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THE USE OF NATURAL OPTIMIZATION ALGORITHMS FOR THE IMPLEMENTATION OF ADAPTIVE CONTROL AT THE CROSSROAD

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The article proposes an adaptive control method for traffic lights, which operates at the strategic level of management. The algorithm uses data on changes in the intensity during the day, which provides forecasting module (for the experiments used neural network prediction). An adaptive algorithm is based on finding the minimum of delay at the crossroad, based on genetic algorithm and the method of "swarm of bees".

Keywords: traffic light, adaptive control, genetic algorithm, artificial bee colony algorithm.

Introduction

Crossroads are the most important nodes of the road network of the city. The largest losses of the roadway are observed there. The main parameter that characterizes the management of traffic lights is the average delay of transport at crossroads. Minimization of this parameter leads to an improved quality of service at the crossroads.

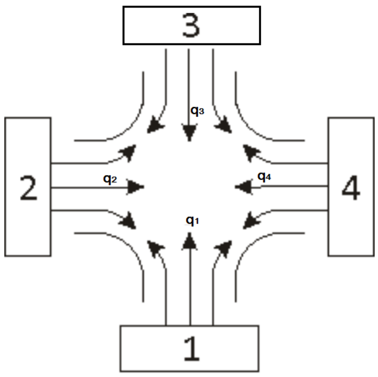

Figure 1. The scheme of traffic light object

The scheme of a typical traffic light object is shown in Fig. 1.

The optimization problem consists in choosing a number and duration of cycles in a controlled cycle in which the delay for traffic would be minimal. The following formula can be used to calculate the delay [1]:

$$e_{ti}^{'} = 0.45 \cdot \left(\frac{C \cdot (1-\lambda^2)}{1-\lambda x} + \frac{x^2}{q_i \cdot (1-x)} \right), \text{ s/vehicle,} \tag{1}$$

where C is duration of the traffic light cycle, s;

λ is a proportion of the green signal for the direction in the cycle;

q_i is traffic volume in this direction, vehicle/s;

x is a coefficient of loading.

Then the target function for the optimization task is as follows:

$$f = \sum_{i=1}^{m} w_i e'_{ti} \rightarrow \min, \quad (2)$$

where w_i is weighting factor of importance (priority) direction of optimization.

The coefficients w_i are determined at the design stage. It is also possible that these values will change during the day. If all values are equal to one, then the intersection is considered to be equivalent for each of the directions of optimization.

Thus, a complex target function f depends on many parameters t_{zi}. It is required to find such values t_{zi}, which satisfy (2).

To solve the problem of optimization the following methods have been chosen:

1. The genetic algorithm;
2. The method of "swarm of bees".

Application of Genetic Algorithm for Adaptive Management at the Crossroads

Genetic Algorithms are the adaptive search methods, which in recent times are often used for solving a functional optimization. They are based on the genetic processes of biological organisms: biological populations evolve over several generations, subject to the laws of natural selection and the principle of "survival of the fittest", discovered by Charles Darwin. Genetic algorithm is a simple model of evolution in nature, implemented by the algorithm. It is used as an analogue of the mechanism of genetic inheritance, as well as an analogue of natural selection. This preserves the biological terminology in a simplified form.

The simulation of an evolutionary process is initially generated by a random population – some individuals with a random set of chromosomes (numeric vectors). A genetic algorithm simulates the evolution of this population as a cyclic process of crossing individuals and change of generations.

The life cycle of the population – a few random crossings and mutation, which resulted in a population, is added to a number of new individuals. The selection of a genetic algorithm is the process of forming a new population from the old one, after which the old population is removed. Following the selection of a new population again used the operation of crossover and mutation, then again there is a selection, and so on (Figure 2).

