Sensors & Transducers, Vol. 22, Special Issue, June 2013, pp. 66-73

Sensors & Transducers

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Research on Traffic Artery Intelligent Control System Based on Wireless Sensor Network

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Received: 15 April 2013 /Accepted: 20 June 2013 /Published: 28 June 2013

Abstract: Based on the researches on controlling urban artery traffic, a hierarchical control method for traffic signals at artery multi-crossings is proposed. This control method, which uses wireless sensor networks and fuzzy control method, has two layers of WSN. The first layer is a data collecting layer which consists of terminal nodes and sink nodes. This data collecting layer is responsible for collecting and transmitting vehicle information to the second layer after data fusion at the single crossings. The fuzzy controller, nested in the sink nodes, is used to accomplish traffic light control and adjusting on-line the green ratio in all directions at crossings. The second layer is the control layer, composed of coordinator nodes in which the fuzzy controller is nested. The coordinator nodes are used to receive the traffic data detected by the first layer, the real traffic data and the forecasting traffic datas are input into the fuzzy controller. The fuzzy controller determines the signal cycles at the artery. Simulation results have shown that this method is superior to the ordinary fuzzy control, effectively reducing queue length of vehicles and traffic delays. *Copyright © 2013 IFSA.*

Keywords: Wireless sensor network, Intelligent traffic, Fuzzy control, Neural network, Traffic flow forecasting.

1. Introduction

The fuzzy control does not need any accurate mathematical models. It is especially suitable for high random traffic control systems. In 1977, Pappis [1] and others designed a two-phase fuzzy logic controller for a single intersection. In the simulation to an ideal plane intersection, such a control algorithm could reduce traffic delays around 7 % than traditional control method. Since then, on the basis of this design, many researchers had made further development .While comparing set-timed control or sensor control with system performance, they also got a more positive and superior result of average waiting time [2-4].

One of the key intelligent traffic system technologies is traffic data acquisition. In present, the majority of traffic information is being transmitted by wire which has a bad effect on protection of roads during designing, influencing the normal regulation of cars, reducing the budget and so on. Because of its good functions, such as low-power- consumption, self-organizing, distributed computing and easy disposer, the wireless sensor networks are widely used in information collections and intelligent control systems. As researches have shown that wireless senor networks have many outstanding features, they can provide an effective mean for intelligent traffic systems to acquire data [5, 6].

Article number P_SI_380

Traffic flow forecasting plays an important role in traffic control system. Adopting present traffic data at real time incessancy to predict traffic flow in several minutes is a first-floor condition for carrying out traffic control and guidance. In the past years, making use of all sorts of different scent methods, many experts and scholars have already designed different kinds of models for traffic flow forecasting. Neural network has been used to forecasted traffic flow for its strong ability of nonlinear mapping [7, 8], and the result are good.

Synthesizing local and overseas researches on crossing signal controls, we have found that control schemes using the WSN and the fuzzy neural work combined together to control traffic arteries are rare, and their theory and practice are not perfect. Learning from the previous researches, we have combined the wireless senor network, the fuzzy control method and the neural network forecasting technology to build a low-cost and practical hierarchical control system for traffic arteries. The WSN detects the number of vehicles entering the crossings from traffic arteries to achieve the wireless real-time transmission. The objective is to minimize the average queuing length. The fuzzy control method is used to on line adjust the prime green light delays in all directions at the crossings and the signal cycles at arteries.

2. Control Model and Algorithm

2.1. Control Model

The system uses two layers of control models, as shown in Fig. 1. The first layer is the data collecting layer, composed of terminal nodes and sink nodes. They form a cluster, while the sink nodes work as the heads of the cluster, and other data collecting nodes work as members. Terminal nodes are located at each crossing for traffic count. Sink nodes are used to collect the data from data collecting nodes. The data are transmitted to the second layer after data fusion. The fuzzy controller, nested in the sink nodes, is used to accomplish traffic light control and adjusting on-line the green ratio in all directions at crossings. The second layer is the control layer which is composed of coordinator nodes. The fuzzy controller, nested in the coordinator node, is used to determine the signal cycles at arteries and adjusting on-line, which then is being inputted to sink nodes at each crossing.

