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THE EFFECT OF INTERFERENCE PARAMETERS ON THE EXPLOITATION CAPABILITIES OF AN UNDERWATER VEHICLE

ABSTRACT

This article presents the results of operations performed by an underwater vehicle in the course of approaching a target across water in which there exist pre-defined obstacles and sea currents. The mathematical model of a self-propelled payload for neutralizing mines type 'Głuptak' is used to model the operations performed by the vehicle. Because the underwater vehicle is powered by batteries it is necessary to assess whether there will be enough energy required to continue the approach to the target in the case of changes in the environment. The results presented refer to the effect of interference, caused by the marine environment, on the possibility to use the vehicle for this task. The energy consumption for the mentioned task is optimized with a genetic algorithm.

Key words:
underwater vehicle, exploitation, interference caused by environment, mathematical model, optimization, genetic algorithms.

INTRODUCTION

The task of underwater vehicles used in mine countermeasure operations is to identify mines by means of technical equipment installed in a vehicle and to destroy the detected mine with an explosive charge which the vehicle carries for this purpose. To perform this task it is important that its movement be precisely controlled, which is the condition for the successful completion of the operation, as on its way the vehicle can encounter some objects which it should pass at a certain distance whilst maintaining the preset speed in order to close in on the target.

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The self-propelled charge vehicle named ‘Głuptak’ designed for mine disposal is a remotely operated underwater vehicle designed in the Department of Ship Design and Underwater Robotics, at Gdańsk University of Technology (KTP PG). It is a one-shot vehicle, powered from its own on-board power source and remotely controlled through a cable-line. To minimize hydrodynamic damping of movement in an underwater environment, the designers used a torpedo shaped hull (fig. 1).

The vehicle is equipped with devices used to detect and identify targets (sonar, TV camera) and an explosive charge to destroy them. In addition, a transponder is installed in it, which together with an antenna and additional equipment installed on board the vehicle constitutes the underwater positioning system [19].

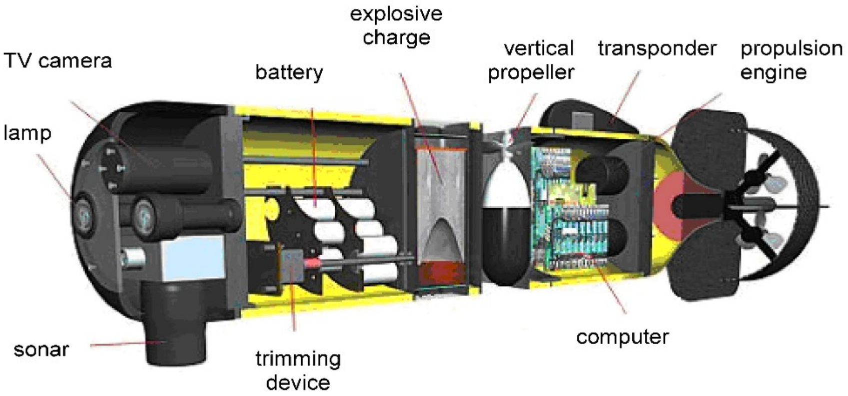


Fig. 1. The cross-section of the type ‘Głuptak’ self-propelled charge for underwater mine disposal [8]

The propulsion system used in ‘Głuptak’ consists of 4 horizontal propellers installed in the stern and a vertical propeller installed at the axis of the center of gravity and buoyancy (fig. 1). The system allows for maximum movement speed in water up to 3 m/s and for movement control within four degrees of freedom.

This article [22] defines the problem of a strategy used by the self-propelled charge in approaching a mine in a water environment in which it is affected by sea currents. It presents two strategies for countering a sea current:

- continuous correction of the preset magnitudes of regulated movement parameters (in the case when the underwater vehicle was pushed away from the preset trajectory by underwater currents — new magnitudes of the preset movement parameters were calculated);
- correction of the preset magnitudes of the regulated movement parameters based on coordinates (after entering the preset movement trajectory coordinates of

the target were calculated in the horizontal and vertical plane; changes in coordinates in time gave the indirect information on the sea current acting on the vessel).

The results of implementation of the two strategies are presented in figure 2.

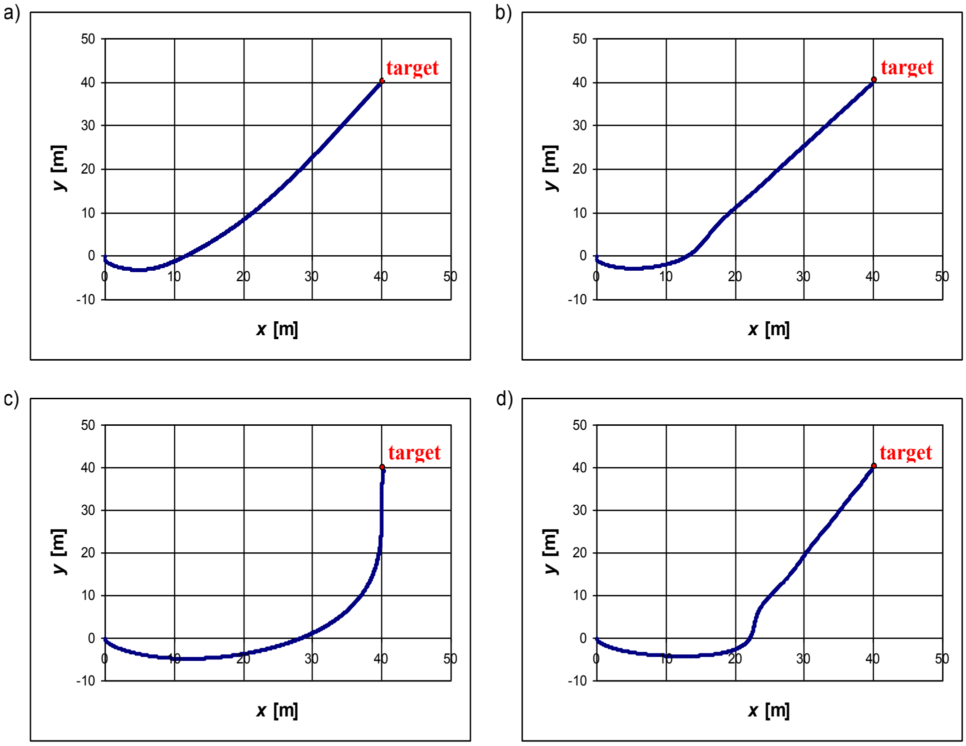


Fig. 2. Automatic control of the self-propelled charge 'Guptak' in the horizontal plane: a) continuous correction; b) correction based on measuring the preset course magnitude in the environment with a sea current having different speed and direction action; a) b) V_c = 1m/s, α_c = 60°, c) d) V_c = 1m/s, α_c = 90° [22]

In the investigations based on method 2 an answer is missing to the question of when using this method the vehicle will reach the target being on the border of its range. This results from the fact that the investigations were carried out only in an area which was a square having a 40 m sides. The effect of control strategy on energy consumption stored in the batteries and the effect of obstacles on the vehicle's track on the effectiveness of the applied strategy were not taken into account. It was also assumed that the approach speed towards the target is 0.5 m/s, which, after taking into account the characteristic describing damping rate (fig. 5) causes the simulation results to be encumbered with a significant error due to absence of the possibility to correctly assess matrix D.

