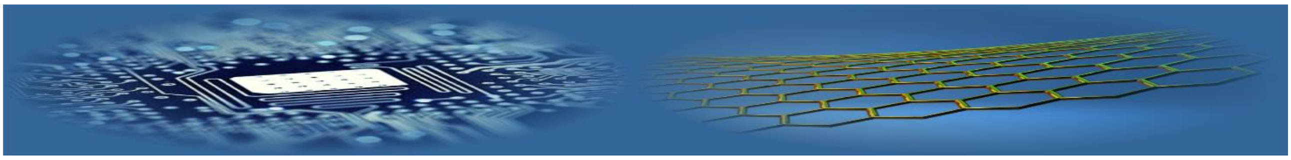

Decision support system on the base of genetic algorithm for optimal design of a specialized maritime platform

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Abstract

The analysis of possibilities of application of the small waterplane area twin hull ships (SWATH) as a specialty (universal) platform is performed. It is shown that the design of the specialized platform with a small waterplane area twin hull is characterized by a large number of parameters to be determined. The optimum relation selection between SWATH dimensions, seaworthiness, cost and efficiency is proposed by solving a multidimensional optimization problem with the use of special methods of searching solutions. The optimization problem of designing a universal platform is formulated. The constraints accounting on SWATH technical characteristics is produced by using the method of penalty functions. To solve the optimization problem, one of modern search methods – genetic algorithm is used. An example of solving the problem of selection the main dimensions of 25 m platform using a genetic algorithm is presented.

Keywords:

SWATH,
specialized platform,
genetic algorithm,
optimization,
Mission Module

1 Introduction

For most small countries, as well as countries with limited funding for the maintenance and development of the fleet, the actual problem is to provide the legal regime and protect national interests in the maritime exclusive zone in difficult weather conditions.

One of the possible ways of solving this problem is to use a universal specialized platform with increased seaworthiness and small dimensions. One of the most rational options for such platform could be a small waterplane area twin hull ship (SWATH).

Universal platform type SWATH use has a number of advantages in contrast with other architectural and structural types of ships, as follows:

