UDC 004.891.3 (045)

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TRAFFIC CONTROL SYSTEM BASED ON NEURON NETWORKS

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Abstract—*The traffic control system based on neuron networks is considered. An accurate model of intersection is represented. It is determined the strategy of intersection traffic control using neural controller, which is based on classical neural network topologies of unidirectional multilayer perceptron.*

Index Terms—Traffic control system; neuron networks; unidirectional multilayer perceptron

I. INTRODUCTION

The surface street traffic control systems technology has seen significant advances in the following areas [2]–[8]:

– improved traffic signal controllers;

– increased use of non-pavement-invasive detectors;

– improved transit priority strategies and equipment based on the use of Global Positioning System technology;

– increased use of fiber optic cable for interconnection of traffic signal controllers and communication with other field devices;

– increased use of standardized protocols to migrate data between intersection controllers and field master controllers or traffic management centers.

The period has also witnessed the following improvements in control strategies and operations:

– greater information migration among adjacent and nearby traffic management centers;

– increased coordination of signals across neighboring jurisdictions and traffic control systems;

– increased use of adaptive traffic control systems;

– improved coordination of surface street and freeway operations;

– provision of traffic control systems with software that facilitates the automatic migration of signal timing plan data derived from signal timing programs into the traffic control system database.

Control and management functions may include the following:

– collection of data for development of signal timing plans and other functions (identification of control section boundaries and provision of parameters in the traffic control systems);

– development of timing plans and the remainder of the traffic control system database.

– implementation of signal timing plans, such as: pretimed, traffic responsive, operator selection of timing plans based on data provided by the traffic control system and other information sources;

– implementation of motorist information by means of changeable message signs, highway advisory radio, independent service providers, media and websites;

– management of incidents on surface streets;

– evaluation of system performance.

II. DEFINITIONS AND DESIGNATIONS

It is proposed to consider the intersection with the four directions L_1, L_2, L_3 and L_4, each movement of which is regulated by light signals T_1, T_2, T_3 and T_4 respectively (Fig. 1).

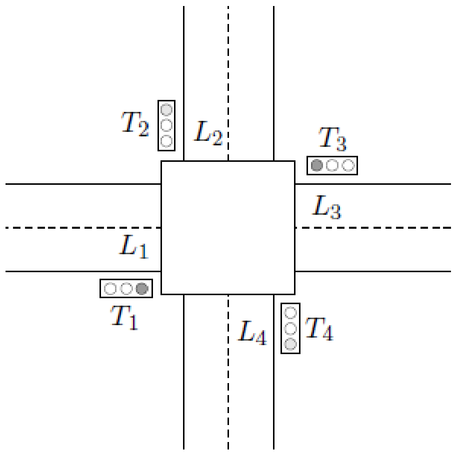

Fig. 1. The topology of the intersection

Each light signal has green, yellow and red phase.

$\lambda_i(t)$ is the arrival rate of vehicles on the L_i direction, where i = 1, 2, 3, 4.

$\mu_i(t)$ is the departure rate of the vehicles at the green phase of the Ti light signal on the L_i direction, where i = 1, 2, 3, 4.

$k_i(t)$ is the departure rate of the vehicles at the yellow phase of the Ti light signal on the L_i direction, where i = 1, 2, 3, 4.

$\lambda_i(t), \mu_i(t), k_i(t) \geq 0$, for all i and t.

δ_a is the duration of the yellow signal. It is assumed that this value is fixed and constant for all light signals.

Let t_0, t_2, t_4, ... be the sequence of moments of time in which the lights T_1 and T_3 are switched from yellow to red, and T_2 and T_4 from red to green. In turn, t_1, t_3, t_5, … is the sequence of moments of time, in which the lights T_1 and T_3 are switched from red to green, and T_2 and T_4 from yellow to red. Switching circuit is given in Table 1 and represented on Fig. 2.

Let $G_1 = G_3 = \{1,3,5,...\}$, and $G_2 = G_4 = \{0,2,4,...\}$, respectively, if $k \in G_i$, then light signal T_i switch from red to green phase at time t_k and arrives in it for $(t_k, t_{k+1} - \delta_a)$. Let us define $\delta_k = t_{k+1} - t_k$ for $k \in \mathbb{N}$. It is obvious that $0 \le \delta_a <= \delta_k$ and $t_k < t_{k+1}$ for all k.