For the above reasons the author decided to deal with the problem described in [22] and extending it by the problem of energy consumption in performance of a task by the underwater vehicle.

THE MATHEMATICAL MODEL OF AN UNDERWATER VEHICLE

For the purposes of analyzing the underwater vehicle 'Głuptak', as in [22] two reference systems were used:

- moving coordinate system $0x_0y_0z_0$ referred to the underwater object;
- fixed coordinate system 0xyz referred to the Earth [3].

The beginning of the moving coordinate system 0 usually corresponds to the center of vehicle's gravity, whereas its axes are defined as x_o — longitudinal axis directed from aft to fore, y_o — perpendicular axis directed from top to bottom. Changes in positions of the moving coordinate system are described with reference to the adopted coordinate system, referred to the Earth.

In order to describe the underwater vehicle in 6 degrees of freedom movement equations were used which in their matrix form adopt the following form[3]:

$$\boldsymbol{M}\dot{\boldsymbol{v}} + \boldsymbol{D}(\boldsymbol{v})\boldsymbol{v} + \boldsymbol{g}(\eta) = \tau, \tag{1}$$

where:

ν — vector of linear and angular speed in the moving system, i.e. $\nu = [u, v, w, p, q, r]$;

η — vector of underwater vehicle's positions and Euler angles in the system referred to the Earth, $\eta = [x, y, z, \phi, \theta, \psi]$;

M — inertion matrix (equal to the sum of rigid body matrix and accompanying masses);

D(ν) — hydrodynamic damping matrix;

g(η) — restoring force matrix (gravity forces and buoyancy forces);

τ — vector of forces and moments acting on the vehicle, i.e. $\tau = [X, Y, Z, K, M, N]^T$.

Due to their negligent numerical significance, in equations of movement of the underwater vehicle 'Guptak', like in [22], matrixes of Coriolis centrifugal forces and centripetal forces were neglected. The problem of nonlinear mathematical model of an underwater vehicle was discussed in a broader manner in [3, 4, 23, 24].

As a result of the experimental research carried out by designers from KTP PG, characteristics describing performance of the propulsion system of the vehicle 'Głuptak' can be used in the vehicle model.

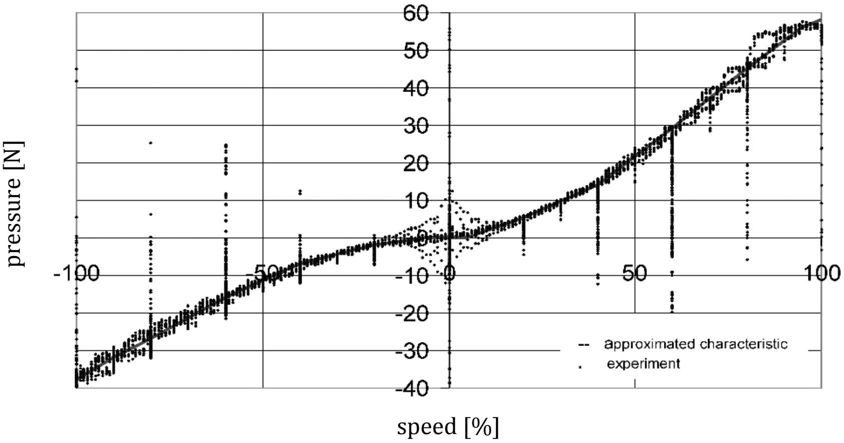


Fig. 3. The ram characteristics of a propeller (when V = 0) [KTP PG]

Figure 3 presents the ram characteristic of an engine used in the mathematical model, which in connection with the current characteristic of a single propeller (fig. 4) makes it possible to generate characteristic T = f(I), which can be used to quickly assess the energy consumed by engines of the underwater vehicle during a performance of its task.

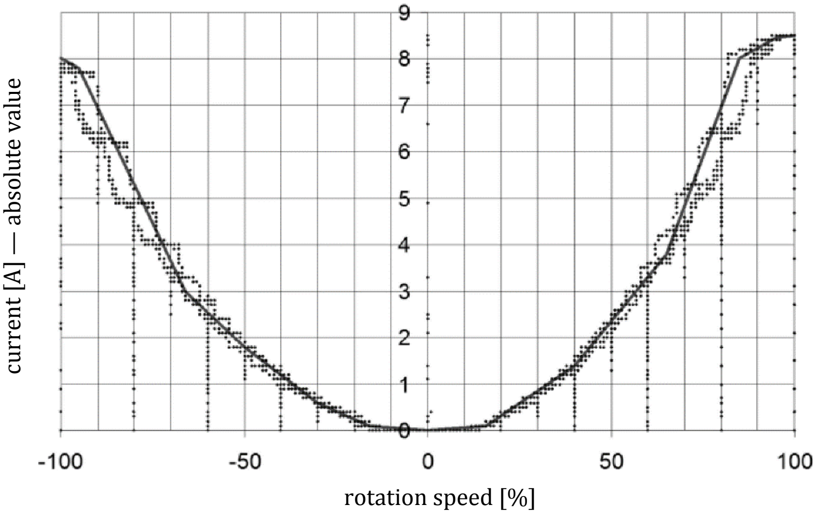


Fig. 4. The current characteristic of a single propeller (mean voltage magnitude 26 [V], maximum drop 1.2 V) [KTP PG]

In the course of the simulation-based investigations adopted, the following simplifications were adopted allowing for faster conduct of the simulation, during which the effect of the direction and speed of the sea current on the performance of the task to approach a target by the vehicle was being observed:

- objects in a water area in which the vehicle was moving were fixed — the dangerous area was limited to the sphere [9–11, 15, 17];
- it was assumed that after the start the vehicle is moving at the speed of 2 m/s — this results from the characteristic describing the magnitudes of damping rate Dx depending on the underwater vehicle speed (fig. 5); this magnitude is the center of the range for which the approximating function was determined.

The effect of power supply for the remaining equipment installed onboard the vehicle on the present magnitude of energy accumulated in the batteries of the underwater vehicle was not taken into account — its impact on the energy in batteries has a constant character and depends on the manner the equipment pieces are used.