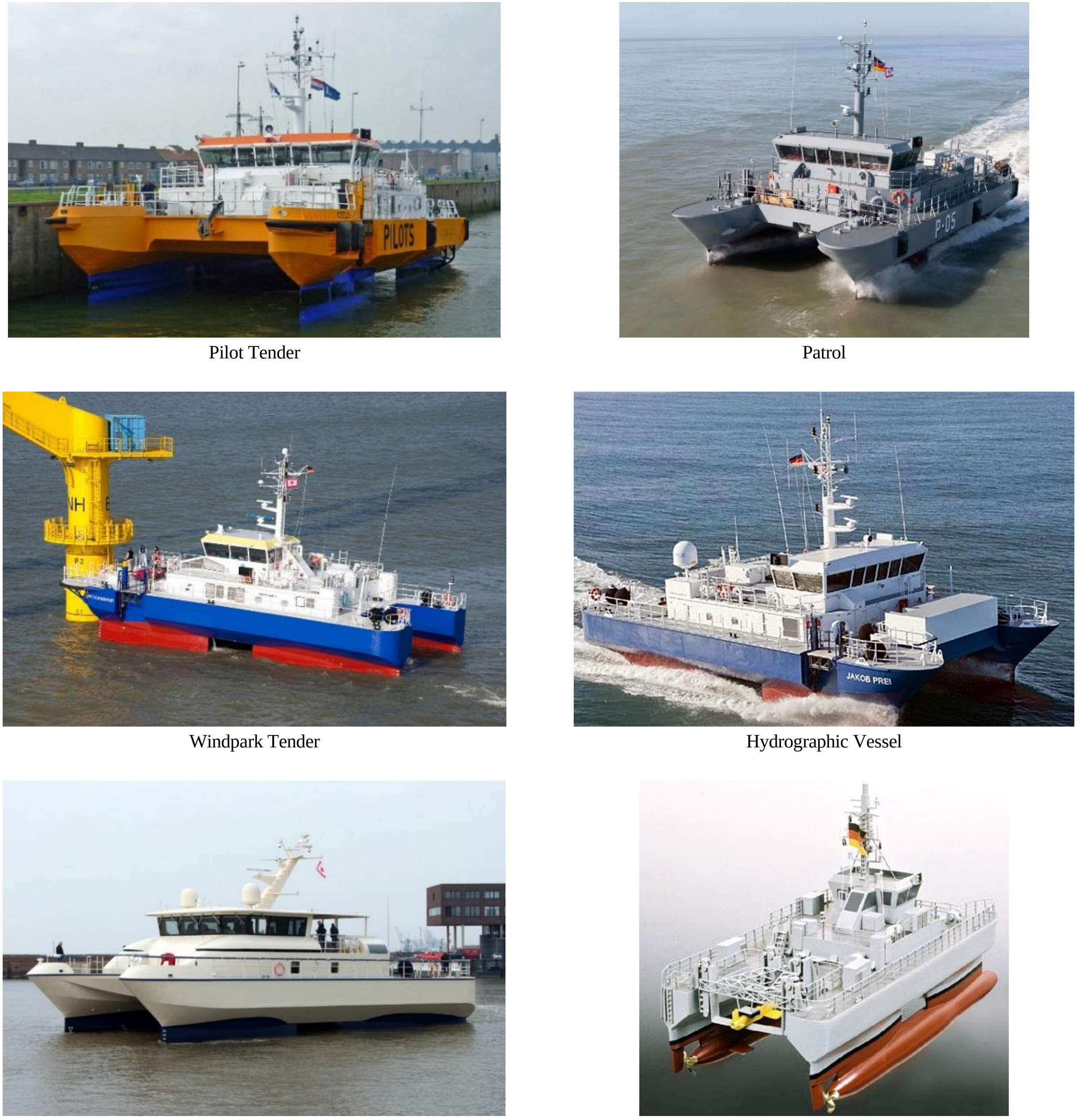
- large area that allows to accommodate replacement modules, additional equipment to expand the functional capacities;
- high seaworthiness, providing speed loss on seaway and smooth motion;
- high survivability in case of emergency;
- high firmness on a course.

Currently there is an experience of using this ships type as a universal platform in the world. For example, a 25 meter ship project developed by Abeking & Rasmussen's (Germany). The platform has the following characteristics: length overall – 25,65 m; length between perpendiculars – 23,25 m; breadth overall – 13,0 m; depth – 5,9 m; design draught – 2,7 m; vertical clearance – 1,7 m; lower hull length – 26,65 m; lower hull maximum diameter – 2,4 m; lower hull transverse section shape – round. 125–135 tons displacement, depending on the purpose. The platform is based on a twin hull ship with two struts on each hull. Propulsion plant type is diesel-electric. Currently on the basis of this platform, 19 ships for various purposes are built, they are: 10 pilot boats, 1 research vessel, 6 patrol vessels, 1 for maintenance personnel delivery to offshore wind power plants and 1 pleasure yacht (Figure 1). Two more pilot boats are planned to be delivered in 2017 for the Houston Pilot. It is also possible to expand the ship functions by installing replacement modules (Figure 2) (Grannemann, 2015).

Small waterplane area twin hull platform designing is associated with certain difficulties caused by the following factors:

1. Insignificant design experience.
2. The presence of a large number of parameters that determine the hull shape. For a traditional single hull ship, the hull is determined by nine parameters: length, breadth, draught, depth, three fullness coefficients, center of buoyancy position by ship length and waterplane centroid position by ship length.

