Hybrid evolutionary algorithm in the optimization problem of the shooting system parameters

L A Demidova¹ and N A Petrova²

¹ MIREA – Russian Technological University, Moscow 119571, Russia
² Ryazan, Russia

demidova.liliya@gmail.com

Abstract. The optimization problem of the shooting system parameters values by means of the hybrid evolutionary algorithm has been considered. The idea of hybridization of the genetic algorithm and differential evolution algorithm to solve the problem of optimizing the coverage of the observed object by the shooting system has been proposed and implemented. The results of solving the optimization problem of the shooting system parameters, confirming the feasibility application of the proposed hybrid evolutionary algorithm which provides minimization of time spent on solving the optimization problem has been described.

1. Introduction

The solution to the problem of optimizing the coverage of the observation object by the shooting system involves search for the shooting parameters values which provide optimal coverage of this object. The solution to this problem is complicated by the need to carefully select the appropriate criterion and taking into account a large number of restrictions for the values of optimization parameters, as well as restrictions imposed on the optimization criterion. In particular, when solving the problem of optimizing the coverage of an object by the shooting system, such parameters as the latitude of the point of the shooting start, the longitude of the point of the shooting start, the start time of the shooting, the duration of the shooting, the speed of the image movement, the azimuth and restrictions on their values are used. Using the grid search method for the possible values of optimization parameters with subsequent calculation of the value of the optimization criterion in order to select the best set of the required values of the parameters for solving this problem is associated with significant time-consuming, which is not acceptable.

One of the approaches which allows to solve the problem of optimizing the coverage of an object by the shooting system with acceptable time costs assumes the use of the evolutionary optimization algorithms such as genetic algorithm, differential evolution algorithm, particle swarm algorithm, bee colony algorithm, ant algorithm, algorithm clonal selection, etc. In this case, the optimization criterion acts as the fitness function of such algorithms operating in the search space by populations of the possible solutions encoded using optimization parameters. As a result of the iterations implementation of the evolutionary optimization algorithms, a certain locally optimal solution, which is assumed to be the sought one, is determined.
The disadvantage of the evolutionary optimization algorithms is that often the solutions found with their use fall into the local extremum of the fitness functions used, since the initialization of the initial population of solutions is performed randomly.

To derive solutions of some evolutionary optimization algorithm from the local extremum, it is necessary to perform some manipulations with the population of solutions atypical for this algorithm. In particular, the hybridization of various evolutionary algorithms (EA) allows improving the results of solving optimization problems [1–3], thanks to which it is possible to derive solutions from the local extremum and continue the effective development of the population (in the sense of moving towards the global extremum of the optimization criterion (fitness function)).

The proposed hybrid evolutionary algorithm (HEA), which intelligently combines the advantages of the genetic algorithm (GA) [1] and the differential evolution algorithm (DEA) [2], which are in many ways similar in the tools used in them, should allow to minimize the risks of “getting stuck” of solutions at the local extremum of the fitness functions.

The problem of optimizing the parameters of the shooting system should be considered as the multi-parameter one-criterion problem of optimizing the values of the parameters which allows to achieve the maximum efficiency of the operation of the shooting system.

The solution to this optimization problem is complicated by the fact that for given initial values of the shooting parameters, which should be modified in some way to determine their optimal values, only the permissible ranges of variation of the values of these parameters are known. Also, there is only some algorithm for assessing the quality of the shooting system functioning, and, in addition, the additional requirements and restrictions, which are imposed by the subject area of the optimization problem, are set.

The solution to the problem of optimizing the values of the shooting parameters should be a set of parameter values which meets all the requirements and limitations of this problem and corresponds to the maximum quality of the shooting system, determined by some reasonably chosen optimization criterion.

For the problem of optimization of the shooting parameters formulated in this way, the use of the evolutionary approach to its solution should ensure with the acceptable time costs obtaining the desired solution under a minimum amount of initial data. In this case, it is advisable to perform hybridization of various EA.

2. Theoretical research

The evolutionary approach (EA) to applied optimization problems allows the use of the genetic algorithms, the evolutionary programming, the evolutionary strategies, etc. as the optimization tools, which implement the simultaneous search for alternative solutions and the subsequent selection of the best one at each iteration [4–6].

The use of EA allows to reduce the solution of the optimization problem to the following two generalized steps.