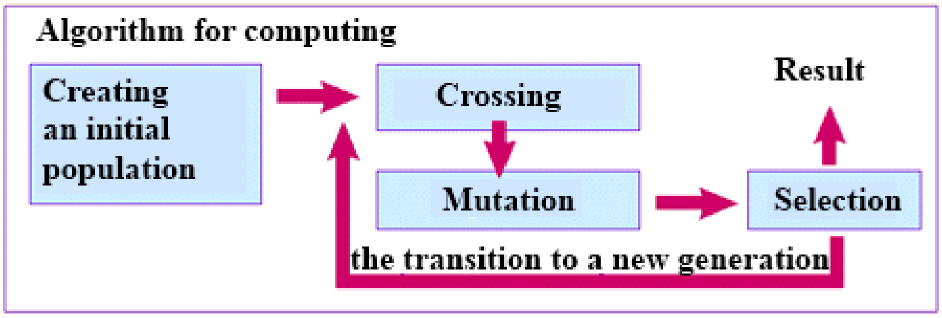

Figure 2. Steps of genetic algorithm

Step 1 – Creating the initial population.

Each member of the population consists of a set of chromosomes t_{zi}, $i = \overline{1, m}$.

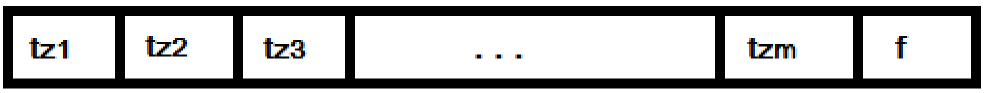

Figure 3. A set of chromosomes of an individual with a fitness function

I member of the population of chromosomes contains a value t_{zi}, which is equal to the duration of the *i*-th phase of the traffic light cycle, if the value is zero, then this phase is not in the cycle of regulation. The value of the genome for each chromosome is in the interval (t_{min},t_{max}). Number of phases m and variations of flow are defined at the design stage of the system. At this stage, as well as during crossing there is checking the admissibility condition of existence of this individual. Testing is to analyze all phases and check on the condition that the entire cycle of time allocated for each direction of motion. If this condition is not satisfied, the fitness function is calculated with an error, so there is no necessity to waste time on the calculation of this set of chromosomes varies.

Step 2 – Crossing.

The selection of a genetic algorithm is closely related to the principles of natural selection in nature as follows:

- The fitness of the individual is the value target function (fitness function) for this individual.
- Survival of the most adapted: the population of the next generation is formed in accordance with the target function. The more adapted an individual is, the greater chance of his participation in the crossover.

Model selection defines how to build the next generation population. As a rule, the probability of an individual's participation in crossing is taken proportionally to its fitness. Thus, each successive generation will be on average better than the previous one. The probability of involvement of *i*-th member of the population as a crossing is determined by:

$$P_i = \frac{1}{m-1}\left(1 - \frac{f_i}{\sum_{j=1}^{m} f_j}\right), \tag{3}$$

After determination of individuals by members crossing, the operation itself is executed crossover.

Single-point crossover works as follows. First, randomly select a point of discontinuity (break point- the area between adjacent values in a row.). Both parent structures are broken into two segments at this point. Then, corresponding to different segments of the parents, there are stuck together and produced two offspring genotypes. They can be applied to multi-point crossover or uniform crossover. In uniform crossover, each gene is inherited by the first parent's first child with a given probability; otherwise it is passed to the second child.

Step 3 – Mutation.

After the final stage of the crossover, the mutation operators are performed. Each of the individuals is subjected to mutation of each gene with probability *Pm*. The population obtained after mutation overwrites the old one. The mutation changes the value for the individual genome t_{zi} to some value in the range [-5,5].

Step 4 – Selection.

At this stage, the sorting of all genotypes of the objective function and the inclusion of the next generation of individuals with the best target function values (Eq. (2)) take place. There is just a switch on parental genotypes with the best values of f, in accordance with the principles of «elitism». The use of «elitism» cannot lose a good interim solution.