For a small waterplane area twin hull ship, there are much more of such parameters as SWATH hull consists of the following structural elements: box, lower hulls, struts and sponsons. Each of these structural elements is characterized by a set of its parameters length, breadth, depth, fullness coefficients. Moreover at the SWATH full hull parametric design, it is necessary to take into account the mutual position and structural elements interaction, which determines the SWATH hydrodynamic characteristics in general. All these factors result in a specialized platform required optimal parameters vector large dimension and technical solutions significant variety.



Pilot Tender — Patrol

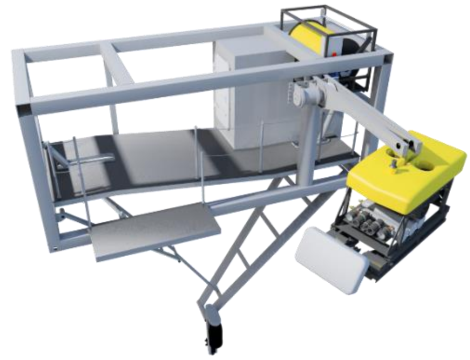
Windpark Tender — Hydrographic Vessel

Yacht — MCMV Demonstrator

FIGURE 1 Different variants of 25 m platform use

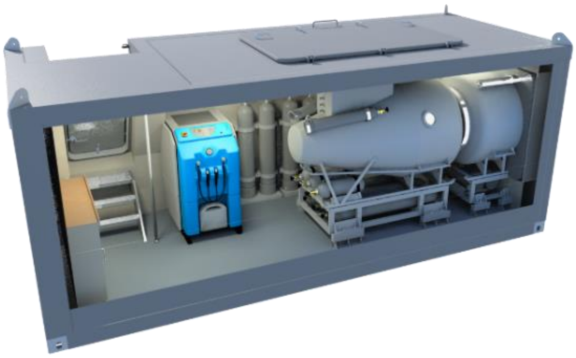
Therefore, it is rational to choose the optimal relationship between SWATH dimensions, seaworthiness, cost and efficiency by solving a multidimensional optimization task using special methods of solution search. The multidimensionality of the optimization problem leads to the so-called "curse of dimension" in optimization theory and, as a result, to a significant increase in the volume of computations and the complexity of finding the global optimum. One of the solutions to this problem is the use of a genetic algorithm. Currently, this algorithm is increasingly used in the marine industry, for example different aspects of passenger SWATH design optimization task solution are considered in (Bondarenko et al., 2013). The issues of genetic algorithm application for ship hull optimization are considered in the following articles (Guha, and Falzarano, 2005), (Zakerdoost et al., 2013) and Dejhalla, R., Mirsa, Z., Vukovic, S. (2001). Application of genetic algorithm for the design of other types of vessels considered in paper (Sekulski, 2011), (Papanikolaou, 2012), (Boulougouris et al., 2012), (Gammon, 2011) and (Brown, Salcedo, 2003). At the same time, the universal specialized small waterplane area twin hull platform optimization design algorithm is underexplored.

Therefore, the objective of this article is to develop a key element in ship design methodology - special algorithm for selecting the optimal characteristics of universal specialized small waterplane area twin hull platform using a genetic algorithm.



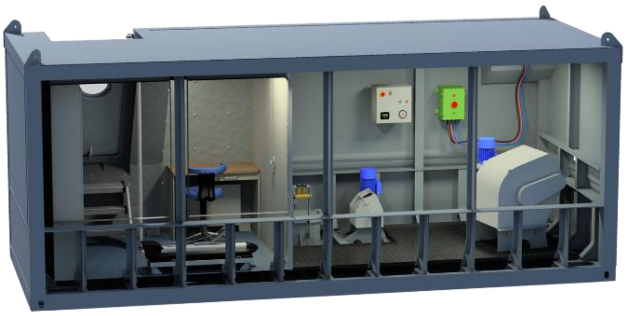
ROV Mission Module

Fire Fighting MissionModule



Diving Mission Module

Gun Mission Module



Sidescan Sonar Mission Module

Oil Spill Recovery Mission Module

FIGURE 2 Mission modules for SWATH

2 Methodology description

2.1 PROBLEM STATEMENT

The optimization task of selecting the optimal characteristics of a universal specialized platform is formulated as follows:

