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Optimization of a Fuzzy Logic Regulator in Hydrotechnical Structures Based on a Genetic Algorithm

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ABSTRACT: The article presents work on developing an algorithm for optimizing a fuzzy logic controller for controlling hydraulic structures. The system structure was created using the genetic algorithm method implemented in the Matlab program. The output parameters and characteristics of the PID controller were obtained through the proposed algorithm.

KEY WORDS: Algorithm, adjuster, program, mathematical model, water, control.

I. INTRODUCTION

Water level control changes in hydraulic facilities is achieved using sluice gates. Managing and monitoring the hydraulic sluice is crucial for maintaining the water level in the upper part of the sluice at the required level and adjusting the flow of water coming out of it.

It is known that hydraulic locks are regulated based on the change in the level and flow rate of water in the upper and lower reservoirs, as well as the requirements of water consumers. The results of using the existing old control system show a delay in the operation of the experimental control object, leading the excessive waste and inefficient use of natural resources [1].

The results of studies and measurements have shown that the water level and flow rate in reservoirs are not constant, as a result, the situation requires management based on ambiguous information at hydraulic structures.

Scientific articles contain the basics of the development of algorithms for the optimization of adjustable parameters of fuzzy logic-based adjusters based on genetic algorithms. This method uses the principles of creating a population over time, recombination, mutation, and gene formation [2]. This optimization method is performed in the following steps [3]:

1) Initial sets of objective function and terminal compositions are created.
2) The steps over the population in the algorithm are repeated until the termination criterion is met.
3) The parameter optimization procedure is performed based on genetic algorithms.

Below is a block diagram of the optimization process based on the genetic algorithm (Fig. 1).

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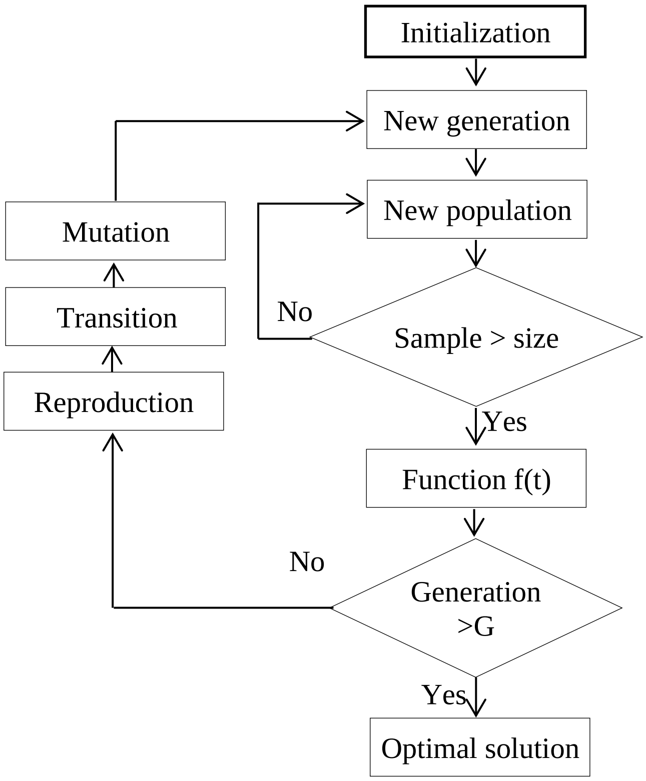

Figure 1. Block diagram of the process of optimizing object parameters using a genetic algorithm

"In optimizing the controller parameters, the objective function is based on certain quality indicators of the transient process through the effect of a step signal: rise time, overshoot value, and integral quality indicators – the area between the transient response curve and the unit step curve, as well as the area between the transient response curve and the desired response curve can be used [4]."

The input and output linguistic variables of the fuzzy logic controller are used as variables in the control system being developed using fuzzy logic inference sets.

We will consider the adjustment of a fuzzy controller using correspondence functions through a simulation model built in Matlab of the fuzzy control system of a reservoir segmented gate shown in Figure 2.