1. Formalization of the optimization problem, as a result of which optimization parameters, ranges of the acceptable values of optimization parameters, optimization criteria (fitness functions) and auxiliary parameters (in particular, constants which are used in calculations) are determined.

2. Optimization and analysis of the results of solving the optimization problem, assuming the launch of EA, determination of the best values of the parameters of the optimization problem for the current iteration of EA and their presentation in the form convenient for analysis.

In recent years, hybridization of various variants of EAs has been actively carried out in order to compensate for their particular shortcomings and obtain more efficient solutions to optimization problems.

When solving the problem of optimizing the parameters of the shooting system, it is proposed to implement the hybridization of GA [1], which is well-known and effectively used in solving various optimization problems, and the DEA [2], less popular, but also found active use in recent years.
Both evolutionary algorithms work with a population of solutions presented in the form of chromosomes, the genes of which encode certain parameters of the optimization problem. In the process of implementing these algorithms, the corresponding populations of solutions are developed using the principles of elitism.

In the basic version of GA algorithm, solutions move in the search space by performing crossover and mutation operations, which modify the coordinates (genes) of solutions from the population.

In GA, the source of noise is an external random number generator which modifies the coordinates (genes) of solutions (chromosomes) of the current population.

In the basic version of DEA, solutions move in the search space according to the law determined by a mathematical formula which provides the modification of coordinates (genes) of solutions from the population. If the newly found solution is better than the existing ones [in the sense of the used optimization quality criterion (fitness function)], it is accepted as a new one and introduced into the population.

In DEA, the source of noise is not an external (as in GA), but an internal random number generator, which is implemented as the difference between the values of genes of randomly selected chromosomes of the population.

An internal source acts as the noise which distorts the “gene pool” of a chromosome, namely, the difference between the values of coordinates (genes) of the randomly selected chromosomes of population. As a result, a chromosome with original genetic characteristics and a chromosome with genetic characteristics distorted according to the formula are involved in crossing.

The advantage of DEA is its ability to dynamically simulate the relief features of the correspondence function by adapting an internal noise source. This allows DEA to very quickly go out of the extended local minima and ensures the efficiency of its application. At present, various versions of DEA have been proposed which implement the adaptation of the values of its parameters in the optimization process.

It is proposed to use DEA together with GA as the parts of HEA in order to find the best solution to the problem of finding the shooting parameters values with minimal time costs.

In the case of HEA, the population of solutions develops on the basis of several subpopulations of two types of equal size. The subpopulations of one type are formed on the basis of GA, and subpopulations of another type are formed on the basis of DEA. All subpopulations first develop independently of each other for a certain number of generations, and then they exchange the best solutions (with the subsequent removal of the worst solutions to keep the subpopulation size unchanged), after which they develop again independently of each other, etc.

The process of development of subpopulations and exchange of the best solutions ends when a given number of iterations is reached or when the condition for stopping HEA, which is based on the requirement to achieve a predetermined computation accuracy of the value of the fitness function, is met.

When solving the problem of optimizing the coverage of the observation object by the shooting system using HEA, in the general case, it is proposed to use:

- subpopulations of different types, generated randomly;
- a fixed size of subpopulations corresponding to a number of alternative options for solving the optimization problem, which are the sets of the shooting parameters values;
- a fixed number of genes in a chromosome, corresponding to the number of optimized parameters.

It is expedient to take the number of subpopulations of one type equal to the number of subpopulations of another type. Each new subpopulation of chromosomes of size $N / K$ ($N$ is the number of chromosomes in the population, $K$ is the number of subpopulations, which is even) of the current iteration is formed from an auxiliary subpopulation of chromosomes containing parent and offspring chromosomes by removing chromosomes with the worst fitness function values so as to maintain a fixed size of the subpopulation and ensure the replacement of chromosomes in the
subpopulation with the “best” ones, the values of genes of which are closer to the optimal values of the parameters of the optimization problem.

Periodically (for example, after a set number of iterations), the best chromosomes are exchanged between subpopulations of different types. When the number of subpopulations $K>2$, the subpopulations participating in the exchange of the best solutions are chosen randomly from the number of subpopulations of different types.

In addition, the exchange of the best solutions can be carried out in a loop, in which, for example, subpopulations of different types are ordered through one.