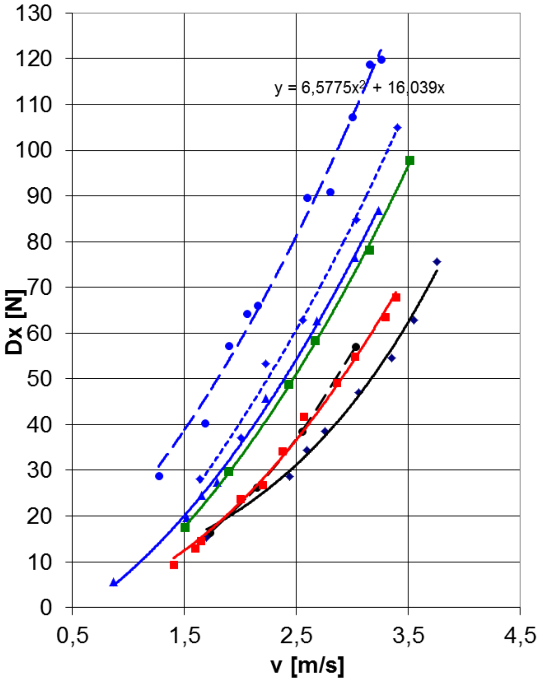


Fig. 5. The magnitudes of damping rate Dx dependent on the underwater vehicle speed calculated for the underwater vehicle 'Głuptak' for trails carried out by the designers in a water tank using varied casing of the propeller screw; the approximation adopted for the mathematical model $y = 6.5775\ x^2 + 16.039\ x$; the approximating function is a function closest to real conditions [KTP PG]

PLANNING A TASK FOR THE UNDERWATER VEHICLE

An important element in carrying out a task by an underwater vehicle is to determine the initial trajectory for the vehicle in the water area in which it is expected to move. In the course of task performance a mechanism of genetic algorithms was used, which using inheritance mechanisms look for a suboptimum solution, dependent, to a large extent, on the form of assessment function [1, 7, 18, 21]. This function conducts the qualification of the investigated trajectories — their adaptation to the existing conditions, which in this case describe successive points of turn for the underwater vehicle.

For the purposes of this problem defined was a gene describing a point of turn in the trajectory and its description is presented in table 1.

Table 1. Gene structure [own work]

Coordinate X in space
Coordinate Y in space
Coordinate Z in space
Additional data — used by some procedures:
- section before — safety
- speed on the section before
- section after — safety
- speed on section after
- gene safety

The trajectory investigated with the assessment function contains genes describing successive points of turn — the number range of points of turn is set in the configuration of the simulation program. For more complete analysis, apart from successive genes, the start point P_P and the final P_K of the track are taken into account, which in the analysis take indexes *0* and *n + 1 respectively*.

Table 2. Building the track [own work]

G_0	G_1	G_2	…	G_n	G_{n+1}

Table 2 presents construction of a single track analyzed by a track algorithm for a chromosome whose length is *n*. The thickened cells have the structure in compliance with table 1, as they are genes, and the beginning and the end of the track can be called pseudo genes as they are needed to improve calculations and because of this they are reduced to the information on position, as important information is contained in the neighboring genes.

In the course of investigating the trajectory, the magnitude determining its quality is the total cost of trajectory taking into account both safety conditions $C_S(S)$, and the movement economy $C_E(S)$ of the vehicle moving along the trajectory, which is defined as [9–11, 15, 17, 21]:

$$C_T(S) = C_S(S) + C_E(S). \tag{2}$$

The safety conditions are met if the trajectory does not extend beyond the safety area around the objects in the water area.

The cost of the trajectory relating to economic conditions $C_E(S)$ is composed of magnitudes:

- The whole length of the trajectory S composed of n stretches s_i – $C_D(S)$.

The simplest method is to use, on the whole of the trajectory, the formula:

$$C_D(S) = \sum_{i=0}^{n} dług(g_i, g_{i+1}). \tag{3}$$

Due to the fact that the underwater vehicle moves in the environment in which there occurs a sea current and there can occur changes in magnitudes of this current, it is not advisable to indicate two successive points of turn being too close to each other, as it may negatively affect the performance of the vehicle in a situation of strong interference.

For this reason assessment of the length of the trajectory is expressed through the sum of proportions of individual stretches of the track in relation to the distance between the beginning and the end of the track (if points of turn overlap, eternity is added to the assessment) — the result is a more even array of points of return, absence of occurrence of 2 successive points of return next to each other:

$$C_D(S) = \sum_{i=0}^{n} \frac{dług(g_0, g_{n+1})}{dług(g_i, g_{i+1})}. \tag{4}$$

- Function of angles of turn between particular stretches of the trajectory in points of return s_i – $C_K(S)$.

Making use of the function of a cosine of the angle contained between neighboring stretches of trajectory, the function of angles of turn can be expressed as the highest magnitude of the angle in points of turn [1, 21].

It follows from the previously made assumptions, that when assessing the energy necessary for making a turn in successive points of turn, determining the minimum sum of the angles becomes more important than determining its maximum magnitude. Thus the function above is for minimizing purposes as follows:

$$C_K(S) = \sum_{i=1}^{n} arccos(\cos k\text{ą}t(g_i)). \quad (5)$$

Where $\cos k\text{ą}t(g_i)$ is cosine of angle at point g_i between the stretch before and the stretch after point g_i calculated using the formula for the angle between two vectors.

- Function of time for realization of trajectory S – $C_t(S)$.

Calculation of time needed to cover the investigated track is as follows:

$$C_t(S) = \sum_{i=0}^{n} \frac{d\text{ł}ug(g_i, g_{i+1})}{V(g_i, g_{i+1})}. \quad (6)$$

- Function of energy needed to realize the trajectory — $C_P(S)$.

An assumption was made that on the investigated stretch of the trajectory speed magnitudes have a constant character within a determined range. As a result it is possible to simplify, in a maximum degree, calculations relating to energy assessment. This led to the necessity to derive, by simplification, equations describing the dynamics of the vehicle in two variants:

- for calculations relating to linear motion;
- for calculations relating to a turn at a point of turn.

Vector $[T_1\ T_2\ T_3\ T_4\ T_5]$ of forcements generated on the individual propellers of the vehicle for both of these variants is determined using a matrix composed of coefficients taking into account characteristics of the individual propellers as well as the vehicle propulsion configuration [3].

Then a model of the propeller is made use of [3, 4, 20, 24], to be more precise of its characteristics in figures 3 and 4, from where obtained is vector $i = [i_1\ i_2\ i_3\ i_4\ i_5]$ of current magnitudes in the power supply system using in succession functions $n = f(T)$ and $I = f(n)$.

It is assumed that the stretch between node g_k, i g_{k+1} is considered and that for this stretch the determined time for passage is t_k (calculated in the course of calculating the time for covering the trajectory)

$$C_P(S) = \sum_{k=0}^{k=n} \sum_{j=1}^{5} i_j U t_k, \quad (7)$$

where:

i_j — magnitude of current in j-propeller in k-stretch of the trajectory;

U — power supply voltage;

t_k — duration time of the k-stretch.

This magnitude expresses the amount of energy needed to cover the whole trajectory.

More detailed information on the amount of energy needed to cover the investigated trajectory is obtained after change in direction at points of turn is taken into account.

In the course of verifying this method, based on observation, it was noticed that this magnitude is proportional to the magnitude of the sum of angles of direction change. This stems from the assumption that the vehicle is moving at a constant speed. This made it possible to quicker assess the magnitude for the purposes of the algorithm.

Eventually, the energy needed to cover the whole trajectory can be determined as follows:

$$C_P(S) = \sum_{k=0}^{k=n} \sum_{j=1}^{5} i_j U t_k + A \sum_{i=1}^{n} k\k{a}t(g_i), \tag{8}$$

where coefficient A is determined in an experimental manner.