TABLE 1

THE SEQUENCE OF LIGHT PHASES

The periods	T_1	T_2	T_3	T_4
$(t_0, t_1 - \delta_a)$	red	green	red	green
$(t_1 - \delta_a, t_1)$	red	red	red	red
$(t_1, t_2 - \delta_a)$	green	red	green	red
$(t_2 - \delta_a, t_2)$	red	red	red	red
$(t_2, t_3 - \delta_a)$	red	green	red	green
$(t_3 - \delta_a, t_3)$	red	red	red	red
…	…	…	…	…

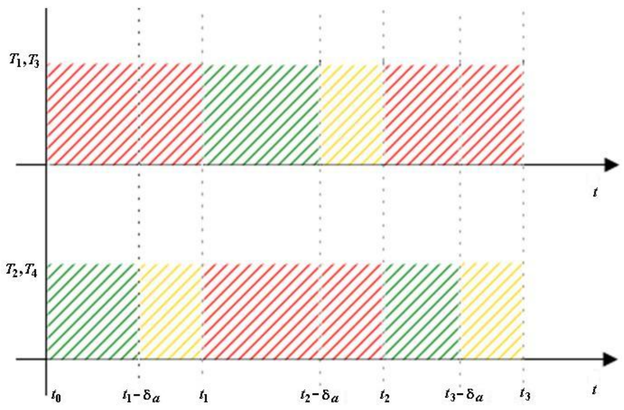

Fig. 2. The sequence of light signal phases

III. THE FORMULATION OF THE OPTIMAL CONTROL PROBLEM

Further assume that the speed of arrival and departure of vehicles are known. For a given natural number N it is necessary to find the optimal sequence t_0, t_1, …, t_N of the moments of light switching, which would have minimized the specified criteria:

1. Queue length:

$$J_1 = \sum_{i=1}^{4} w_i \frac{\int_{t_0}^{t_N} l_i(t)dt}{t_N - t_0}.$$

2. The average length of the loaded queue:

$$J_2 = \max_i \left(w_i \frac{\int_{t_0}^{t_N} l_i(t)dt}{t_N - t_0} \right).$$

3. The length of the loaded queue:

$$J_3 = \max_{i,t} \left(w_i l_i(t)dt \right).$$

4. Average waiting time:

$$J_4 = \sum_{i=1}^{4} w_i \frac{\int_{t_0}^{t_N} l_i(t)dt}{\lambda_i (t_N - t_0)}.$$

5. The average waiting time in the loaded queue:

$$J_5 = \max_i \left(w_i \frac{\int_{t_0}^{t_N} l_i(t)dt}{\lambda_i (t_N - t_0)} \right),$$

where $w_i > 0$ for i = 1, 2,3, 4. The weights w_i can be used to determine the benefits of different directions. It is also worth noting that the criteria J_1 and J_4 are equivalent, in the sense that for any vector of weights $\boldsymbol{w}$ for J_1 there is a vector $\dot{w}$ for J_4, that J_1 and J_4 which will be equal. J_2 and J_5 are also equivalent.

In the formulation of optimal control traffic at the intersection, additional restrictions should be set:

– the maximum and minimum duration of green phase;

– the maximum permissible length of queues.

IV. CONTROL STRATEGY

From the point of control theory view model of the intersection can be written in the following form:

$$x_{k+1} = f(x_k, u_k).$$

Given x_0 is the initial state of the system. Here x_{k+1} is vector of the next system state, based on the current state; x_k and u_k is control vector; $f(\cdot)$ is a mathematical model of the intersection.

We write the state vector x_k for intersection:

$$x_k = l_1, l_2, l_3, l_4, \lambda_1, \lambda_2, \lambda_3, \lambda_4, \mu_1, \mu_2, \mu_3, \mu_4, k_1, k_2, k_3, k_4,$$

here l_i is a queue length; λ_i is a arrival rate of vehicle; μ_i is a speed departure of the vehicle at the green light; k_i is a speed departure of the vehicle at the yellow signal light, for $i = 1, 2, 3, 4$.