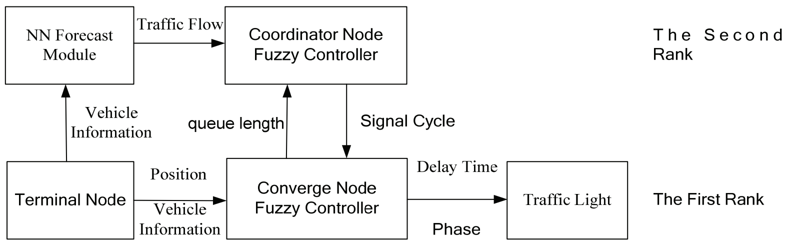

Fig. 1. Two-Rank WSN control model.

2.2. Control Algorithm

In the traffic control system, the harmonious cycle at each crossing cycle cannot change too frequent, otherwise the traffic delay loss caused by the change of the solution would outstrip the benefit gained by the new scheme[9]. In this article we have assigned six cycles as a time period, in which signals and phases used in the artery are kept unchanged, but the green ratio can be adjusted in real-time.

Step 1: The coordinator nodes calculate the phase difference ω_i (i=1,2,3,…, m) among the crossings at the arteries, and unify the cycle T and the green ratio at each crossing according to the previous traffic flow data. Data are sent to the sink nodes at the crossings to initialize the cyclic variable n=0.

Step 2: In the cycle T period, the sink nodes at the artery crossings start the green light signals in sequence, basing on the phase difference ωi. The fuzzy controller, nested in the sink nodes, is used to accomplish traffic light control and adjusting on-line the green ratio in all directions at crossings.

Step 3: At the end of a given cycle time, the sink nodes, which use the data sent by the terminal node, compute the vehicle queue length P of the green light phase and the queue Q of the next green light phase at the crossings, and transmit the data to the coordinator nodes.

Step 4: Use n=n+T to check the validity of n>6T. If it is valid, then go to step 5. If not, return to step 2.

Step 5: Using the fuzzy control method, the coordinator nodes use the data of the traffic flow by the sink nodes at the crossings and by the forecasting model to determine the cycle and phase difference so that the average vehicle queue length is kept to a minimum. Return to Step 2.

3. The Wireless Sensor Networks and its Node Hardware Design

3.1. The Wireless Sensor Traffic Information Collecting Network

The wireless traffic information collecting network is made up of the terminal nodes, the sink nodes and the coordinator nodes, as shown in Fig. 2. The terminal nodes, disposed on the roadside, are used to collect the signals from the observation area, to process the original signals, to extract the vehicle information, and to transmit the traffic information through the wireless network. The sink nodes gather and fuse the data from all the terminal nodes at the crossings, and transmit the traffic information to the coordinator nodes [10, 11].

3.2. Hardware Design of the Nodes

The hardware structure of the nodes is the same and the only difference between them is in software configurations. Each wireless sensor node is made up of a data acquisition module, a processor module, a wireless communication module and a power supply module, as shown in Fig. 3.

The data-processing module and the wireless communication module consist of a Chipcon's SOC chip CC2430, which is a new generation of a Zigbee wireless single chip computer with a positioning engine. The CC2430 integrates the Zigbee RF front-end, the memory and the controller into a single chip. It includes an 8051 processor kernel and an IEEE 802.15.4 RF transceiver, which is a high-performance RF transceiver CC2420, and supports the Zigbee low-rate communication standards. It has a 32 MHz internal clock and its power consumption is only 7.0 mA at the work peak level in the processor core. Wireless transceiver consumes 24 ~ 27 mA. It supports a 4-grade low-power mode. To implement wireless data transmitting and receiving, it controls the operation of the entire sensor node, including the storing and processing of the data collected. The single-chip microcomputer in CC2430 communicates with the sensor by its figure port [12].

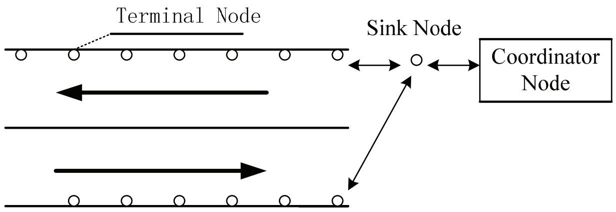

Fig. 2. Wireless traffic information collecting network.

