then, the construction of the mini CyberSeal was inserted. Next, the software for the small BUV control and positioning using video was described. In the next two sections, the results of initial research and conclusions including schedule of future research were illustrated. At the end, the acknowledgment and references were inserted.

2. Structure of the laboratory stand

The main assumptions for design and implementation of the laboratory stand for research on mini CyberSeal were:

1) to imitate propulsion system of a larger CyberSeal,
2) to use simple and cheap elements for the stand.

The stand is equipped with the following components (Fig. 4):

1) mini CyberSeal, equipped with 4 servomotors for driving each fin separately, gyro compass, Inertial Measurement Unit IMU and pressure sensor for navigation, wifi antenna mounted on a float for communication and microcontroller for low-level control,
2) video camera for capturing images needed for determination of a position of the mini CyberSeal,
3) PC with software for determination of a position and an orientation of the mini CyberSeal and its control, e.g. testing different control algorithms.

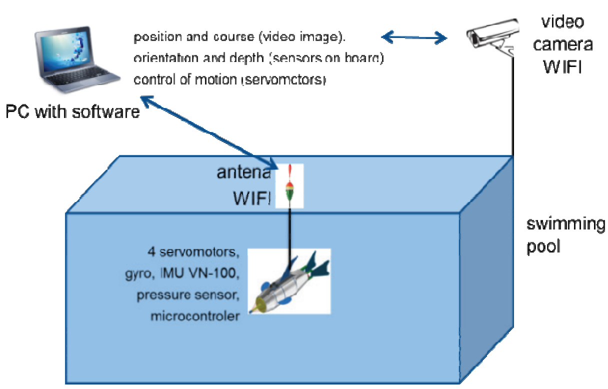

Fig. 4. Scheme of the test stand for research on mini CyberSeal

All the control of mini CyberSeal is carried out by software implemented in the PC. The communication between the BUV and the PC is supported by a wifi channel using antenna mounted on a float and swimming on a surface of water – Fig. 5.

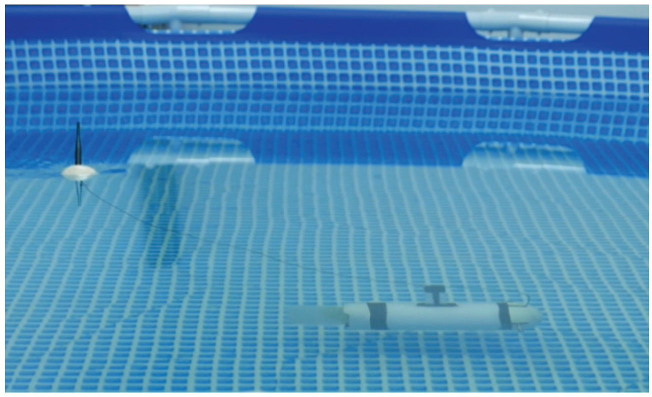

Fig. 5. BUV mini CyberSeal in underwater position connected with PC through wifi channel (antenna mounted on a float on a surface of water)

3. Construction of the mini CyberSeal

Construction of the mini CyberSeal is based on POM-C tube housing all the electronic components, sensors, li-ion 7.2V 10 Ah accumulator and servomotors – Fig. 3.

CyberSeal is equipped with the following sensors:

1. a digital compass OS-5000 from Ocean Server company,
2. a depth sensor A-10 from Wika company with 0-1 bar range.

Fins are driven by the servomotors with the 1:1 angular gears. Servomotors are controlled by POLOLU-1353 miniMaestro servo controller via RS-232 interface. Communication is based on the wifi network supported by the TP-LINK TL-WR702N access point and server port WIZNET Wiz-145SR, providing four serial ports. The block diagram of the connections between different electronic devices located inside a hull of mini CyberSeal is illustrated in the Fig. 6.

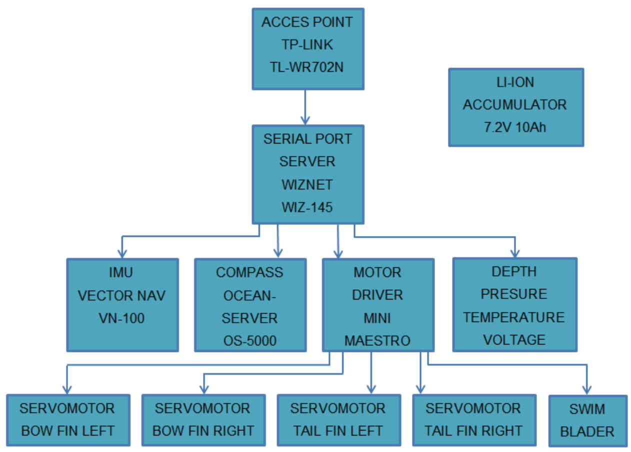

Fig. 6. Block diagram of the mini CyberSeal components

The mini CyberSeal was additionally equipped with internal artificial swim bladder responsible for a buoyancy control of the vehicle.