$$F(X,C) \rightarrow \min_{X \in R^n} (\max_{X \in R^n})$$

subject to a: $g_j(X) = 0, \quad j = p+1,...,k$,

$$g_j(X) \geq 0, \quad j = 1,...,p ,$$

$$a_i \leq x_i \leq b_i, \quad i = 1,...,n$$

where $X \in R^n$ is the vector of independent variables, $F(X,C)$ is the objective function, $C(C_1,...,C_m)$ is a vector of the parameters that form the design task; m is a number of the C vector parameters; n is a number of independent variables; k is a total number of optimization task constraints; p is a number of optimization task constrains in the form of inequalities; R^n is n-dimensional Euclidean space; g is the vector constraints; a_i is lower bounds on the independent variable, b_i is upper bounds on the independent variable ; x_i is values of the independent variables, j is index for constrains; i is index for independent variables.

The main questions connected with a universal specialized platform design task formulation were considered in (Zvaigzne and Bondarenko, 2017). One of the features of this task is the availability of a limitations system to the platform technical qualities as $g_j(X) \geq 0$. To take them into account in this research, the Penalty Functions method (Rao, 2009) is applied. The main idea of the Penalty Functions method is to turn the task of conditional optimization into unconditional by replacing the objective function:

$$F_l(X,C,r_l) = F(X,C) \pm \sum_{j=1}^{k} \left[\frac{g_j^+(X)}{r_l} \right]^n ,$$

where r_l is the penalty coefficient, which value decreases from one stage to another; l is calculating optimization process cycle number; n is the degree, in this research $n = 2$; $\sum_{j=1}^{k} \left[\frac{g_j^+(X)}{r_l} \right]^n$ is penalty for limitations violation (penalty function):

$$g_j^+ = \begin{cases} \max\{g_j(X);0\}, j \in [p+1,k] \\ \left| g_j(X), j \in [1,p] \right| \end{cases} .$$

The resulting new objective function $F_l(X, C, r_l)$ hereinafter referred to as fitness function, which corresponds to the terminology used in (Back, 1996), (Davis, 1991), (Rutkovskaya et al., 2006), (Sivanandam and Deepa 2007). The fitness function is minimized (maximized) using the genetic algorithm. While using the genetic algorithm, the independent variables boundary values do not participate in the penalty functions creation, since they are used in encoding/decoding of independent variables (an independent variable will always be in the boundary range).

For example, encoding/decoding real-valued independent variable

$$c = \frac{(x_i - a_i)(2^s - 1)}{(b_i - a_i)};$$

$$x_i = \frac{c(b_i - a_i)}{2^s - 1} + a_i ,$$

where
a_i, b_i is lower and upper bounds of the i-th independent variable;
s is the number of bits per one element of chromosome (gene);
x_i is the decoded real value from bit string of length s.
c is the coding representations of x_i.

2.2 ALGORITHM DESCRIPTION

Let us consider in more detail the genetic algorithm nature and the features of its use for the universal (specialized) platform designing.

The genetic algorithm operation is based on the processes of natural selection and evolution occurring in living nature. In nature, the most adapted individuals survive and give offspring, i.e. the principle "the strongest survives" is observed. In terms of optimization, the search of optimal, i.e. the best solution, corresponds to the search of the fittest individual. And the best solution searching iterative process resembles the population evolution in nature. Only in nature the fittest individuals give offspring, and in the optimization task – they form the task allowable solutions.

The independent variables X vector numerical values are the individual genetic code and should be stored in the computer's memory in the form of a fixed-length line for the selection process realization. There is range of ways to represent numbers (encoding) in genetic operators: decimal, binary, Gray encoding.

At fitness function calculations, as well as at the optimal solution output, the values are decoded, i.e. converted into numerical values.