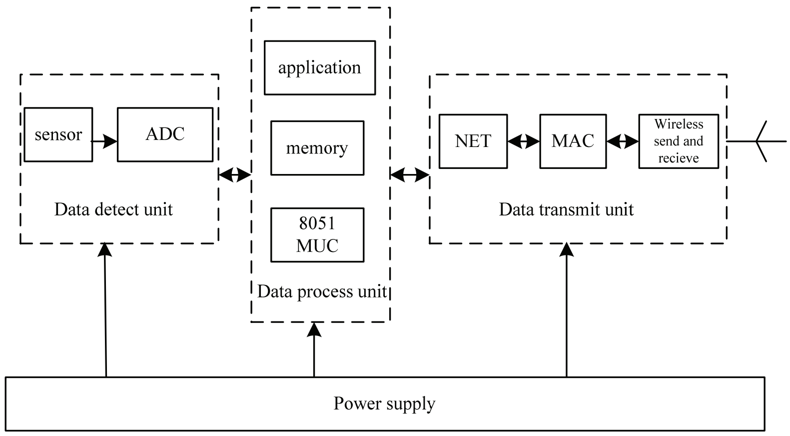

Fig. 3. Sensor node structure.

4. Design of Fuzzy Controller

The system includes two fuzzy controllers: a green light delay fuzzy controller and a signal cycle fuzzy controller. The green light delay fuzzy controller is located in the sink nodes. The signal cycle fuzzy controller is located in the coordinator node. The green light delay fuzzy controller adjusts the green ratio for each direction of the crossing according to the real-time traffic flow data at the crossing. The signal cycle fuzzy controller determines the signal cycles on the arteries according to the real traffic flow and the forecast traffic flow.

4.1. Design of Green Light Delay Fuzzy Controller

4.1.1. Fuzzy Process of Input and Output Variables

There are two inputs (green light phase vehicle queue length P and next green light phase vehicle queue length Q) and an output (the green light delay ΔG). The universes of discourse of input variables P and Q are {0,2,4,6,8,10,12,14,16,18,20}. The fuzzy set of P and Q are defined as {p1 (very short), p2 (short), p3 (shorter), p4 (middle), p5 (longer), p6 (long), p7 (very long)}.

Their membership function assignment is shown as Table 1.

The universes of discourse of output variable △G are {0, 3, 6, 9, 12, 15, 18}. Its fuzzy set is defined as {g1 (very little), g2 (little), g3 (less), g4 (middle), g5 (more), g6 (much), g7 (very much)}. Its membership function assignment is shown as Table 2.

4.1.2. Fuzzy Control Rule

According to of control experiences of traffic policemen, the following green time delay fuzzy control rules can be summed up as shown in Table 3.

According to of control experiences of traffic policemen, we can sum up 49 green time delay fuzzy control rules:

Rule 1: if P is very long and Q is very long then ΔG is much;

Rule 2: if P is very long and Q is long then ΔG is very much;

Rule 3: if P is very long and Q is longer then ΔG is very much;

Rule4: if P is very long and Q is middle then ΔG is very much;

Rule 5: if P is very long and Q is shorter then ΔG is very much;

Rule 6: if P is very long and Q is short then ΔG is very much;

Rule 7: if P is very long and Q is very shorter then ΔG is very much;

and so on, all fuzzy control rules as shown in Table 3.

Table1. Membership function assignment table of P and Q.

P/Q	0	2	4	6	8	10	12	14	16	18	≥20
p1	1.0	0.9	0.6	0.2							
p2	0.2	0.7	1.0	0.7	0.2						
p3		0.2	0.8	1.0	0.8	0.2					
p4			0.1	0.4	0.6	1.0	0.6	0.4	0.1		
p5						0.2	0.8	1.0	0.8	0.2	
p6							0.2	0.7	1.0	0.7	0.2
p7								0.2	0.6	0.9	1.0

Table 2. Membership function assignment table of ΔG.

△G	0	3	6	9	12	15	18
g1	1.0	0.7	0.3				
g2	0.7	1.0	0.7	0.3			
g3	0.3	0.7	1.0	0.7	0.3		
g4		0.3	0.7	1.0	0.7	0.3	
g5			0.3	0.7	1.0	0.7	0.3
g6				0.3	0.7	1.0	0.7
g7					0.3	0.7	1.0

Table 3. Green time delay fuzzy control rule table.