Side an tail fins of the BUV were made a polycarbonate and a rubber. The dimensions of the fins were illustrated in Fig. 7.

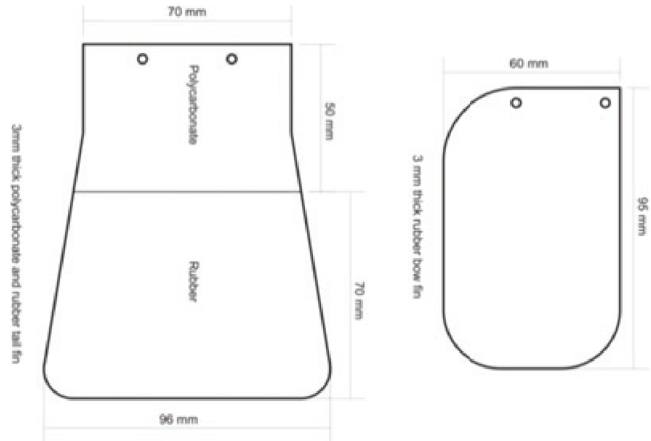

Fig. 7. Dimensions of the side and tail fins of mini CyberSeal

The side fins can move in the range of ±45° with a speed up to 3 Hz, while the tail fins can move in the range from approx. 80° outside to 12° inside according to the longitudinal axis of symmetry with a speed up to 3 Hz. The range of tail fins were illustrated in Fig. 8.

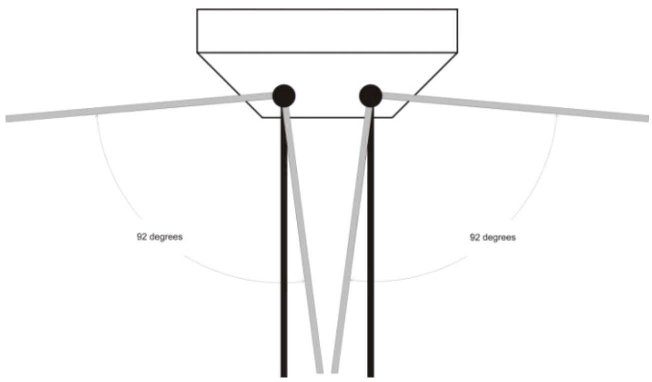

Fig. 8. Range of motion of the tail fins of mini CyberSeal

4. Software for the mini CyberSeal control

The software for control motion of the mini CyberSeal was written in C++ and allow us to control all the parameters of fins (a frequency and an amplitude of oscillation) and read the following parameters from the CyberSeal (Fig. 9 and 10):

- Voltage and current driven from the batteries, measured by microprocessor battery management system,
- Depth achieved from the pressure sensor,
- Heading received from the digital compass,
- Pitch obtained from the Inertial Measurement Unit IMU,
- Roll from the IMU,
- Inside temperature and pressure, measured by the additional sensors.

Moreover, the vehicle was equipped with sensor for water leakage detection. The information about possible leakage is transmitted together with the itemized above parameters.

Changes of the fins' parameters can be made using joystick or the autonomy software. All the settings are presented in the control application windows (Figs 9 and 10).

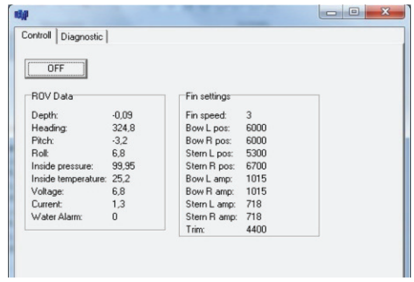

Fig. 9. Software for control motion of mini CyberSeal – visualization of fins' parameters