The whole cost of adapting the trajectory to the environment, stemming from the economic conditions is equal to:

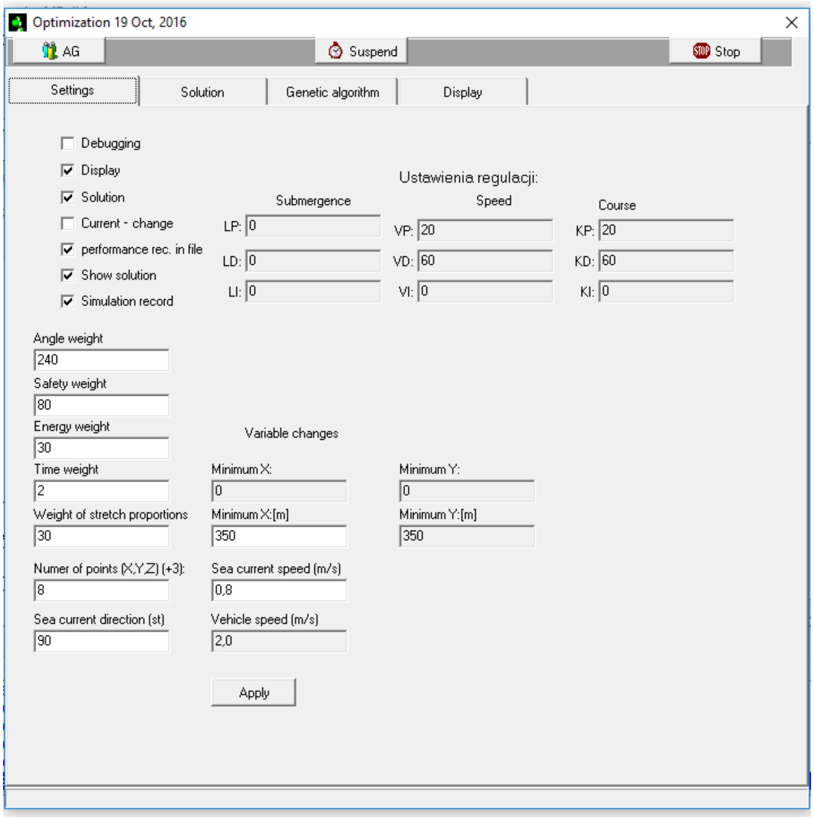
$$C_E(S) = w_D \cdot C_D(S) + w_K \cdot C_K(S) + w_t \cdot C_t(S) + w_P \cdot C_P(S), \tag{9}$$

where:
w — weights of particular components of movement economy.

For the purposes of the problem considered in the article dedicated software package was designed and then elaborated. The main aim of this package was to make calculations concerned with seeking for a suboptimum track for the underwater vehicle for various settings. Another feature of the software is that it can be used to carry out a vehicle performance simulation for a defined environment and earlier found track. Apart from this, it is also possible to add, in the course of simulation, changes in the description of the environment. All the operations of the vehicle in the course of simulation are recorded, which allows for later analysis of selected parameters of the vehicle, e.g. using MATLAB environment.

Weight settings for particular assessment function components can be seen on the software display (fig. 6).

The effect of the simulation program on the settings of the genetic algorithm (fig. 7) is the suboptimum trajectory (fig. 8), for which the effect of interference parameters was investigated.



☐ Debugging
☑ Display
☑ Solution
☐ Current - change
☑ performance rec. in file
☑ Show solution
☑ Simulation record

Ustawienia regulacji:

Submergence
LP: 0
LD: 0
LI: 0

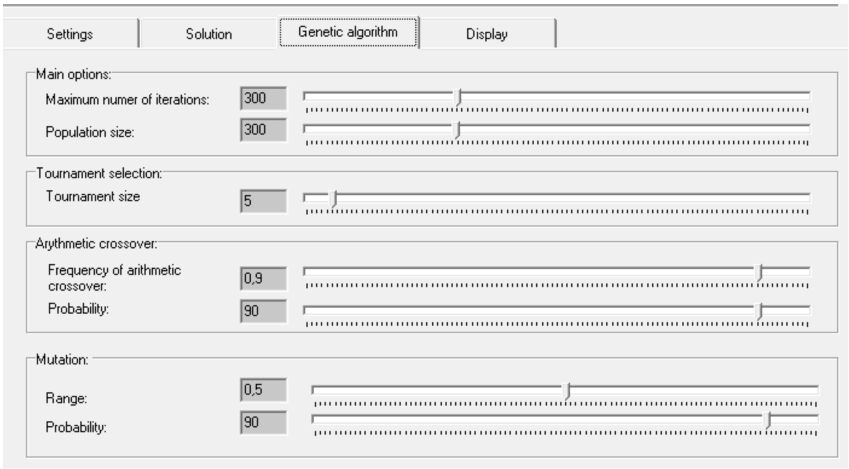
Speed
VP: 20
VD: 60
VI: 0

Course
KP: 20
KD: 60
KI: 0

Angle weight: 240
Safety weight: 80
Energy weight: 30
Time weight: 2
Weight of stretch proportions: 30
Numer of points (X,Y,Z) (+3): 8
Sea current direction (st): 90

Variable changes
Minimum X: 0
Minimum X:[m]: 350
Minimum Y: 0
Minimum Y:[m]: 350
Sea current speed (m/s): 0,8
Vehicle speed (m/s): 2,0

Fig. 6. Settings of weights and environment for a simulation [own work]



Main options:
Maximum numer of iterations: 300
Population size: 300

Tournament selection:
Tournament size: 5

Arythmetic crossover:
Frequency of arithmetic crossover: 0,9
Probability: 90

Mutation:
Range: 0,5
Probability: 90

Fig. 7. Settings of main parameters of the genetic algorithm for the simulation; the maximum length of the trajectory in fig. 6 [own work]

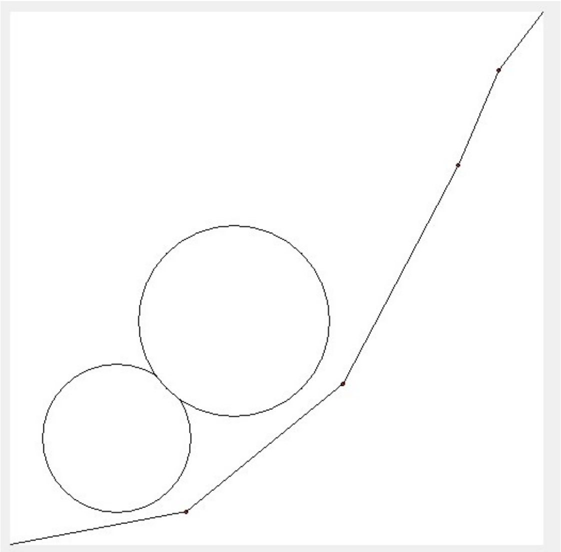


Fig. 8. The suboptimum trajectory for settings in fig. 6 [own work]

EXPLOITATION OF THE UNDERWATER VEHICLE IN INTERFERENCE CONDITIONS

In the course of the simulation-based investigations the following changes in vehicle parameters and interference were determined:

- varied vehicle speed, constant magnitude of sea current speed and course;
- varied sea current speed, constant magnitude of vehicle speed and sea current course;
- varied sea current course, constant magnitude of vehicle speed and sea current speed.