This approach to the exchange of the best chromosomes makes it possible to implement a kind of parallel EA, which has some properties of the island model, suggesting the existence of a group of the “closely spaced islands” with evolving subpopulations of the same type, developing independently and only occasionally exchanging chromosomes.

The considered island model assumes the existence of several subpopulations of the same fixed size; a fixed number of genes on a chromosome; the use of arbitrary variants of strategies for the selection and formation of generations in subpopulations; no restrictions on crossing and mutation operations; exchange of chromosomes between subpopulations.

3. Experimental results

To check the operability of HEA and the optimization software system based on it, the applied problem of optimizing the coverage of the observation object by the shooting system was considered [7–9].

Figure 1 shows the initial boundaries of the shooting, calculated from the initial values of the parameters (the dark rectangle is the object; the light polygon is the capture of the shooting system).

As a criterion for optimal coverage of the observation object, it is advisable to use the minimum value of the difference between the coverage area of the shooting and the area of the object.

To solve the problem of optimizing the parameters values of the shooting system, the above-described HEA was applied.

Previously, the subject area of the optimization problem was presented in terms of EA.

The solution to the problem of optimizing the coverage of the observation object by the shooting system was presented in the form of the chromosome, in which the parameters of the problem, which are coordinates in the search space, are encoded.

If, for example, the number of subpopulations is 2, that is, $K = 2$, then the $i$-th chromosome in the subpopulation of solutions of size $N/2$ can be written as [7]:

$$ P_i = (nshir_i, ndolg_i, ontel_i, dliit_i, sdi_i, azim_i), $$

where $P_i$ is the $i$-th chromosome ($i = 1, N/2$); $nshir_i$ is the latitude of the shooting start point; $ndolg_i$ is the longitude of the shooting start point; $ontel_i$ is the shooting start time; $dliit_i$ is the duration of shooting; $sdi_i$ is the image movement speed; $azim_i$ is the azimuth; $N/2$ is the subpopulation size; $N$ is the population size.

For each gene in the chromosome $P_i$ ($i = 1, N/2$), it is advisable to determine (in accordance with the restrictions imposed by the subject area of the optimization problem) the range of the acceptable values (Table 1).

During the experimental research, the planning of the shooting of the observation objects was carried out and the initial values of the parameters of the shooting system for the selected object were determined. Table 1 shows the initial values of the optimization parameters, the intervals of the acceptable values of the optimization parameters for the selected object.

As the genes of the chromosome in the applied problem under consideration, it is proposed to use the latitude of the shooting start point, the longitude of the shooting start point, the shooting start time, the shooting duration, the image movement speed and the azimuth.
Figure 1. The shooting boundaries which are calculated from the initial parameters values.

Table 1. The initial values of the shooting parameters, ranges of the acceptable values of the shooting parameters and the names of genes in the i-th chromosome.

| Shooting parameter                      | Initial value | Range of the acceptable values |
|-----------------------------------------|---------------|---------------------------------|
| Latitude of the shooting start point, deg. \(( nshir_i )\) | 49.7843       | (40; 50)                       |
| Longitude of the shooting start point, deg. \(( ndolg_i )\) | 52.4260       | (47; 58)                       |
| Shooting start time, sec. \(( ontel_i )\) | 2024411       | (2024350; 2024470)             |
| Shooting duration, sec. \(( dlit_i )\) | 7.90497       | (5; 15)                        |
| Image movement speed, meters per second \(( sdi_i )\) | 60            | (55; 65)                       |
| Azimuth, deg. \(( azim_i )\)            | 0             | (0; 360)                       |

Table 2. The generalized sequence of steps of GA and DEA.