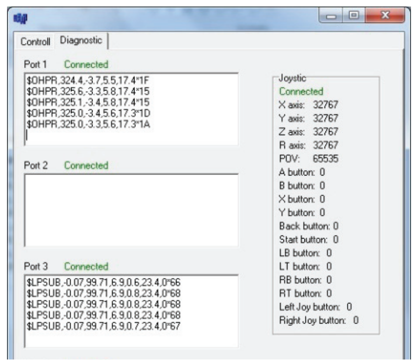

Fig. 10. Software for control motion of mini CyberSeal – visualization of the joystick settings and CyberSeal parameters

5. Software for the mini CyberSeal positioning

The application for determination of a position of the mini CyberSeal was based on a marker detection. One marker located in the middle of the BUV's hull is used for the purpose of calculating position of the mini CyberSeal. The application was developed using C++ language and Qt and OpenCV library. The communication with a user was established via user interface presented below.

The GUI (Fig. 11) was equipped with following functionality:

- changing colours of blow and stern markers,
- calibration of the camera,
- determination of transformation matrix,
- cropping images,
- review images,
- changing camera parameters,
- tracking objects,
- saving tracking data to a file.

Calibration of the camera and determination of transformation matrix are essential for the purpose of measurement accuracy, therefore it can be conducted at any moment, for example after changing position of the camera. Cropping images is useful for reducing calculation time, because only region of mini CyberSeal movement is taken under consideration. Changing camera parameters is essential for calculation time and for compensation of lighting conditions.

For the purpose of tracking CyberSeal the following computer vision algorithms were implemented:

- image filtering,
- morphological operation,
- image transformation,
- image segmentation,
- contour calculation,
- image moments calculation.

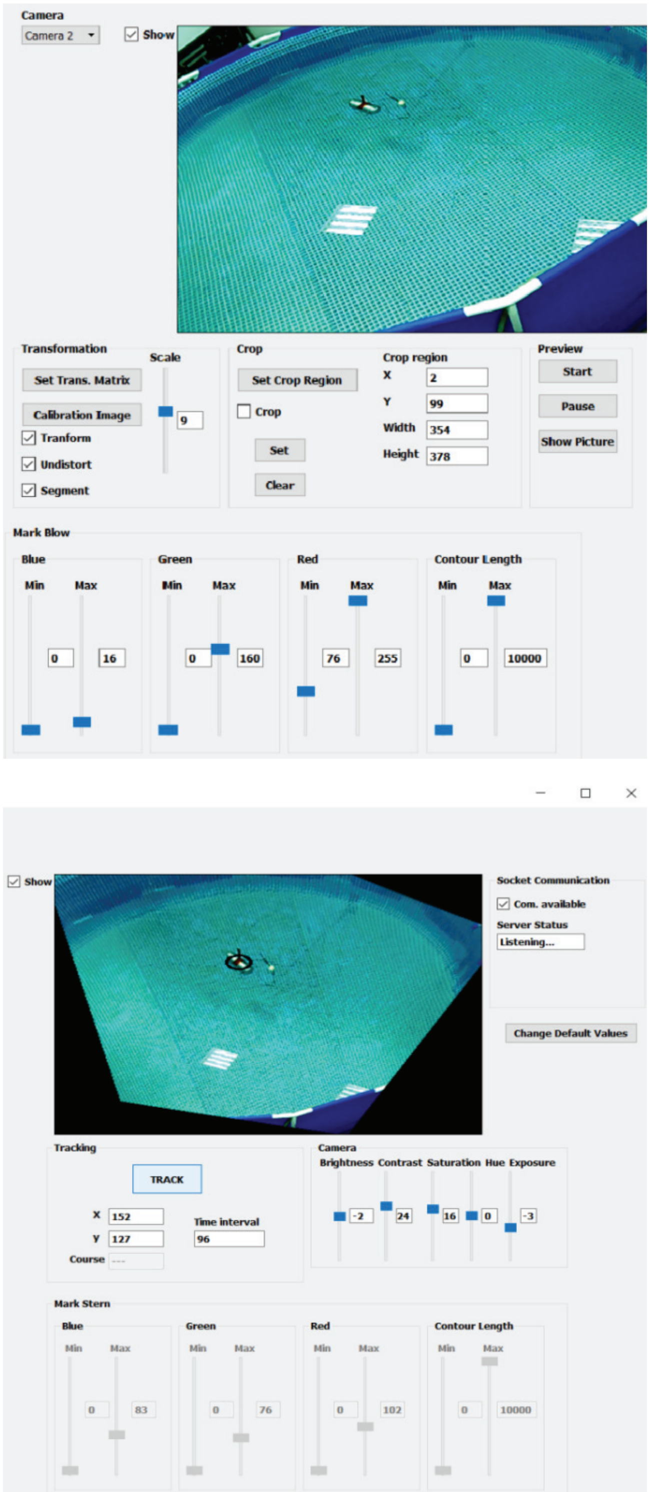

Fig. 11. Graphical User Interface of software for positioning mini CyberSeal (left and right parts of the main window)

As the result of tracking algorithm processing, the position coordinates x, y, course and execution time are returned. They are presented on elaborated GUI and saved to a file.