The optimal solution searching general scheme using a genetic algorithm can be represented as follows (Figure 3):

1. To generate N individuals initial population;
2. To measure chromosomes fitness in the population on the basis of the objective function $F_l(X, C, r_l)$;
3. To perform the selection operation, i.e. for each agent of the new generation to select two parents from the current generation in proportion to fitness;
4. For selected parents to create candidates for the new population creation using genetic operators (mutations, crosses, inversions, mutation);
5. To create a new population;
6. If the criterion for stopping the algorithm is done, then finish the search, otherwise – to do the iteration search next cycle.

To create a new population, the so-called genetic operators are used: selection, crossover, mutation, inversion.

The selection of individuals (parents) involved in the creation of offspring is done using selection operators. There are several options of selection mechanism realization: roulette-wheel selection, tournament selection, ranking selection etc. Detailed information about each of the selection options is given in (Back, 1996), (Davis, 1991), (Rutkovskaya et al., 2006), (Sivanandam and Deepa 2007). In this article the tournament selection in which all populations are divided into subgroups that consist of two individuals is used by authors. Then the individuals with the best fitness are selected in each of these subgroups. The diagram in figure 4 below illustrates the tournament selection method for subgroups that consist of two individuals.

The crossover operator is a language construction that allows creating descendants chromosomes on the basis of the parents chromosomes transformation (crossing) (or their parts). The crossing operator exchanges chromosome parts between two (maybe more) chromosomes in the population. There are different types of crossing, as their structure basically determines the genetic algorithms efficiency (Back, 1996), (Davis, 1991), (Rutkovskaya et al., 2006), (Sivanandam and Deepa 2007).

In this article, single-point crossover is realized. In this case, two individuals are selected, the chromosomes of which are cut into parts at the so-called Crossover point. Two segments are the result. Then, the corresponding segments of different chromosomes are glued together and two genotypes of descendants are obtained.

Crossing does not always apply to all pairs of individuals. Couples are usually chosen randomly, and the probability of crossing is assumed to be equal to any number from 0,6 to 1,0. Crossing is allowed if the random number (obtained with the help of the random number sensor in the range from 0 to 1) is less than the predetermined probability. If the crossing does not occur, the offspring copy parents exactly.

The crossing operator operation is illustrated by the following example (Figure 5).