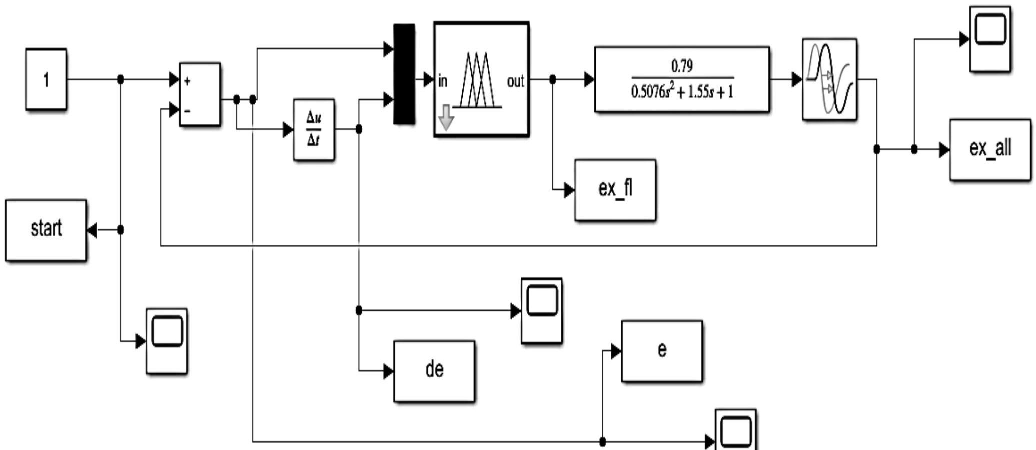

Figure 2. Model of the system in Matlab environment

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The gathering kind operation can be considered the key type step in performing the complex kind of mathematical type operations basically because of the required type multiple kind inputs which are geo kind dispersed. Gathering type scheme basically in order to aid in real time and also non real time can be of the geo dispersed type big kind data in application.

II. SYSTEM ANALYSIS

In the Matlab environment, the parameters of the genetic algorithm are entered by the user, and a program that adjusts the parameters of the fuzzy set based on the entered parameters was developed (Figure 3).

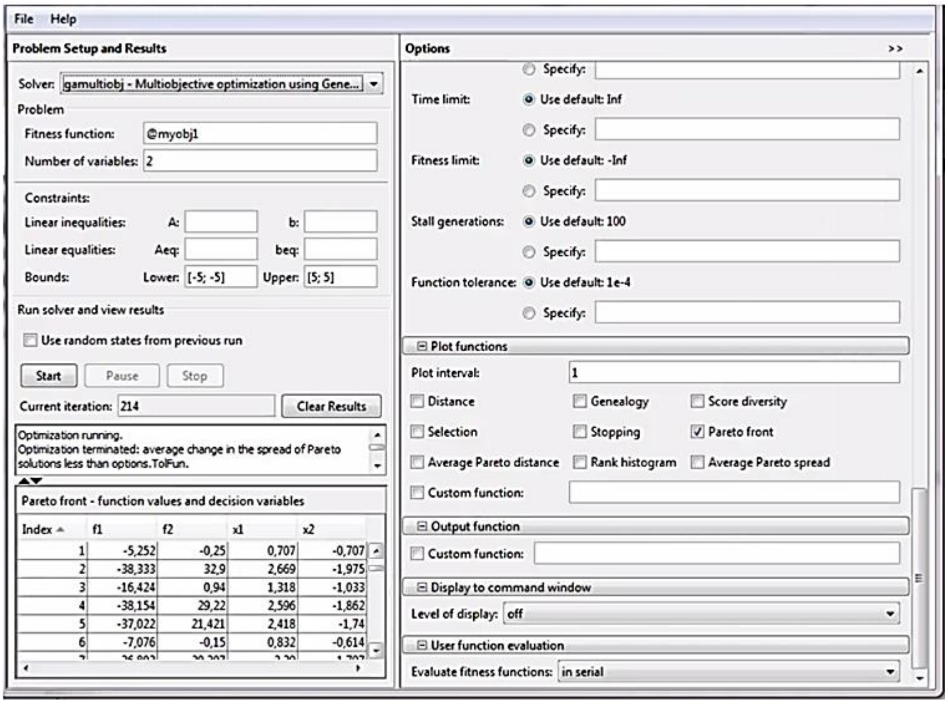

Figure 3. Interface of a program that adjusts fuzzy set parameters based on a genetic algorithm in a Matlab environment

In this algorithm, we use the group of chromosomes as initial multipliers in the optimization method used in the study. These chromosomes have multiple genomes and represent a target function classification. These genes can be used to calculate the individual function value for each chromosome. Then, the function is used to evaluate the chromosomes. During this process, we combine a certain percentage of individuals (i.e., chromosomes) to determine the best of them [5].
This process continues until the fitness function [6] is equal to or less than the criterion for a good population. The optimization process and operating principle of a genetic algorithm involves developing and searching for the most likely optimal responses.
A group of particles is created during the optimization process. These particles play the same role as chromosomes in the genetic algorithm [7].
The purpose of creating particles is to determine the adjuster's optimal parameters. In the dynamics of each particle, the speed and position are controlled using two classifications. The new state and velocity mean for each particle are calculated as follows [8]:

$$V_{i,d}^{t+1} = W^t V_{i,d}^t + c_1 r_1^t (p_{i,d}^t - x_{i,d}^t) + c_2 r_2^t (g_{i,d}^t - x_{i,d}^t) \quad (1)$$

$$x_{i,d}^{i+1} = x_{i,d}^t + v_{i,d}^{t+1}, \quad (2)$$

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where, i=1, 2, ... , n; n – is the particle flow size; t – is the iteration number; c_1 and c_2 - are the acceleration coefficients; W – is the inertia weight; r_1 and r_2 – [0, 1] are random numbers in the interval; x_i^t - the state of particle i at time t; v_i^t - the velocity of particle i at time t; p is the best particular solution and g is the best solution..
(1) According to the equation, the updated velocity of a particle at each iteration is related to the previous velocity of that particle, and is the best position of that particle at the previous iteration and the most optimal global position among the remaining particles.