| Step | GA                          | DEA                          |
|------|-----------------------------|------------------------------|
| 1    | To create the initial subpopulation of size \( N/2 \) from chromosomes \( P_i \) \(( i = 1, N/2 )\). | To create the initial subpopulation of size \( N/2 \) from chromosomes \( P_i \) \(( i = 1, N/2 )\). |
| 2    | As long as the current number \( g \) of iterations is less than the maximum number \( G \) of iterations, to select the parent chromosomes from the population are randomly and to go to step 3; when the number of iterations is reached, to go to step 5. | As long as the current number \( g \) of iterations is less than the maximum number \( G \) of iterations, to select the parent chromosomes from the population are randomly and to go to step 3; when the number of iterations is reached, to go to step 5. |
| 3    | To create the auxiliary population from parent chromosomes and offspring chromosomes by means of the single-point crossing and (or) mutation, to calculate of the values of the fitness function (2) and to check the constraint (3). | To create the auxiliary population by crossing the direct parent chromosome and the parent chromosome distorted by the special mutation operator, to calculate the values of the fitness function (2) and to check the constraint (3). |
| 4    | To create the new subpopulation of size \( N/2 \) by excluding the chromosomes with the worst fitness function values; to go to step 2. | To create the new subpopulation of size \( N/2 \) by excluding the chromosomes with the worst fitness function values from the number of the offspring chromosome, the direct parent chromosomes and the distorted parent chromosome; to go to step 2. |
| 5    | To select the chromosome with the minimum value of the fitness function (2) from the subpopulation. | To select the chromosome with the minimum value of the fitness function (2) from the subpopulation. |

The considered applied optimization problem can be formulated as the problem of finding the optimal values of the shooting parameters: \( nshir_{opt} \), \( ndolg_{opt} \), \( ontel_{opt} \), \( dlit_{opt} \), \( sdi_{opt} \), \( azim_{opt} \).

Since it is required to ensure the maximum approximation of the shooting area to the area of the observation object so that the vertices of the observation object lie within the boundaries of the shooting, and the shooting area differs from the area of the observation object by a minimum value, the formula for the fitness function of EA can be written as:

\[
(S_s - S_{ob}) + N_{ob} \cdot N_{od} \rightarrow \min,
\]  

\( (2) \)
where $S_s$ is the shooting area; $S_{ob}$ is the area of the object; $N_{ob}$ is the number of object vertices which do not fall within the boundaries of the shooting; $N_{kr}$ is the number which is significantly greater than the difference in areas and is necessary to ensure the significant deterioration in the value of the fitness function if the condition that all the vertices of the object fall into the shooting area is not met.

\[
((S_s - S_{ob}) + N_{ob} \cdot N_{kr}) > 0.
\]

Table 2 shows the generalized steps of GA and DEA.

| no | name | code | crit | det | sol | size | criterion |
|----|------|------|------|-----|-----|------|------------|
| 219 | 49,594,523 | 53,563,16 | 202,442,500,004 | 9.10739 | 63.40073 | 9.54000 | 9.41553,915,004 |
| 241 | 49,522,458 | 52,617,395 | 202,442,500,004 | 9.10539 | 63.40073 | 9.54000 | 9.41553,915,004 |
| 256 | 49,693,454 | 52,664,348 | 202,442,500,004 | 8.80765 | 63.77850 | 12.50767 | 9.61560,446,004 |

**Figure 2.** The fragments of the dialog box of the optimization program with the sets of the optimized parameters values and the values of the optimization criterion (named as criteriy).

**Figure 3.** The shooting boundaries calculated according to the optimal parameters values.

The fitness function can be used as the optimization criterion in the problem of optimizing the parameters of the shooting system.

Since the difference between the areas of the object and the shooting will tend to the minimum value of the square kilometers, it is advisable to set the value for the $N_{kr}$ equal to 100000.

The choice of such value for the $N_{kr}$ will provide the increase in the area difference by a factor of hundreds and will make it possible to reject solutions to an applied problem with uncovered object vertices.

Since the shooting area must cover the area of the object, it is advisable to ensure that the positive condition is satisfied for the fitness function:

\[
((S_s - S_{ob}) + N_{ob} \cdot N_{kr}) > 0.
\]

Table 2 shows the generalized steps of GA and DEA.

If the current number $g$ of iterations is not a multiple of some number $I$ ($I < G$, where $G$ is the maximum number of iterations), then the operations of crossing and mutation are implemented in each subpopulation independently of each other. If the current number $g$ of iterations is a multiple of the number $g$, then the best chromosomes are exchanged between subpopulations of GA and DEA (when the number of subpopulations $K$ is greater than 2, the exchange of chromosomes occurs in a ring). From subpopulations of GA and DEA algorithms, one chromosome, which has the best fitness function value in its subpopulation, is extracted. To the extracted chromosomes, the operation of the exchange of chromosomes-clones is applied [while in their subpopulations the best chromosomes are preserved, and the worst ones are replaced by chromosomes-clones (if they are really the best)]. A herewith, $I$ is the number of iterations, which makes it possible to increase the efficiency of HEA by means of the redistribution of genes in chromosomes during the exchange of chromosomes between the different subpopulations at each iteration.