P	Q						
	p7	p6	p5	p4	p3	p2	p1
p7	g6	g7	g7	g7	g7	g7	g7
p6	g5	g6	g6	g6	g7	g7	g7
p5	g4	g5	g5	g5	g6	g6	g6
p4	g3	g4	g4	g4	g4	g4	g5
p3	g3	g3	g3	g4	g4	g4	g4
p2	g2	g2	g2	g3	g3	g3	g3
p1	g1	g1	g1	g1	g1	g1	g2

4.2. Signal Cycle Fuzzy Controller

In the traffic control system, the cycle should keep the same in order to ensure harmonious traffic signals at artery and steady phase difference, accomplishing green wave control for traffic artery.

4.2.1. Traffic Flow Forecast

The adaptive weight model base on neural network and Linear regression. Its input variable is road parameters, and the output variable is weight vector quantities. The error between forecast data and the real data is been used to train the neural network.

Due to the relevant between crossroads with periods of cars, 24 hours are divided into m time slot according to different ways to choose the corresponding linear of regression model in different time. Regression coefficient uses the neural network method of offline training acquisition to acquire it according to historical data. And according to regression model, it can calculate the prediction vehicle number of the certain crossing.

4.2.1.1. Linear Regression Model

$$Y_t = a_{t0} + a_{t1}X \quad \text{t=1,2,...,m}$$

T is a time slot in a day. X is the vehicle number coming from the last traffic light crossroads. a_{t0}, a_{t1} are the Corresponding regression coefficient respectively. Y_t is the prediction vehicle number of the certain crossing.

4.2.1.2. The BP Neural Network Model

This text has used the BP nets neural network of training regression coefficients. The learning process of the BP is made of the model of forward-propagating and EBP. In propagation process, input information through implied unit which is in depth analysis and then headed the output layer. If the output layer can't meet the expected output, it will back the propagation process and make the error between the actual regression coefficient values and regression coefficient value of the output network return along the original connected pathways. By change the connection weights of the hidden layer neurons, it can minimize the error and switch to the positive propagation process. In this interactive method, it can make the error less than the set value[13]. The neural network model is Fig. 4.

Set X_t as Input vector:

$$X_t = (x_1, x_2, x_3) \quad \text{t= 1,2,…,n}$$

In formula: n is training example; x_1 is the number of vehicle that come from last traffic light intersection, x_2 is the time, x_3 is the number of non-green lights around two green lights, unit of input layer is 3.

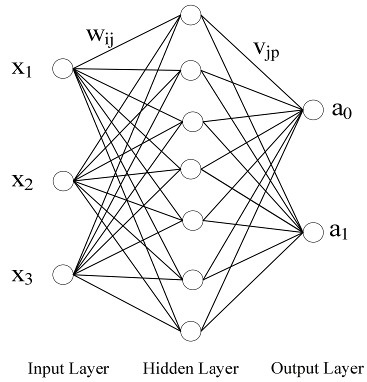

Fig. 4. NN model.

Input vector is:

$$A_t = (a_{t0}, a_{t1})$$

Hidden layer number of neurons chooses 2*3+1=7. Effect function chooses in (0,1) to get Sigmoid function value continuously:

$$f(x) = 1/(1+e^{-x}) \tag{1}$$

The input and output of hidden layer unite is respectively as follows:

$$H_j = \sum_{i=1}^{3} w_{ij}x_i - \theta_j \quad \text{=1,2,...,7.} \tag{2}$$

$$h_j = 1/[1+\exp(-\sum_{i=1}^{3} w_{ij}x_i + \theta_j)] \quad \text{j=1,2,...,7.} \tag{3}$$

In formula, w_{ij} is the most important connection between input layer and hidden layer; θ_j is the threshold of hidden layer unit; j is the number of hidden layer unit.

The input and output of output layer unit is respectively as follows:

$$O_p = \sum_{j=1}^{7} v_{jp}h_j - \gamma_p \quad \text{p=1,2} \tag{4}$$

$$U_p = 1/[1+\exp(-\sum_{j=1}^{7} v_{jp}h_j + \gamma_p)] \tag{5}$$

In formula, v_{jp} is the most important connection between hidden layer and output layer; γ_p is the threshold of output layer unit.