Then the steps of the algorithm are performed again starting from the second one. So is the limited number of epochs (an acceptable calculation time), resulting in the best option is chosen solving the optimization problem. Genomes of the options will be used to specify the structure and duration of phases for the traffic light cycle.

Genetic algorithm is a combined method of iterate and gradient descent. The mechanisms of crossover and mutation, in a sense part of the implement of iterative method, and the selection of the best solutions is gradient descent.

Method of "Swarm of Bees" for the Solution of the Optimization of Management at the Crossroads

One of the newest varieties of genetic algorithms is the search algorithm for swarm of bees. The algorithm for finding the global extrema of functions of complex multidimensional emerged relatively recently. The basis of the method Particle Swarm Optimization is first described in [2].

Every bee in the swarm is considered as a particle or agent. All swarm particles act individually in accordance with one control principle: to move towards the best personal and global best position, constantly checking the value of the current position.

The position coordinates of the bees in the study is *m*-dimensional space.

The personal best position (BPP) is a position with the best value of the target function, discovered by a bee. Each bee has its own BPP. At each point along the path of the bee the value of the target function at the current position is compared with a value of BPP. If the current position is set to the suitability of the above, the importance of BPP is replaced by the value of current position. The global best position (BGP) is defined as the position with the best value of the target function, found by all the swarm. Information about the value of BGP is available for each individual bee. If in the process of moving from a bee finds a position with a best target function replaced by the current position of the BGP of the bees.

Description of the algorithm for finding the optimal solution using the «swarm of bees» method:

Step 1.

Similarly, the genetic algorithm creates a population of bees, each of which contains *m* coordinates and the current value of the optimality of *f* (which is determined by the formula (2)) and also by given random initial speed of movement. Each coordinate corresponds to the duration of some phases in the traffic light cycle t_{zi}.

Step 2.

Each bee in the swarm moves in a new direction in accordance with its position and speed. There is a performance of check of exit bees solutions of bounds and limit the required actions.

Step 3.

For each bee we calculate the value of the objective function in its new position. We compare this value with the value of the BPP bees, and if necessary, replace the BPP current position.

Step 4.

For each bee we calculate new speed of movement in accordance with the equation:

$$v_i^{j+1} = w \cdot v_i^j + c_1\psi_1(p_i - t_{zi}) + c_2\psi_2(g_i - t_{zi}), \quad (4)$$

where v_i^j is a speed of the bees in the measurement of *i* to *j* iteration;

w is inertia weight, the number (located in the interval [0,1]) reflects the extent to which the particle retains its original speed;

p_i, g_i are the values of the *i* position, respectively, for the BPP and the bees swarm of BGP; ψ_1, ψ_2 is a random value in the range [-1, 1];

c_1,c_2 are constant weighting factors determining the attraction of its own BPP and BGP of swarm.

The parameter c_1 determines what effect on the particle its memories of BPP have, and c_2 determines what effect on the particle the rest of the swarm has. These factors are sometimes considered as a cognitive and social factor.

Step 5.

We check the termination condition of the algorithm (5); if the search is completed, the transition to Step 3 is executed.

As an estimate of the current state of the search process is proposed to use the average value for the swarm of Euclidean distance ε from each bee to the center of gravity of the cluster:

$$\varepsilon = \frac{1}{k}\sum_{j=1}^{k}\sqrt{\sum_{i=1}^{m}\left(t_{zi}^j - \tilde{t}_{zi}\right)^2}, \quad (5)$$

where k is population size;

$\tilde{t}_{zi}$ is a center of gravity of the swarm in the coordinate *i*:

$$\tilde{t}_{zi} = \frac{1}{k}\sum_{j=1}^{k} t_{zi}^j. \quad (6)$$

The search result is a swarm of BGP. The value of the response function at this point in relation to the known value of global optimization determines the accuracy of search results. An important advantage of this method for finding the optimal solution is its robustness, i.e. it keeps performance at rather complex response surfaces, as well as the presence of the stochastic component in the measured value of the response function.