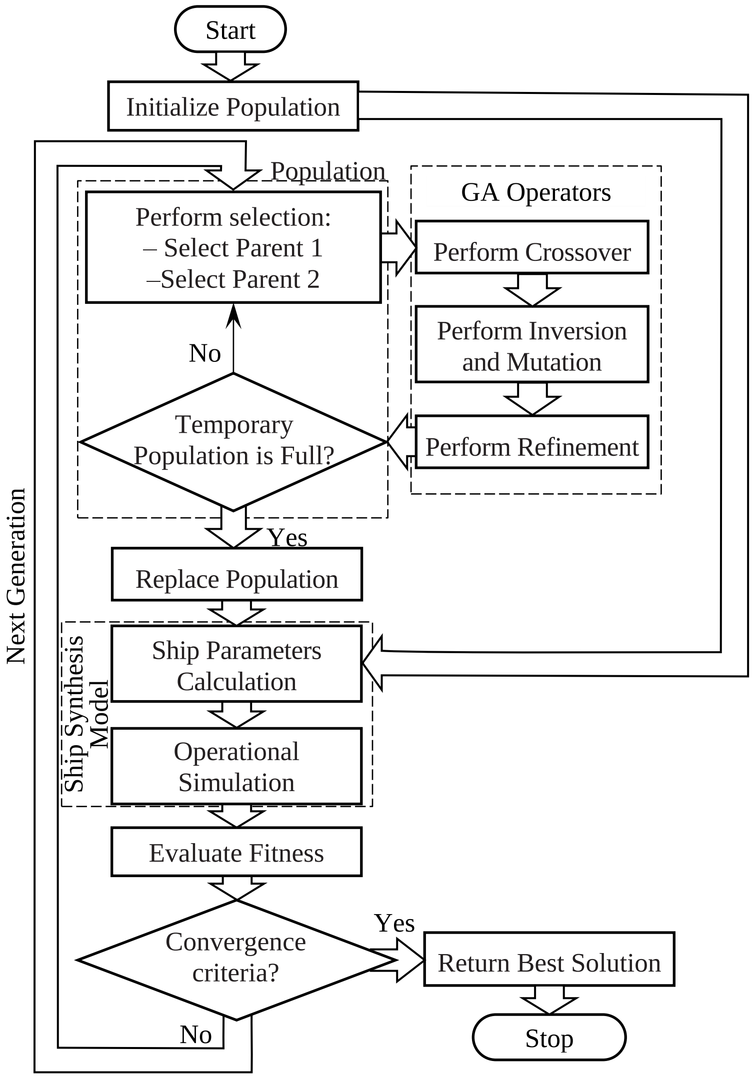


FIGURE 3 Block scheme of platform optimal parameters selection using the genetic algorithm