In procession of transmission error reversely, the first thing is to set calculation for error, and then set NO. k as a training samples with actual output and expected one

$$E_k = \frac{1}{2}\sum_{p=1}^{2}(A_{kp} - U_{kp})^2 \quad (6)$$

A_k is output expectation, in order to make E_k reduce by gradient principle, Δv_{jp} is proportional to the negative of $\frac{\partial E_k}{\partial v_{ip}}$, namely:

$$\Delta v_{jp} = -\alpha \frac{\partial E_k}{\partial v_{jp}} \quad (7)$$

it can deduce that:

$$\Delta v_{jp} = \alpha d_{kp} h_j \quad (8)$$

$$\Delta \gamma_p = \alpha d_{kp} \text{ j=1,2,...,7, p=1,2, k=1,2,...,n.} \quad (9)$$

α is the rate of study

$$d_{kp} = (A_{kp} - U_{kp})U_p(1 - U_{kp}).$$

It's the same to the importance of hidden layer and to the threshold adjustment quantity, as follows:

$$\Delta w_{ij} = \beta D_{kj} x_i \quad (10)$$

$$\Delta \theta_j = \beta D_{kj} \text{ i=1,2,3, j=1,2,...,7, k=1,2,...,n.} \quad (11)$$

In formula, $D_{kj} = (\sum_{p=1}^{2} d_{kp} v_{jp}) h_j (1 - h_j)$

4.2.2. Signal Cycle Fuzzy Controller

Signal cycle fuzzy controller has two inputs: saturation X, sum Y of the queue length in next green light phase and the forecast traffic flow in 15 seconds, one output: cycle increment ΔC.

4.2.2.1. Fuzzy Process of Input and Output Variables

The universes of discourse of input variables X are {0.40, 0.55, 0.70, 0.80, 0.85, 0.90, 0.91, 0.92, 0.94, 0.97, 0.99}, Its fuzzy set is defined as: {VerySmall, Small, Medium, High, VeryHigh}, shortly, {VS, S, M, H, VH}. Its membership function assignment is shown as Table 4.

The universes of discourse of input variables Y are {0, l0, 20, 30, 40, 50, 60, 70, 80, 90, 100}, Its fuzzy set is defined as: {VeryShort, Short, Medium, Long, VeryLong }, shortly, {VS, S, M, L, VL}. Its membership function assignment is shown as Table 5.

The universes of discourse of input variables ΔC are {-10, -8, -6, -4, -2, 0, 2, 4, 6, 8, 10}, Its fuzzy set is defined as: { VeryShort, Short, Medium, Long, VeryLong }, shortly, {VS, S, M, L, VL}. Its membership function assignment is shown as Table 6.

Table 4. Membership function assignment table of X.

X	0.40	0.55	0.70	0.80	0.90	0.91	0.92	0.93	0.94	0.96	0. 98
VS	0.2	0.7	1.0	0.7	0.2						
S		0.2	0.8	1.0	0.8	0.2					
M			0.1	0.6	1.0	0.6	0.1				
H				0.2	0.8	1.0	0.8	0.2			
VH							0.2	0.8	1.0	0.8	0.2

Table 5. Membership function assignment table of Y.

Y	0	10	20	30	40	50	60	70	80	90	100
VS	0.2	0.7	1.0	0.7	0.2						
S		0.2	0.8	1.0	0.8	0.2					
M			0.1	0.6	1.0	0.6	0.1				
L				0.2	0.8	1.0	0.8	0.2			
VL							0.2	0.8	1.0	0.8	0.2

Table 6. Membership function assignment table of ΔC.

ΔC	-10	-8	-6	-4	-2	0	2	4	6	8	10
VS	0.2	0.7	1.0	0.7	0.2						
S		0.2	0.8	1.0	0.8	0.2					
M			0.1	0.6	1.0	0.6	0.1				
L				0.2	0.8	1.0	0.8	0.2			
VL							0.2	0.8	1.0	0.8	0.2

4.2.2.2. Fuzzy Control Rule

A large number of research and application indicate that adjusting cycle time should keep saturation reach around 0.9 [2], while at this point traffic ability is the largest and delay is the smallest. Experience shows, as saturation is small than 0.9, cycle should be reduced to improve the traffic efficiency at crossings, otherwise cycle should be increased. Meanwhile, when traffic flow is bigger, cycle should be increased. On the contrary, when traffic flow is smaller, cycle should be reduced.