6. Results of the initial tests

The initial tests were conducted in three phases. In the first phase, the motion parameters of the mini CyberSeal propulsion system during straight forward motion were examined. In the second phase, the similar tests of propulsion system, but for turning maneuvers were carried out. Then, in the third phase the application for BUV positioning was tested.

At the beginning, tests of the side and tail fins were conducted separately. Then, the combined operation of the side and tail fins was examined. The fins of the mini CyberSeal can move with a frequency from 0.5 to 3 Hz with steps of 0.5Hz and an amplitude of oscillation up to 50°. The tests were performed in the swimming pool with the following dimensions: 5 m diameter and 1 m depth. The best results were obtained for the amplitude of approx. 30° and the frequency in the range of 1 to 2 Hz.

The results of tests of side and tail fins were included adequately in the Table 1 and 2. While the images' sequence showing the tail fins during straight forward motion was presented in the Fig. 12.

Tab. 1. The results of testing side fins of the mini CyberSeal

	Velocity, Hz	Amplitude, deg	Behavior
1	0.5	30	No movement
2	0.5	50	No movement, small oscillations
3	1	30	Very slow motion, lack of oscillations
4	1	50	Very slow motion, small oscillations
5	1.5	30	Slow motion, lack of oscillations
6	1.5	50	Slow motion, small oscillations and vertical movement
7	**2**	**30**	**Slow motion, lack of oscillations**
8	2	50	Slow motion, small oscillations and vertical movement
9	2.5	30	Slow motion, growing oscillations and vertical movement
10	2.5	50	Slow motion, big oscillations and big vertical movement
11	3	30	Rapid motion, big oscillations and big vertical movement
12	3	50	Rapid motion, big oscillations and big vertical movement

Tab. 2. The results of testing tail fins of the mini CyberSeal

	Velocity, Hz	Amplitude, deg	Behavior
1	0.5	30	No movement
2	0.5	50	Stroke movement
3	1	30	Very slow motion, lack of oscillations
4	1	50	Very slow motion, lack of oscillations
5	**1.5**	**30**	**Slow motion, lack of oscillations**
6	1.5	50	Slow motion, lack of oscillations
7	2	30	Slow motion, small oscillations
8	2	50	Slow motion, small oscillations and vertical movement
9	2.5	30	Fast motion, growing oscillations and vertical movement
10	2.5	50	Fast motion, growing oscillations and vertical movement
11	3	30	Rapid motion, big oscillations and vertical movement
12	3	50	Rapid motion, big oscillations and vertical movement

To achieve slow motion without oscillation and vertical motion, the side fins should work with frequency 2 Hz and amplitude of oscillation 30°, and the tail fins should work with frequency 1.5 Hz and the same amplitude. To achieve faster velocity, the both side and tail fins should work with larger frequency. During the higher velocity of motion, growing oscillations of course and vertical motion were observed.

The oscillations of course and additional vertical motions should be eliminated and/or minimized during the straight forward movement of the BUV, because they may cause additional hydrodynamic dumping and may complicate operation of some of the sensors, e.g. sonars. In the other hand, the larger vehicle has larger hydrodynamic resistance in longitudinal axis of symmetry and larger inertia due to its larger mass and accompanying water, what may cause smaller oscillations. This phenomena was observed in the ABPP with a length approx. 2 m and a mass approx. 55 kg comparing to the smaller CyberFish with a length approx. 0.6 m and a mass approx. 6 kg. The higher oscillations was observed for CyberFish than ABPP for the similar frequencies of oscillation of the fins.

In the Fig. 12, images' sequence of tail fins motions of the mini CyberSeal was illustrated. The tail fins are work in the counter phase, what gives an effect of throwing water located between tail fins backwards.

In the Tab. 3, the results of combined side and tail fins oscillations with different parameters were presented. The biggest velocity 0.4 m/s was obtained for tails' oscillations with frequency 2.5 Hz and amplitude 50°.