All the simulations were carried out using two regulators PD (settings in fig. 5). The first one was responsible for the vehicle speed and the other one for the vehicle course in relation to the nearest point of turn on the pre-planned trajectory of the underwater vehicle. The trajectory is calculated from the place the vehicle is put on water, so its initial speed is 0 m/s.

Tables 3–5 present energy consumption by the power supply system of the vehicle 'Głuptak' on the stretch from the place it is put on water to the target placed on the opposite apex of the area in the shape of square, having the side of 350 m. The energy consumption was compared with the energy accumulated in batteries. The maximum operation time of the vehicle given by the designers is 30 min.

Exploitation of the underwater vehicle at varied speed

Table 3. Simulation results — varied vehicle speed magnitudes, sea current from the direction 90° and speed 0.8 m/s [own work]

No.	Vehicle speed [m/s]	Simulation time [s]	Track covered in simulation [m]	Energy consumed in simulation [mAh]	Energy consumption max time of work [%]
1	1.2	571	684.14	356.48	7.03
2	1.6	371	592.99	577	17.5
3	2.0	283	565.46	759.29	30.18
4	2.4	231	552.76	946.42	46.09
5	2.8	195	545.34	1316.71	75.96

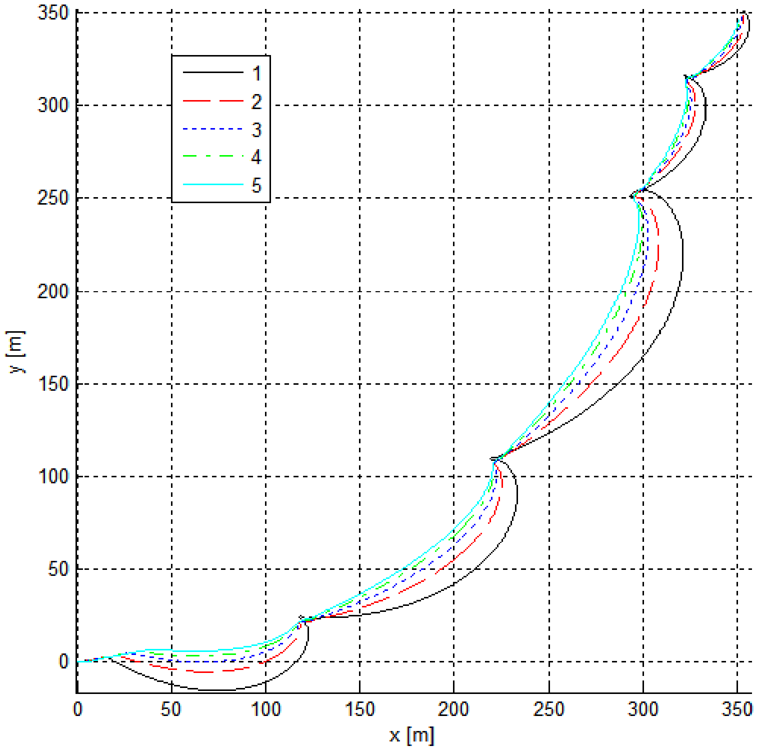


Fig. 9. Vehicle trajectories — description based on table 3 [own work]

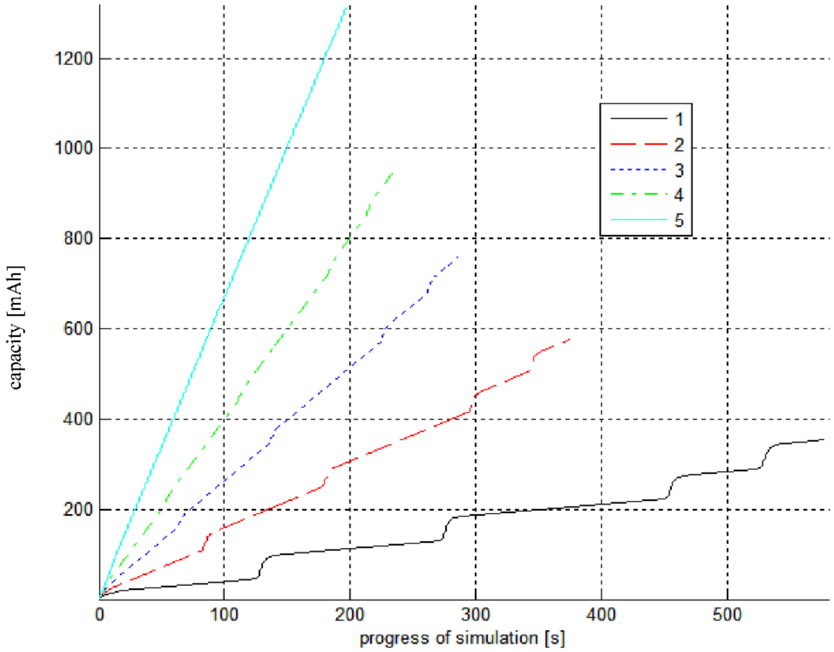


Fig. 10. Energy consumption in batteries — based on table 3 [own work]

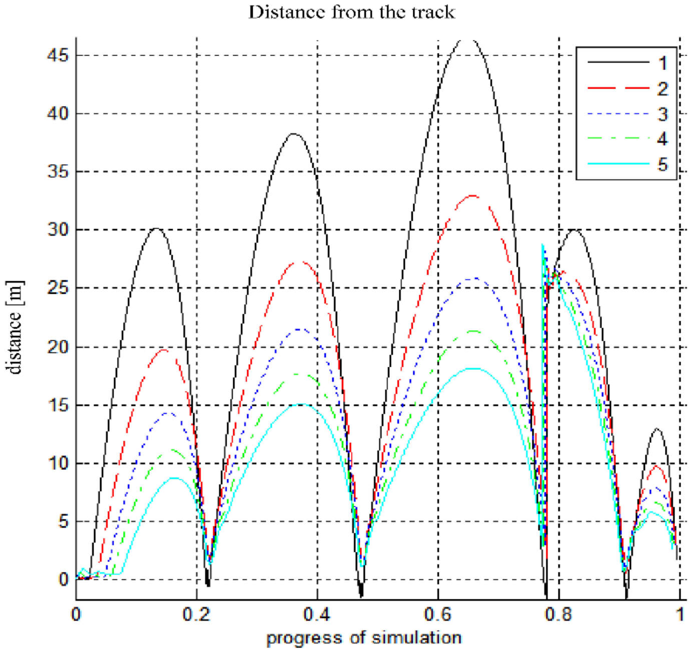


Fig. 11. Distance of vehicle from trajectory — based on table 3 [own work]

Exploitation of the underwater vehicle at varied sea current speed

Tabele 4. Simulation results — various sea current speed magnitudes, vehicle speed id 2.0 m/s, sea current from the direction 90° [own work]

Lp.	Sea current speed [m/s]	Simulation time [s]	Track covered in simulation [m]	Energy consumed in simulation [mAh]	Energy consumtion max time of work [%]
1	0.4	268	534.45	777.05	32.62
2	0.6	274	546.56	777.27	31.91
3	0.8	283	565.46	759.29	30.18
4	1.0	298	595.14	729.56	27,54
5	1.2	323	644.37	693.02	24.14