According to of control experiences, we can sum up 25 cycle increment fuzzy control rules as following:

Rule 1: if X is VS and Y is VS then ΔC is VS;
Rule 2: if X is VS and Y is S then ΔC is VS;
Rule 3: if X is VS and Y is M then ΔC is VS;
Rule4: if X is VS and Y is L then ΔC is M;
Rule 5: if X is VS and Y is VL then ΔC is H;
Rule 6: if X is S and Y is VS then ΔC is VS;
Rule 7: if X is S and Y is S then ΔC is S;
Rule 8: if X is S and Y is M then ΔC is M;
Rule 9: if X is S and Y is L then ΔC is M;
Rule 10: if X is S and Y is VL then ΔC is H;
Rule 11: if X is M and Y is VS then ΔC is S;
Rule 12: if X is M and Y is S then ΔC is M;
Rule 13: if X is M and Y is M then ΔC is M;
Rule 14: if X is M and Y is L then ΔC is H;
Rule 15: if X is M and Y is VL then ΔC is VH;
Rule 16: if X is H and Y is VS then ΔC is M;
Rule 17: if X is H and Y is S then ΔC is M;
Rule 18: if X is H and Y is M then ΔC is H;
Rule 19: if X is H and Y is L then ΔC is VH;
Rule 20: if X is H and Y is VH then ΔC is VH;
Rule 21: if X is VH and Y is VS then ΔC is M;
Rule 22: if X is VH and Y is S then ΔC is H;
Rule23: if X is VH and Y is M then ΔC is H;
Rule 24: if X is VH and Y is H then ΔC is VH;
Rule 25: if X is VH and Y is VH then ΔC is VH.

5. Simulation Experiments

Provided there is a highway including three crossings, where east-west direction is the artery, while south-north direction is the branch. Saturation flow on artery is 3600 PUC/h, while Saturation flow on branch is 1800 PUC/h. The distance between each two crossings is 600 M, as shown in Fig. 5. Traffic flow of reaching vehicles obeys Poisson distribution, while traffic flow of leaving vehicles obeys negative index distribution. Proportion of traffic flow for turning left and going straight and turning right is 1:2:1.

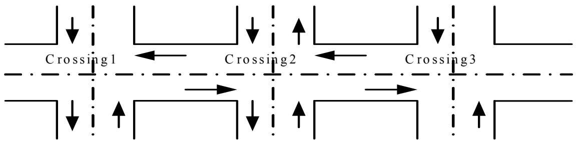

Fig. 5. Diagram of three crossings on artery.

We developed a program by VC# to make a simulation in different traffic flow 400, 600, 800, 1200, 1400, 1600, 1800, 2000 /h for the fuzzy neural control algorithm, summed up average vehicle queue length and compared them with common fuzzy control method [14]. Simulation results are shown in Table 7.

Table 7. Simulation result comparison of the new control with ordinary fuzzy control.

Time Segment		Low Cycle	Middle Cycle	Fastigium
Traffic Flow		400~800	800~1200	1200~2000
Average Vehicle Queue Length	Fuzzy Forecast	0.28	2.78	13.28
	Fuzzy	0.42	4.23	18.79
Improve %		33.33	34.28	29.32

From Table 7, we notice that the new control has no obvious advantage comparing with ordinary controls. But when the traffic flow gets heavier, i.e. the average traffic flow in the artery direction exceeds 1200 /h, the average queue length is reduced obviously by the new control. When the average traffic flow in the artery direction exceeds 2000 /h, the new control still works better, but the ordinary fuzzy control will cause a solid traffic jam.

6. Conclusions

In this paper, we have applied the wireless sensor network and the fuzzy control to the traffic signal control system and have used the hierarchical control method to accomplish the intelligent control on traffic arteries. The system takes advantage of the wireless sensor network, such as low power consumption, self-organization and distributed computing, to complete quick vehicle data acquisition. Meanwhile, by using the fuzzy control and neural network technology, the system has achieved a good immediacy and control precision, while traffic delays are greatly reduced.

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