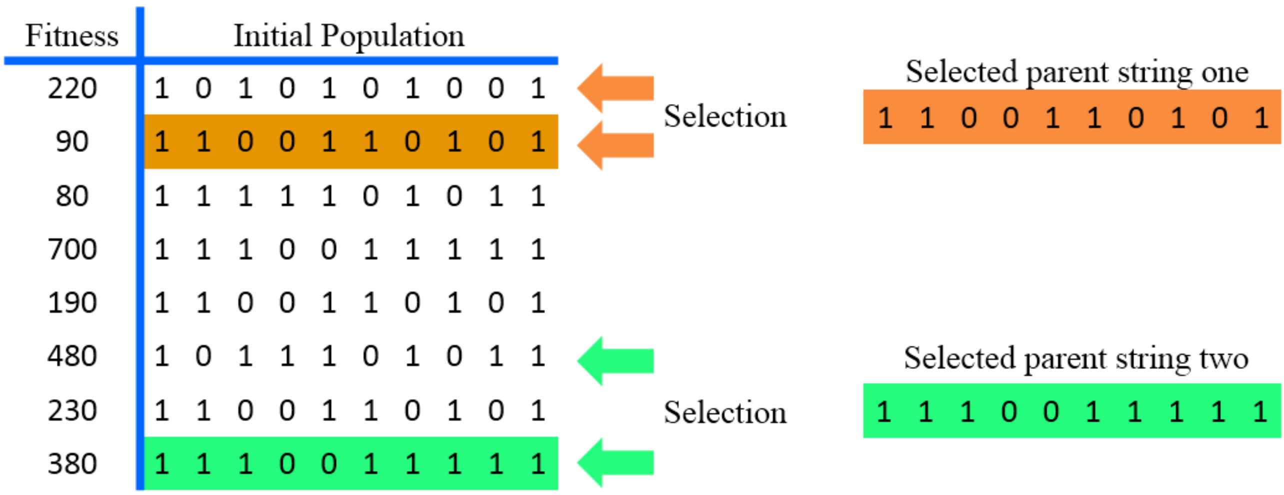


FIGURE 4 Example GA population solutions and selection operation

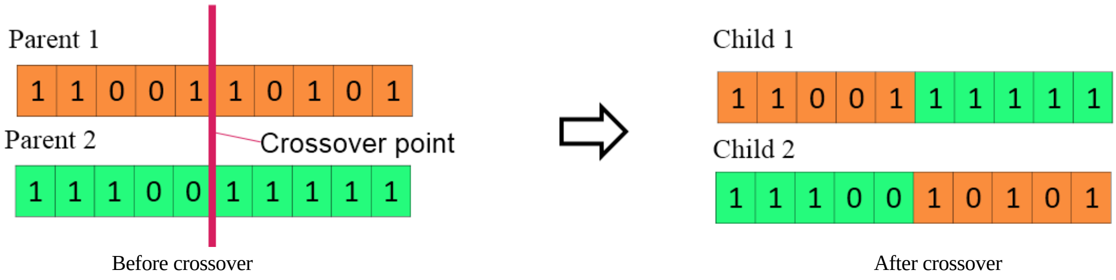


FIGURE 5 Genetic algorithm one point crossover operations

To support the diversity of individuals in a population, a mutation operator is used, a language construction that allows the descendant chromosome creation on the basis of the parent chromosome transformation (or its part). The mutation operator randomly changes each gene in the chromosome with a little probability P_{mut} (user-defined), with 0 being replaced by 1 and backwards (Figure 6). It is realized with the random number generator help in the same way as crossing.

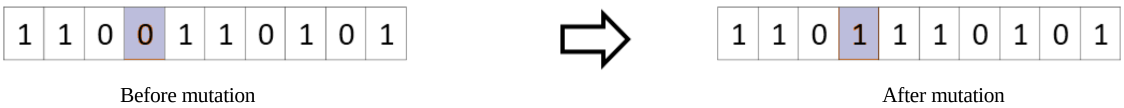


FIGURE 6 Genetic algorithm mutation operations

Inversion (inversion operations) – is piece or full chromosome *U*-turns. Inversion is performed on a single chromosome; at its realization, the consequence of alleles between two randomly chosen positions in the chromosome changes (the last gene changes places with the first, the penultimate - with the second, etc.). An example of an inversion is illustrated below (Figure 7).

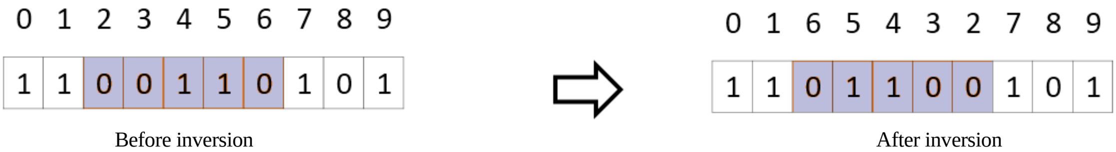


FIGURE 7 Genetic algorithm inversion operations

At new population creation, either a complete replacement or a partial replacement of the previous generation is possible, at which part of the population goes into the next generation without changes, i.e. the chromosomes of this part are not exposed to the crossing and mutation operations (the elitism strategy).

The new population creation corresponds to the genetic algorithm one iteration.

As a search completing criterion can be:

- generations given limiting number achievement;
- time set period expiration;
- fitness function values stabilization (lack of fitness function values changes);
- good enough solution getting.

As a result of modeling the evolutionary process with the genetic algorithm help, we get the most adapted individual, i.e. the optimization problem solution.

The proposed approach to the solution of the optimization task of selecting the design characteristics of the offshore platform using the genetic algorithm was implemented in the form of the software product "SWATHShips"

2.3 CALCULATION RESULT

Let us consider the genetic algorithm use for choosing the ship optimal dimensions on the example of small waterplane area twin hull small-specialized platform designing. The main task of such a platform - high-speed transportation of passengers and service personal. Change the target purpose of the platform is possible by modifying of the superstructure and plug-in mission modules.

The initial data for the designing: ship speed is 30 knots, seaworthiness is force 4, number of struts is two on each hull, and endurance at maximum speed is 300 miles. As an indicator of economic efficiency, net discounted income was used (Net Present Value – NPV):

$$NPV = \sum_{t=1}^{T} \frac{(\mathrm{Pr}_t + A_t) - IC_t}{(1+d)^t},$$

where Pr_t - the sum of net profit in the *t*-th period; A_t - the amount of depreciation deductions in the *t*-th period; IC_t - the amount of investment costs in the *t*-th period; *t* - current year of the billing period; *T* - duration of ship life cycle (assumed to be 15 years); *d* is the discount rate.