In the second phase of the research, the circulation tests were performed. During these tests, it was found that the side fins are not capable of controlling the direction of movement and turning in the same time. The side fins were only used for generating thrust for forward motion. While the turning maneuvers were based on synchronous motion of the tail fins. One of the tail fins was deflected outside to 65° and oscillated with an amplitude equal to 30°, while the other fin was only deflected to 12 degrees inside – Fig. 13. For the frequencies of oscillation in the range of 1 to 2.5 Hz, the circulation radius was approx. 1 to 1.5 m and the circulation times were illustrated in the Tab. 4.

The best circulation time was received for the highest frequency of the tail fin oscillation. In this case, the biggest moment of force relative to the vertical axis of symmetry was generated.

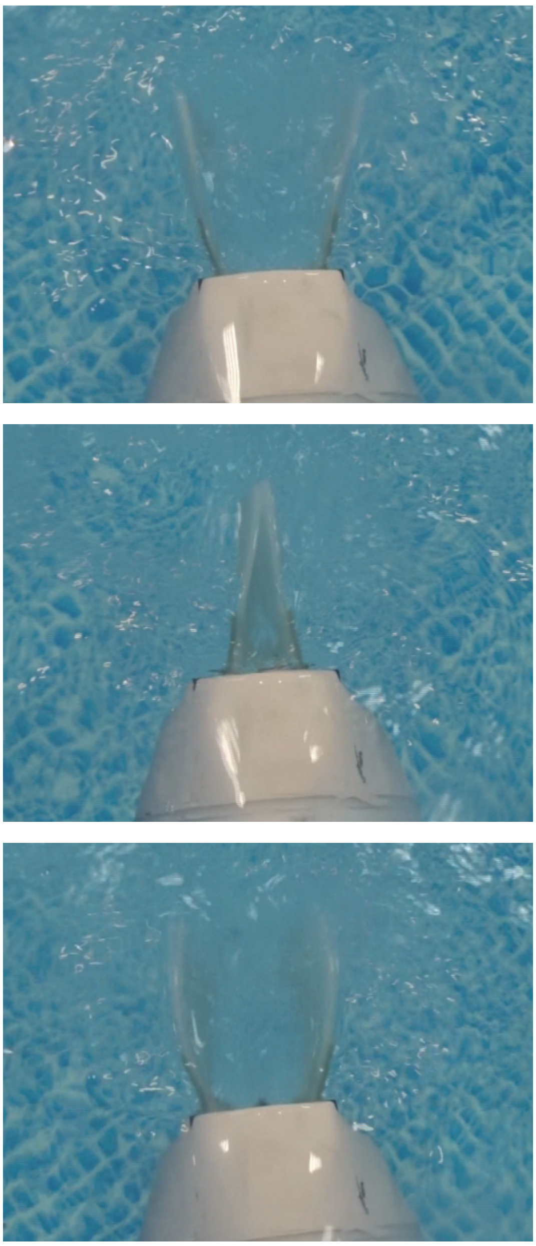

Fig. 12. Images' sequence of tail fins motions of the mini CyberSeal

Tab. 3. The results of side and tail fins oscillations with different parameters

Frequency of fins oscillation, Hz	Amplitude of fins oscillation, deg	Velocity of CyberSeal, m/s
1	30	0.15
1	50	0.2
1.5	30	0.2
1.5	50	0.3
2	30	0.25
2	50	0.3
2.5	30	0.35
2.5	50	0.4

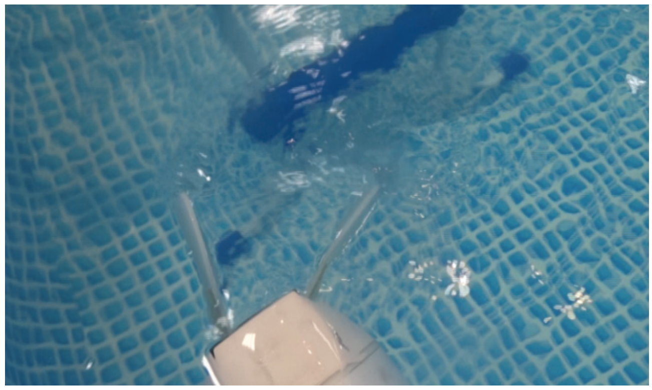

Fig. 13. The position of the mini CyberSeal tail fins during maneuver of turning left

Tab. 4. The results of circulation tests of mini CyberSeal

Fins velocity, Hz	Circulation time, s
1	50
1.5	40
2	35
2.5	35

In the last phase of the research, the positioning application was tested. In the Fig. 14, the mini CyberSeal positioned by the application for image processing was visualised. The red top fin is a marker recognized by the application. The fin is marked on the right image of the application by a circle moving together with the BUV – Fig. 14.