Using the proposed HEA, the optimal values of the shooting parameters of the coverage of the observation object were calculated for the given initial values of the parameters and constraints (Table 1). A herewith, the maximum number $G$ of iterations is equal to 1000, the number $I$ of iterations through which the interaction of subpopulations is carried out is equal to 10, the error in reaching the minimum of the fitness function is equal to 0.0001, the number of subpopulations $K$ is equal to 2, the number of offsprings in the crossing operators of DEA is equal to 1, the number of offsprings in the crossing operators of GA is equal to 2, the size of population $N$ is equal to 20, the size of the subpopulations is equal to 10, the mutation strength $M$ in DEA is equal to 0.8, the probability $c_{GA}$ of crossing in GA is equal to 0.6, the probability $m_{GA}$ of mutation in GA is equal to 0.7.
As a result of the operation of HEA on the computer with the Intel Core i7 processor with the clock frequency of 3.07GHz and 1.99GB RAM for 3 minutes, the fitness function (2) was sequentially minimized.

Figure 2 shows fragments of the dialog box of the optimization program based on the proposed HEA, containing the sets of the optimized parameters values and values of the optimization criterion determined on the basis of the fitness function (2).

Figure 3 schematically shows the boundaries of the shooting, calculated according to the obtained parameter values (the dark rectangle is the object; the light polygon is the capture of the shooting system).

The calculation results confirm the advisability of using HEA when solving the problem of optimizing the coverage of the observation object by the shooting system, which assumes that the discrepancy between the object area and the shooting area should be minimal, and the shooting area should cover the object area at the given values of the number of iterations and the accuracy of HEA.

The considered example of solving the problem of optimizing the coverage of the observation object by the shooting system clearly demonstrates the capabilities of the proposed HEA and the developed software product when solving an applied optimization problem.

During the experimental studies, the effectiveness of the application of the program for optimizing the values of the parameters of the shooting system was shown. Using of program allowed to reduce the initial value of the optimization criterion (2) by more than 75.7 times: 2674.567939 at the one thousand iteration against to 202627.913184 at the first iteration.

Earlier, to solve the considered optimization problem, a version of the parallel GA [7] was used, hybridization of which with DEA allows in some cases to reduce (depending on the topological features of the observation object) the search time for optimal values of the shooting system parameters by 5–10% in the context of minimizing the optimality criterion (2): the similar values of the optimality criterion (2) can be obtained with less time.

4. Conclusion
The obtained results of the practical application of HEA confirm its effectiveness in solving the problem of optimizing the parameters values of the shooting system, since it allows to obtain the desired solution with minimal time costs.

In the future, the solution of the problem of the multi-objective optimization of the parameters values of the shooting system by means of EA [10] is of considerable interest.

In addition, it is planned to consider the solution of the problem of optimizing the parameters values of the shooting system, if it is necessary to cover a group of objects by shooting.

References
[1] Anfyorov M A 2019 Rossiiskii tekhnologicheskii zhurnal = Russian Technological Journal 7(6) 134–150 (In Russian). https://doi.org/10.32362/2500-316X-2019-7-6-134-150
[2] Chakraborty U K 2008 Advances in Differential Evolution
[3] Demidova L A and Gorchakov A V 2020 Symmetry 12(5) 784 10.3390/sym12050784.
[4] Krus P K and Ölvander (Andersson) J 2013 Engineering Optimization 45(10) 1167–1185
[5] Afonin P V 2009 Proceedings of the XIV Int. Conf. “Knowledge-Dialogue-Solution” 1 81–84
[6] Younis A and Dong Z 2010 Engineering Optimization 42(8) 691–718
[7] Demidova L A, Petrova N A and Nikulchev E V 2017 Contemporary Engineering Sciences 10(6) 253–262
[8] Demidova L A, Petrova N A and Sablina V A 2018 7th Mediterranean Conf. on Embedded Computing (MECO) 182–185
[9] Demidova L A, Petrova N A and Gazizova O R 2017 IOP Conf. Series: Materials Science and Engineering 312 012004
[10] Deb K, Pratap A, Agarwal S and Meyarivan T 2002 IEEE Transactions on Evolutionary Computation 2 182–197