Implemented on the basis of the simplex-method, the optimizer will be denoted as follows: $u_k = \rho(x_k)$.

In order to avoid misunderstandings, we note that in the second section to denote the vector of optimal control u_k we have used δ^*.

Strategy of automated control of the intersection is shown in block diagram Fig. 3.

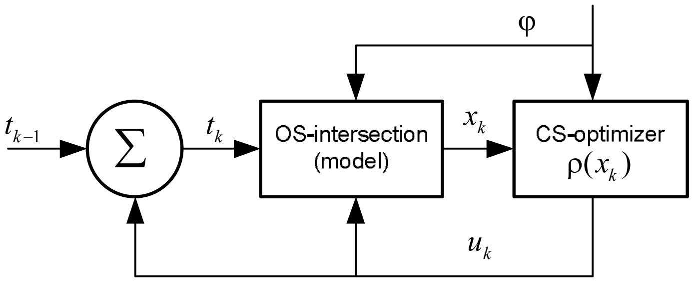

Fig. 3. Strategy of automated control of the intersection

At the time t_k the vector of the current state of the intersection x_k is given to the optimizer. The optimizer calculates the vector of control actions u_k is sequence of six alternating durations of phases, during which minimizes the objective function J is the average length of the queues. Here φ denotes the noise acting on the object and the control system.

The task of designing neural controller $\eta(x_k)$

$$u_k = \eta(x_k, \omega),$$

which would approximate the work of optimizer $\rho(x_k)$:

$$\rho(x_k) \cong \eta(x_k, \omega),$$

here ω are the weighting coefficients of the neural network.

Concerning the dependence μ_i and k_i on λ_i, for $i = 1, 2, 3, 4$, the state vector of the intersection we would write as:

$$x_k = l_1, l_2, l_3, l_4, \lambda_1, \lambda_2, \lambda_3, \lambda_4.$$

The block diagram of the control using neural controller instead optimizer shown on Fig. 4.

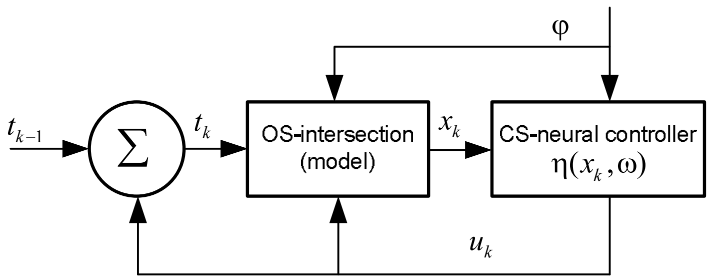

Fig. 4. The block diagram of the control using neural controller

Neural controller calculates the sequence of control actions u_k, which consists of six consecutive durations of alternating phases:

$$u_k = (\delta_1, \delta_2, \delta_3, \delta_4, \delta_5, \delta_6).$$

To the intersection control system will use the first two elements of the control vector δ_1 and δ_2. After it will perform a new calculation. This control strategy is called the control according to the time horizon that moves or the N-step control in order to achieve the desired system state. The idea of using this strategy of neurocontrol has been adopted from the work of Bernard Widrow [1], in which he solved the problem of parking of the truck using the multilayer Adaline. The meaning of this idea is to workout NN to produce control actions based on the current state of the system to bring the system to the desired state for a certain number of steps. Features of this neural controller will be considered more in the development of the training algorithm.

For training the neuron network (NN) we will need the model of the intersection $f(\cdot)$ and the optimizer $\rho(\cdot)$. For this, they were implemented as software modules using Mathematica 7.0.

V. THE TOPOLOGY OF A NEURAL NETWORK

Neural controller is based on classical neural network topologies of unidirectional multilayer perceptron. Activation of neurons in the hidden layer is the hyperbolic tangent. The number of hidden layers and number of neurons in each layer required for the maximum approximation were determined recursively in the course of the experiment. The end result of determining the topology of NN is depicted on Fig. 5.