Results of Testing Algorithms

For the beginning we generate the intensity of 8 tests of 15 minutes, equivalent to 2 hours. Table 1 shows the intensity of the input streams at a crossroads.

Table 1. Initial intensity for adaptive algorithms

№	The intensity of the *i* phase, 15 min			
	1	2	3	4
1	157	86	162	124
2	142	153	165	112
3	145	157	167	114
4	157	135	159	126
5	156	138	166	130
6	144	116	174	120
7	140	116	161	114
8	166	122	145	117

At received intensities using the adaptive algorithms we obtain the duration of the phase traffic light cycle. These data are summarized in Table 2 for the genetic algorithm and in Table 3 for the algorithm swarm of bees.

Table 2. Duration of the phases of the genetic algorithm

№	Duration of the *i* phase of the traffic light cycle					
	1	2	3	4	1+3	2+4
1	32	0	23	0	0	14
2	21	29	0	0	14	14
3	18	0	32	0	0	28
4	27	0	0	0	14	14
5	19	0	0	21	14	24
6	39	27	0	0	26	14
7	16	0	35	0	22	14
8	38	32	0	0	23	14

Table 3. Duration of the phases of the algorithm of bee swarm

№	Duration of the *i* phase of the traffic light cycle					
	1	2	3	4	1+3	2+4
1	18	0	0	0	14	14
2	27	0	32	0	0	14
3	0	23	30	0	14	14
4	0	0	0	0	39	19
5	0	0	0	0	31	24
6	28	0	38	14	19	14
7	0	0	31	0	14	17
8	0	0	0	0	17	14

The inputs to the algorithm are the intensity, which equals the amount of the intensities of the first and third phases for phase five, and phase 6 – the second and fourth.

Figure 4 shows the dynamics of the queue number 2 for the rigid control and adaptive, based on genetic algorithm.

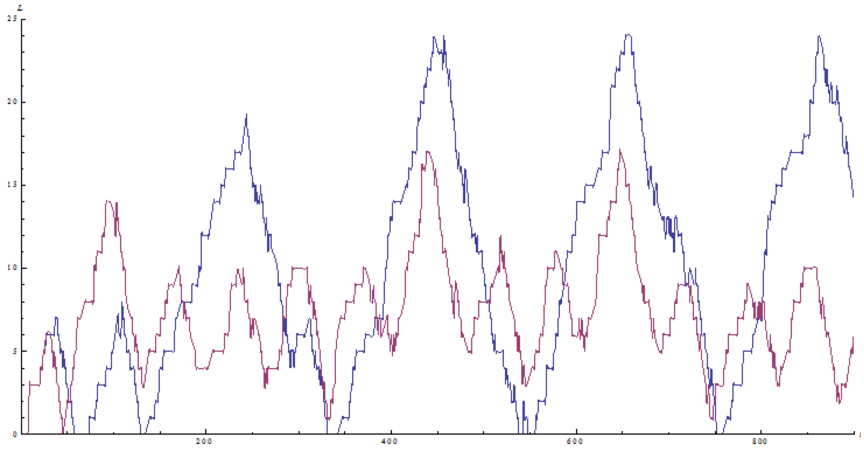

Figure 4. The dynamics of the queue for the genetic algorithm

Figure 5 shows the dynamics of the queue number 2 for the rigid control and an adaptive algorithm based on swarm of bees.