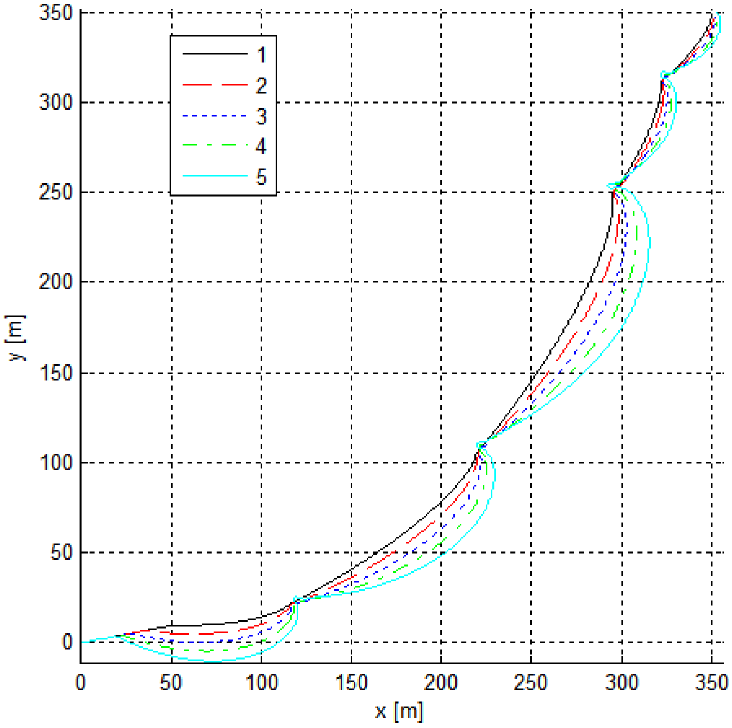


Fig. 12. Vehicle trajectories — description based on table 4 [own work]

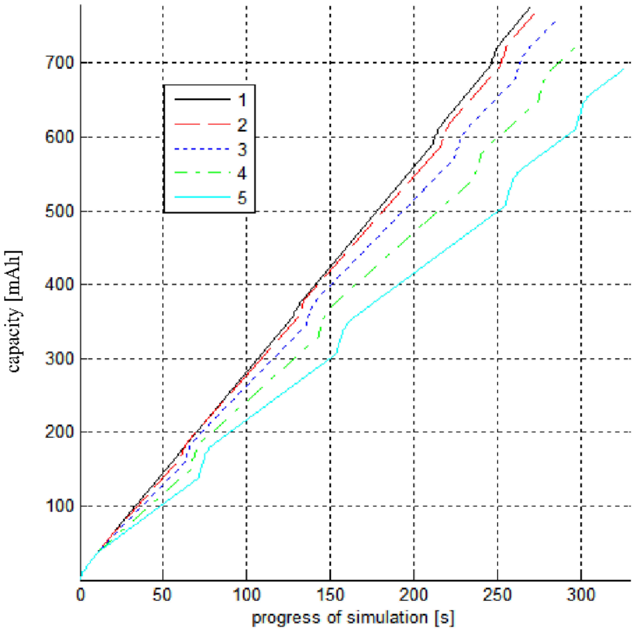


Fig. 13. Energy consumtion in batteries – based on table 4 [own work]

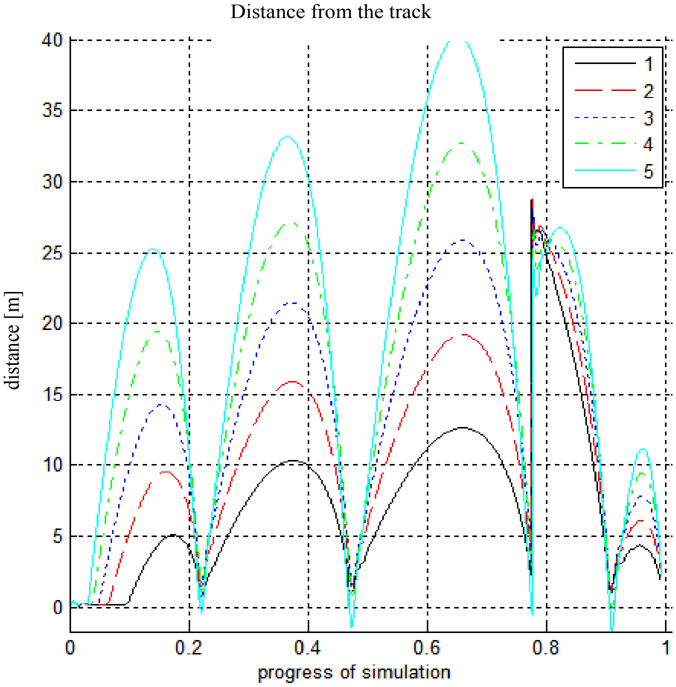


Fig. 14. Distance of vehicle from trajectory — based on table 4 [own work]

Exploitation of the underwater vehicle at varied sea current magnitude

Table 5. Simulation results: various directions of sea current activity, vehicle speed is 2.0 m/s, sea current speed — 0.8 m/s [own work]

Lp.	Sea current course [°]	Simulation time [s]	Track covered in simulation [m]	Energy consumed in simulation [mAh]	Energy consumption max time of work [%]
1	60	278	554.24	932.73	37.75
2	75	282	562.27	844.88	33.71
3	90	283	565.46	759.29	30.18
4	105	282	562.28	681.95	27.21
5	120	278	554.49	614.64	27.87

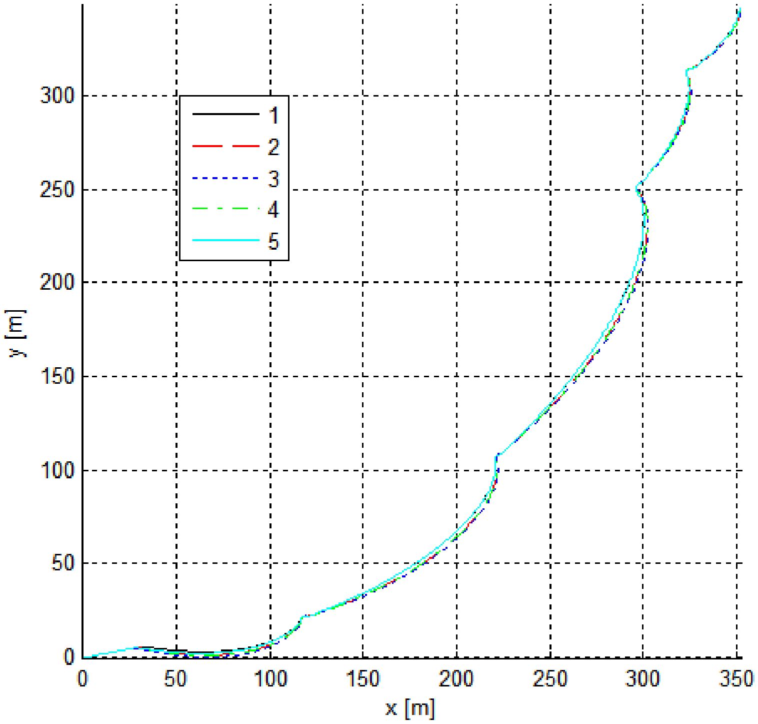


Fig. 15. Vehicle trajectories — description based on table 5 [own work]