III. RESULTS

The conceptually created variables move in the solution space. At each iteration, the best global position and the best position of each particle are determined based on the calculated values of the fitness function for all particles. Taking into account equation (1), the new velocity of each particle depends on its previous velocity.
(2) From the equation, we can see that the new state of the particle is the result of the particle's previous state and its updated velocity. The updated velocity is affected by its best state and the global best state..
The positions of all particles are evaluated using a fitness function and compared to enter the global best position at each iteration. Thus, all particles influence the subsequent movement of each particle. The sequential processes of formulas (1) and (2) are repeated for all particles and finally, the states of the particles coincide at a certain position, and this position is considered to be the almost absolute optimal solution with a high probability [9].
The fitness function fulfills the high-level requirements of the problem, i.e. adds to our fitness measure, tries to optimize the integral, absolute time errors and increase the sensitivity of the adjuster.
Based on the obtained results, we present the specification of the genetic algorithm in the table below.

Population size	20
The speed of the particles	0.7
The rate of mutation	0.05
Length of chromosomes	12
Accuracy of variables	3
The generation gap	1

An initial population of trial and error is determined to select the parameters of the fuzzy logic based PID controller.
Where $K_P = 1.2560,\ K_I = 0.0062$ and $K_D = 0.0275$. A relevance value is generated based on the parameters of the adjuster:

$$f(t) = \int_0^l t|e(t)|dt\ , \tag{3}$$

where [0,t] is the period of time during which the adjuster is tuned to find a set of parameters that gives it the minimum fitness value. During this period, the adjuster parameters are tuned, after which, at the end of the cycle, new sets of fitness values are created. They are of higher order than the initial values of the adjuster. These retuned values of the adjuster continue to be fed back into the iterative fitness evaluation function until the process reaches the most optimal value [10].
A new population is obtained again using different operators with the best genes until a predetermined termination criterion is met. The termination criterion can be formulated as the difference between the index value of the previous generation and the current generation, which is less than a predetermined value. This process continues until the termination criterion is reached [11].
During the research, the initial parameters of relevance functions of linguistic variables were obtained based on the assessments of experts working on the basis of the regulation (Fig. 4, *a*): input variable – five relevance functions for water inflow consumption, input variable – five relevance functions for water storage consumption, output variable – water consumption seven relevance functions were formulated for the flow. After the parameters of the relevance function of the considered fuzzy adjuster are optimized using a genetic algorithm, they are changed in order to ensure the necessary quality of the adjustment process.

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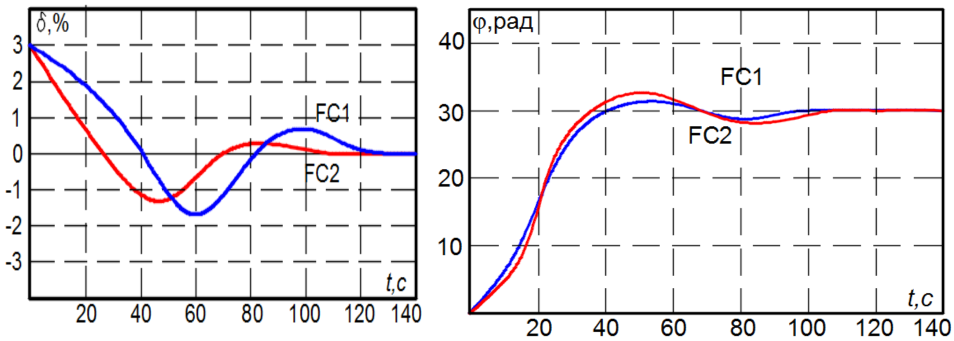

Figure 4. Fuzzy Adjuster Setup Error and Dependence on Adjustment Time Control Object Parameters Change

IV. CONCLUSION

Based on the results of the comparison of the initial results obtained by the expert evaluation of the fuzzy adjuster parameters based on the genetic algorithm, the following conclusion can be drawn: The adjusted system is significantly better than the initial system, and the adjustment value δ is reduced by half, and the adjustment time t is reduced by almost 10%.

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