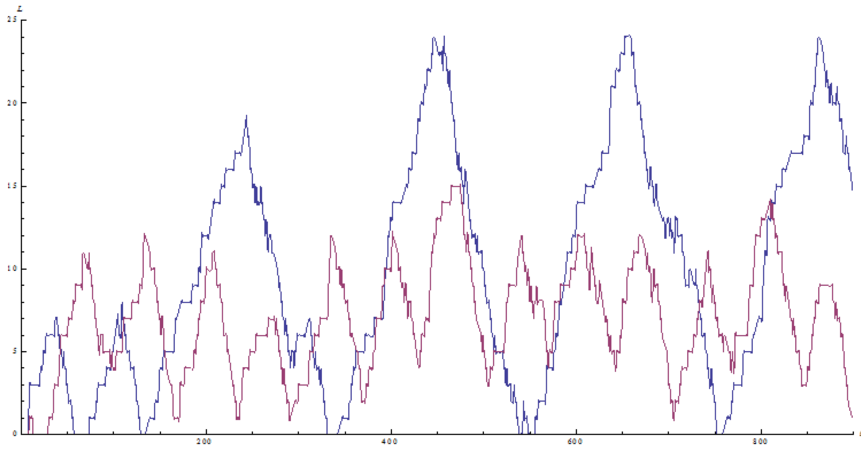

Figure 5. The dynamics of the queue for the algorithm bee swarm

Comparison of changes in the length of the queue of two adaptive algorithms is shown in Figure 6.

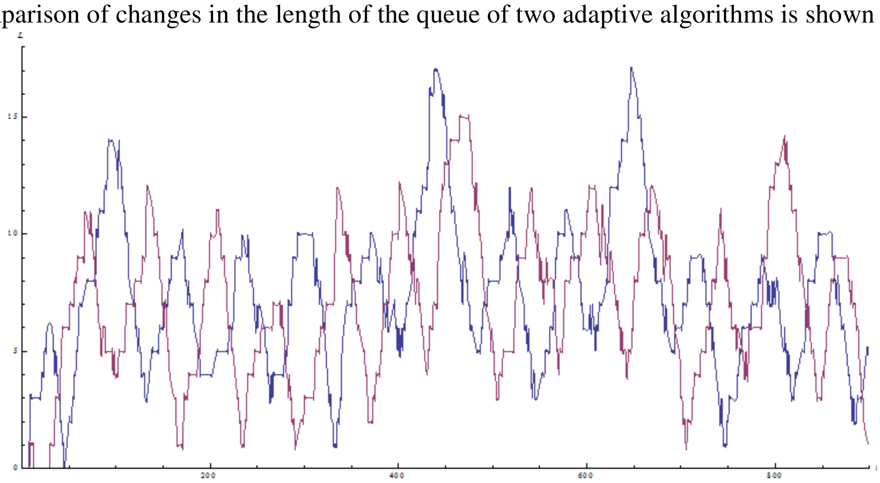

Figure 6. The dynamics of the queue adaptive algorithms

Statistics on the queue for the first 15 minutes is shown in Table 4.

Table 4. Queues statistics for the first 15 minutes

№	Number of queue	The maximum value of queue	The average value of queue	Average time in queue
Rigid algorithm				
1	Ocher1	22	7,726	45,298
	Ocher2	10	1,598	34,097
	Ocher3	23	8,088	44,732
	Ocher4	19	5,8	40,85
The genetic algorithm				
1	Ocher1	15	4,14	24,014
	Ocher2	9	1,482	30,507
	Ocher3	16	5,35	30,205
	Ocher4	16	5,285	39,44
The algorithm of swarm of bees				
1	Ocher1	9	1,108	6,45
	Ocher2	6	0,902	18,259
	Ocher3	12	4,711	25,363
	Ocher4	11	3,276	23,411

Conclusion

The article considers the option to optimize the management of traffic lights at the level of strategic management.

The proposed methods of genetic algorithm and the method of bee swarm as methods for solving the optimization problem management traffic, show their effectiveness in comparison with a rigid management mode. Since the information for calculating the parameters of traffic lights cycle is continuously entered to the adaptive control module, it allows quicker response to the current transport situation at the crossroads. Method of swarm of bees showed better performance in comparison with the genetic algorithm.

These methods belong to a class of strategic management and are a synthesis of control algorithms for a sequence of phases and the calculated algorithm for determining the duration of the cycle and phases.

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