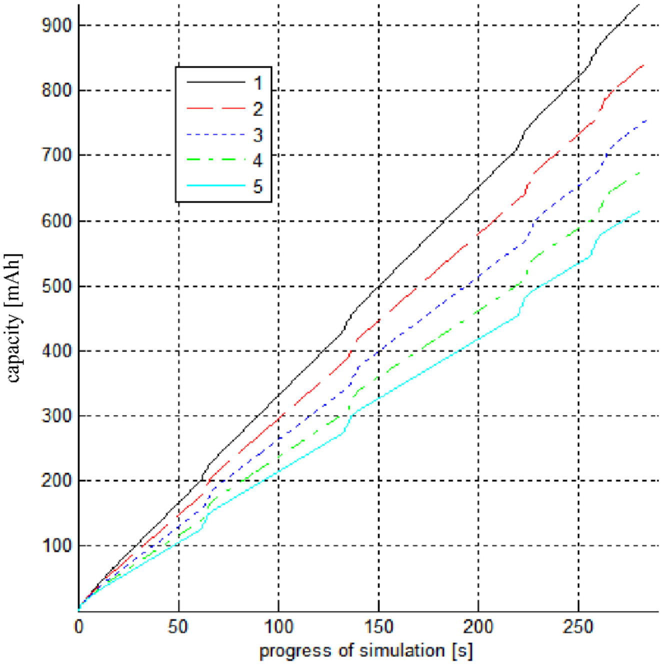


Fig. 16. Energy consumption in batteries — description based on table 5 [own work]

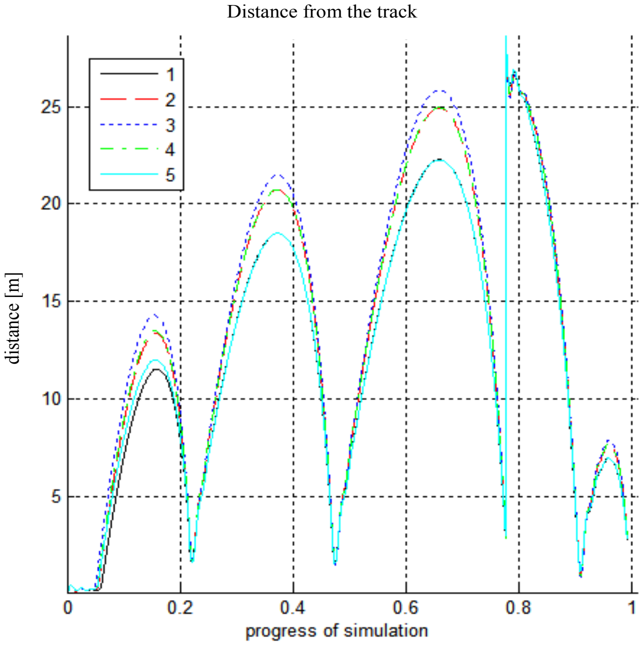


Fig. 17. Distance of vehicle from trajectory — description based on table 5 [own work]

SUMMARY

The simulation-based investigations of the self-propelled charge were carried out without taking into account the maximum error in determining the vehicle position, which according to the designers is estimated as approx. 1 m.

It can be noticed from the simulations carried out, that of the investigated environment parameters the sea current direction has the least effect on the underwater vehicle: table 5, figures 15–17. It can be seen in them, that the change in the sea current direction changes the vehicle trajectory in a small degree, as its magnitude is similarly compensated for the investigated magnitudes of the current — the trajectories are close to each other (fig. 15 — deviation between the extreme trajectories does not exceed 4 m). Energy consumption does not change dramatically (fig. 16), and the distance from the preset trajectory was similar in the case of each variant (fig. 17).

In the case of change in the underwater vehicle speed (table 3, fig. 9–11) it can be seen that the result of using the underwater vehicle at close to maximum speed is most of the energy from the batteries is consumed by the propulsion system. Such a situation limits the time for use of the underwater vehicle.

In the case of changes in the sea current speed magnitudes it can be seen (table 4, fig. 12–14) that as a result of the adopted control system the consumption of energy accumulated in the battery will differ insignificantly (table 4). In addition, a strong extension of the trajectory can be seen (fig. 12), dangerous pushing away from it.

Analyzing figures 11, 12 and 17, which for each of the investigated variants determine the distance of the vehicle from the preset trajectory, it can be seen that using course regulation for the vehicle is not sufficient, as deviation of the vehicle from the preset trajectory sometimes exceeded 30 m, which in the case of the simulation water tank having dimensions 350 x 350 m is too high, which can disqualify the vehicle from use in a water area where there are obstacles or if it was necessary for the vehicle to pass near a dangerous area. In the presented simulation the vehicle should pass about 6m from a dangerous area, and the sea current in this configuration pushes it away from dangerous areas. In this control configuration it is necessary to use information on vehicle deviation from the preset trajectory.

Comparing the simulation results with the results presented in [22] attention should be focused on the following data: in [22] the vehicle was to pass through the water area in which the target was 56 m away. In this water area the vehicle in variant 2 moved away from the preset trajectory by about 16 m. As a result of the simulation the nearest case is the case from table 3, position 1, where the vehicle is moving at a speed of 1.2 m, where the distance to the first point of turn was about 110 m — deviation from the preset trajectory was 30 m. It should be noticed that in [22] the sea current direction has big effect on the deviation from the preset trajectory — for 90° the deviation is 16 m, and for 60° twice less. For the variant 1 the difference was significantly higher from 22 m to 5 m. In the presented simulation results following table 5, it can be seen that the difference in deviation magnitudes from the preset trajectory for changes in the sea current does not exceed 20%. The possible cause of the discrepancy is presented in the introduction to this article.

In both cases it can be seen that similar modifications of the control system are needed.

It follows from the analysis of the performance of the underwater vehicle that another regulator must be added. Its task will be to regulate the position of the vehicle in relations to the preset trajectory. The result of the added regulator will be flattening the characteristics presented in figures 11, 14 and 17. The form of the characteristics suggest using a PD regulator. It will be possible to lower the characteristics presenting the energy consumed by the vehicle (fig. 10, 13 or 16) due to actual shortening of the track, which the underwater vehicle will cover in relations to the preset trajectory, preset set for the vehicle to carry out the task.

It should be expected that an extra result of using a vehicle position regulator in relations to the preset trajectory will be decrease in the effect of an error in vehicle position. This will allow for more precise passage of the vehicle through a variable environment.

REFERENCES

[1] Dulęba I., *Metody i algorytmy planowania ruchu robotów mobilnych i manipulacyjnych*, EXIT, Warszawa 2001 [*Methods an algorithms used for planning movement of mobile and manipulation robots* — available in Polish].

[2] Fossen T. I., Fjellstad O. E., *Nonlinear modelling of marine vehicle in 6 degrees of freedom*, 'Journal of Mathematical Modelling of Systems', 1995, No. 1.