The positioning application was tested for the mini CyberSeal in both underwater and surface positions. In both cases, the red top fin was recognized and the coordinates *x* and *y* were calculated. The only problem was in the case that the BUV was submerged and the waves were on a surface of a swimming pool.

The additional issue is that the software is not capable to recognize if the vehicle is submerged or not. Therefore, the correction on coordinates determination in the case that the BUV is submerged should be calculated by PC, which receives information on BUV's depth by the wifi channel directly from the mini CyberSeal.

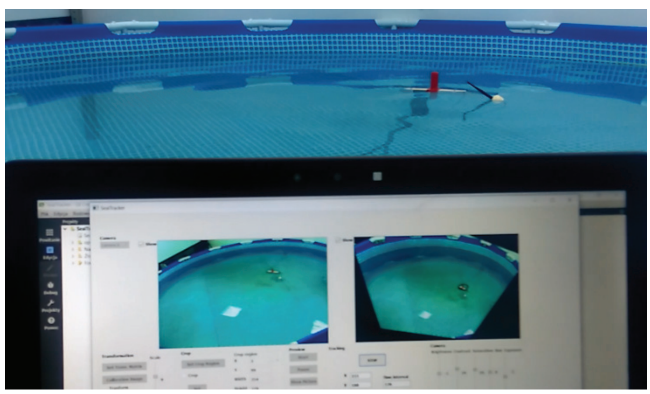

Fig. 14. The mini CyberSeal positioned by application for image processing

In the Fig. 15 and 16, changes in time of coordinates *x* and *y* are illustrated for motion of the mini CyberSeal on a surface of a swimming pool, registered from the application for image processing. As it can be observed, there is no gap in courses of coordinates *x* and *y*, which is a result of correct work of the application.

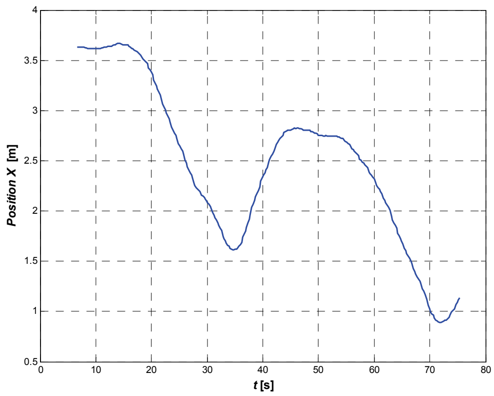

Fig. 15. Coordinate *x* of the mini CyberSeal obtained from the positioning application

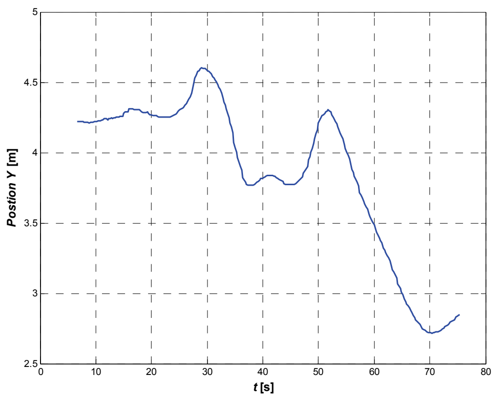

Fig. 15. Coordinate *y* of the mini CyberSeal obtained from the positioning application

7. Conclusions

The designed and implemented laboratory stand for research on the mini CyberSeal enabled to test initially the new propulsion system implemented in the mini CyberSeal, consisting of two side fins and two tail fins. The stand will be used in the following future research on:

- new ways of turning using tail fins,
- different kinds of course and depth's controllers, e.g. classical PID, slide mode, fuzzy controllers, etc.,
- submerging control with the assistance of the artificial swim bladder,
- control algorithms along desired trajectory,
- verification of errors of positioning application using video processing.

In the opinion of the Authors, the research carried out with the aid of the described laboratory stand allows for faster and more comfortable study on the larger CyberSeal.

The research described in this paper were achieved in the international project No. B-1452-GP, carried out in European Defence Agency in the years 2015-2018.

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