To determine the SWATH main characteristics the genetic algorithm was used with the following parameters: the population number is 50 chromosomes, the genes length are 32 bits, the crossover probability is 0,9, the mutation probability is 0,1, the inversion probability is 0,05 the initial value of penalty coefficient r_l is 0,5, the extremum reaching accuracy is 0,000001. The elitism strategy was used at optimization. These parameters are set experimentally as a result of many test runs of the program. The search for optimal characteristics was carried out using the software product "SWATHShips".

The optimized variables values and the SWATH main characteristics that are obtained as a result of the optimization program are given in Table 1 and Table 2 respectively.

TABLE 1 The optimized variables values

Independent variable	Material of hull and superstructure		
	Steel	*Aluminum*	*Steel+Aluminum*
Relative length of lower hull L_H/D_H	11,883	14,705	12,270
Slenderness coefficient of strut L_S/t_S	22,508	19,910	24,388
Waterplane area strut coefficient C_{WPS}	0,849	0,873	0,853
Relative waterplane area $A_{WPS}/\nabla^{2/3}$	1,310	1,378	1,084
Ratio of the distance between lower hull center-line to the length of the ship B_S/L_{OA}	0,408	0,383	0,400
Ratio of the ship draft to the lower hull diameter d/D_H	1,417	1,617	1,421
Ratio of the lower hull beam to its depth, B_H/H_H	1,301	1,092	1,190
Lower hull prismatic coefficient C_{PH}	0,891	0,868	0,880
Factor of the lower hull nose shape n_f	2,275	3,833	3,818
Factor of the lower hull tail shape n_a	2,244	3,996	2,233
Factor of the lower hull cross section shape n_h	4,617	2,506	4,164
Strut nose and tail shape factor n_s	3,906	2,553	2,508
Strut setback L_{CS}/L_H	–0,019	0,002	0,014

TABLE 2 The SWATH main characteristics obtained as a result of optimization

Description	Hull/Superstructure material		
	Steel /Steel	*Aluminum Alloy /Aluminum Alloy*	*Steel/Aluminum Alloy*
Lower hull length, m	25,755	25,123	25,808
Lower hull beam, m	2,472	1,786	2,295
Lower hull depth, m	1,9	1,635	1,928
Hull nose length, m	3,863	3,768	3,871
Hull tail length, m	3,963	9,731	5,887
Strut length, m	26,024	20,888	23,734
Strut thickness, m	1,156	1,049	0,973
Strut height, m	2,885	2,752	2,817
Strut nose length, m	6,506	5,222	5,934
Strut tail length, m	10,852	6,672	8,994
Waterplane area strut coefficient	0,849	0,873	0,853
Box clearance, m	2,092	1,743	2,005
Distance between lower hull center line, m	10,507	9,628	10,328
Ship draft, m	2,693	2,643	2,740
Depth up to the main deck, m	5,79	5,367	5,749
Length overall, m	26,378	25,123	25,808
Box length, m	26,378	25,123	25,808
Box beam, m	12,979	11,413	12,623
Heigh of cross structure box, m	1,004	0,98	1,004
Displacement, t	250	150	225
Deadweight, t	39,26	34,75	37,95
Main Engines, number × kW	2 × 3460	2 × 2300	2 × 3460
Generator, kW	190	190	190
Payback period, years	9,3	5,9	8,4
Net present value, thousand$.	2390	4357	2427

3 Conclusions

Practice shows that 80% of the ship's lifecycle costs formed during the ship conceptual design faze (Brown, A., Salcedo, J. 2003), and it may be several million dollars in ship lifecycle years. Small waterplane area twin hull specialized platform designing is characterized by a large number of parameters to be determined. The parameters optimal values can be selected using a genetic algorithm, the algorithm help in short time solve complicated problems of optimization tasks by using parallel calculations possibility, providing possible options for the ship preliminary design. Without that information, it will be more complicated to take correct, optimal decisions on maritime platform design.

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