[3] Fossen T. I., *Guidance and Control of Ocean Vehicles*, John Wiley & Sons Ltd., 1994.

[4] Garus J., *Dynamika i sterowanie bezzałogowego statku głębinowego*, 'Zeszyty Naukowe Akademii Marynarki Wojennej', 2005, No. 162 A [*Dynamics and control of unmanned deep water vehicle* — available in Polish].

[5] Gwiazda T. D., *Algorytmy genetyczne, kompendium*, Vol. I, *Operator krzyżowania dla problemów numerycznych*, PWN, Warszawa 2007 [*Genetic algorithms, compendium. Criss-crossing operator for numerical problems* — available in Polish].

[6] Gwiazda T. D., *Algorytmy genetyczne, kompendium*, Vol. II, *Operator mutacji dla problemów numerycznych*, PWN, Warszawa 2007 [*Genetic algorithms, compendium. Mutation operator for numerical problems* — available in Polish].

[7] Haupt R. L., *Practical Genetic Algorithms*, John Wiley Publication, Hoboken 2004.

[8] http://www.underwater.pg.gda.pl [access 21.04.2016].

[9] Leszczyński T., *Funkcja oceny dla metody wyboru drogi dla bezzałogowego pojazdu podwodnego*, 'Zeszyty Naukowe Akademii Marynarki Wojennej', 2007, No. 169 K/1, pp. 251–258 [*The assessment function for the method for choosing a track for an unmanned vehicle* — available in Polish].

[10] Leszczyński T., *Funkcja oceny dla metody wyboru drogi na przykładzie modelu pojazdu podwodnego typu 'Ukwiał'*, 'Zeszyty Naukowe Akademii Marynarki Wojennej', 2008, No. 172 K/2, pp. 115–126 [*The assessment function for the method for choosing a track based on the example of underwater vehicle 'Ukwiał'* — available in Polish].

[11] Leszczyński T., *Funkcja oceny w metodzie wyboru drogi*, 'Pomiary. Automatyka. Robotyka', 2008, No. 2, pp. 410–417 [*Assessment function in the method for choosing a track* — available in Polish].

[12] Leszczyński T., *Problem sterowania pojazdem podwodnym w środowisku zmiennym*, [in:] *Automatyzacja i eksploatacja systemów sterowania i łączności*, ed. Z. Kitowski, J. Lisowski, Gdynia 2005 [*The problem of control of a vehicle in a changeable environment*, [in:] *Automation and exploitation of control and communication systems* — available in Polish].

[13] Leszczyński T., *Przegląd wpływu niektórych parametrów ewolucyjnych na działanie metody wyboru drogi*, 'Zeszyty Naukowe Akademii Marynarki Wojennej', 2009, No. 177 B, pp. 231–242 [*Review of the effect of some evolutionary parameters on the method for choosing the track* — available in Polish].

[14] Leszczyński T., *The concept of the optimal use of the underwater vehicle in a changeable environment*, [in:] *The Role of Navigation in Support of Human Activity on the Sea*, Proceedings of the XVth International Scientific and Technical Conference, Gdynia 2006, pp. 171–176.

[15] Leszczyński T., *Wpływ funkcji oceny na algorytm sterowania pojazdem podwodnym w przypadku wystąpienia awarii pędnika*, [in:] *Perspektywy i rozwój systemów ratownictwa, bezpieczeństwa i obronności w XXI wieku*, ed. Z. Kitowski, J. Lisowski, Gdynia 2005 [*The effect of evaluation function on an algoritm of underwater vehicle control in case of propeller malfunction* [in:] *Prospects and developments in rescue, security and defense* — available in Polish].

[16] Leszczyński T., *Wpływ parametrów ewolucyjnych na działanie metody wyboru drogi bezzałogowego pojazdu*, 'Pomiary. Automatyka. Robotyka', 2009, No. 2, pp. 345–354 [*The effect of evolutionary parameters on performance of the method for choosing the track for an unmanned vehicle* — available in Polish].

[17] Leszczyński T., *Zarys metody wyboru optymalnej drogi dla pojazdu podwodnego*, 'Pomiary. Automatyka. Robotyka', 2007, No. 2, pp. 10 [*An outline of the method for choosing an optimum track for an underwater vehicle* — available in Polish].

[18] Mitchell M., *An Introduction to Genetic Algorithms*, MIT Press, Cambridge 1999.

[19] Rowiński L., *Opis rozwiązań technicznych analizowanych dla samobieżnego ładunku niszczącego, sprawozdanie z pracy badawczej*, Politechnika Gdańska, Gdańsk 2002 [*Description of technical solutions analysed for a self-propelled explosive charge* — available in Polish].

[20] Siegwart R., Nourbakhsh I. R., *Introduction to Autonomous Mobile Robots*, MIT Press, Cambridge 2004.

[21] Śmierzchalski R., *Synteza metod i algorytmów wspomagania decyzji nawigatora w sytuacji kolizyjnej na morzu*, WSM, Gdynia 1998 [*Synthesis of methods and algorithms used in nawigator decision suport in a collision situation at sea* — available in Polish].

[22] Szymak P., Garus J., Małecki J., *Strategia podejścia samobieżnego ładunku do celu-miny w środowisku podwodnym z oddziałującymi prądami morskimi*, 'Biuletyn WAT', 2008, Vol. LVII, No. 3, pp. 119–127 [*Strategy of approach of a self-propelled charge to a mine-target in an underwater environment with sea currents* — available in Polish].

[23] Szymak P., *Using of fuzzy logic method to control of underwater vehicle in inspection of oceanotechnical objects*, Artificial Intelligence and Soft Computing, 'Polish Neural Network Society', 2006, pp. 163–168.

[24] Szymak P., *Wykorzystanie metod sztucznej inteligencji dla sterowania pojazdem podwodnym w inspekcji obiektów oceanotechnicznych*, Akademia Marynarki Wojennej, Gdynia 2004 [*Use artificial intelligence methods for control of an underwater vehicle used to inspect oceanotechnical objects* — available in Polish].

WPŁYW PARAMETRÓW ZAKŁÓCEŃ NA MOŻLIWOŚCI EKSPLOATACYJNE POJAZDU PODWODNEGO

STRESZCZENIE

W artykule przedstawione zostały efekty działania pojazdu podwodnego podczas realizacji zadania jego podejścia do celu przez akwen, w którym występują określone wcześniej przeszkody oraz działają prądy morskie. Działania pojazdu są zamodelowane z wykorzystaniem modelu matematycznego samobieżnego ładunku do zwalczania min 'Głuptak'. Z uwagi na to, że pojazd podwodny jest zasilany z akumulatorów, w przypadku wystąpienia zmian w środowisku konieczne jest oszacowanie, czy wystarczy energii na kontynuację podejścia do celu. Prezentowane wyniki dotyczą wpływu zakłóceń środowiska morskiego na możliwości wykorzystania pojazdu podczas tego zadania. Zużycie energii dla wspomnianego zadania jest optymalizowane algorytmem genetycznym.

Słowa kluczowe:

pojazd podwodny, eksploatacja, zakłócenia środowiska, model matematyczny, optymalizacja, algorytmy genetyczne.