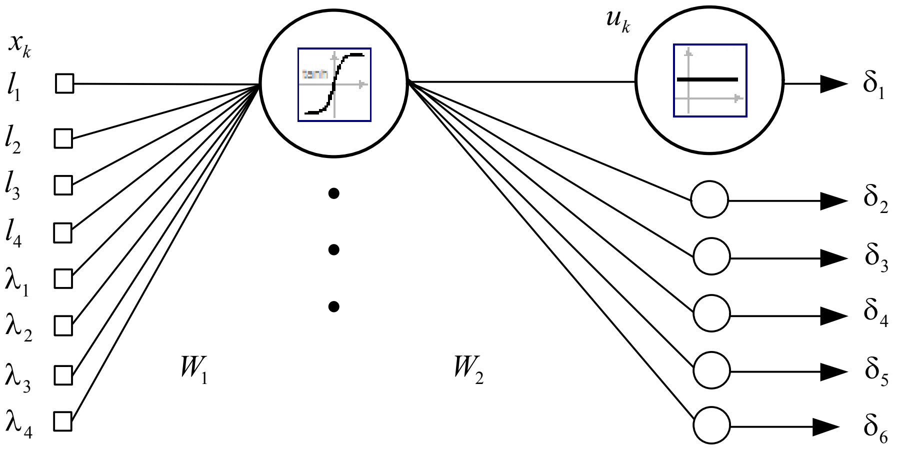

Fig. 5. Topology of NN

When selecting a topology of the neural network, the best result (lowest achieved value of the objective function) of NN was shown with three layers, one of which is hidden:

– the input layer contains 8 passive neurons on which the input state vector intersection $x_k = l_1, l_2, l_3, l_4, \lambda_1, \lambda_2, \lambda_3, \lambda_4$. is sent;

– the hidden layer contains 520 neurons, the activation of which is the hyperbolic tangent;

– the output layer has 6 neurons – $u_k = (\delta_1, \delta_2, \delta_3, \delta_4, \delta_5, \delta_6)$, the activation function is linear and is used to scale the output vector. W_1, W_2 are matrices of weights between layers of NN.

Example. The visual image of the investigated intersections shown in Fig. 6.

Detail of the studied characteristics are shown in Table 2, and set parameters for each of the points in the same cycle regulation.

Fig. 6. Crossroads for research:

1 is direction in a straight st. Tolstoy (east-west);
2 is st. Tolstoy (west-east); 3 is st. Volodymyrska (north-south)

TABLE 2

CHARACTERISTICS FOR RESEARCH

Starting point	Number of cars in line before the green signal	Number of cars that drove to right	Number of cars that drove straight	Number of cars that drove to left	Number of machines that turned to right at the red signal	Number of cars that per-left after the green signal
1	21	8	11	3	7	0
2	20	4	10	7	1	0
3	25	8	1	4	0	0
1	23	10	12	2	0	0
2	18	6	7	10	0	0
3	23	5	12	10	0	0
1	28	15	7	3	4	8
2	26	8	12	2	0	11
3	30	5	8	10	1	13
1	33	10	5	2	5	16
2	29	4	8	13	0	12
3	28	2	10	9	1	14

CONCLUSION

It is realized the traffic control system based on neuron network. The researches of this system are carried out on example of Volodymyrska and Tolstoy streets intersection in Kyiv. The implementation of such traffic control system will give good results.

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Received 14 August 2014.

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О. І. Чумаченко. Автоматизована система керування дорожнім рухом на основі нейронних мереж

Розглянуто автоматизовану систему керування дорожнім рухом, яка базується на використанні нейронних мереж. Представлено математичну модель перехрестя. Визначено стратегію керування дорожнім рухом на перехресті з використанням нейроконтролера, побудованого на базі багатошарового персептрона.

Ключові слова: система керування дорожнім рухом; нейронні мережі; однонаправлений багатошаровий персептрон.

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Кількість публікацій: 52.
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Е. И. Чумаченко. Автоматизированная система управления дорожным движением на основе нейронных сетей

Рассмотрена автоматизированная система управления дорожным движением, основанная на использовании нейронных сетей. Представлена математическая модель перекрестка. Определена стратегия управления дорожным движением на перекрестке с использованием нейроконтроллера, построенного на базе многослойного персептрона.

Ключевые слова: система управления дорожным движением; нейронные сети; однонаправленный многослойный персептрон.

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