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Study on the Road Traffic Survey System Based on Micro-ferromagnetic Induction Coil Sensor

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Abstract: Road traffic information is the basis of road traffic management and control. Due to the special design of the sensor coil and ferromagnetic core, traffic survey system which uses micro ferromagnetic inductive coil vehicle detector, not only has the features of small size, simple installation and little road surface damage, but also has the advantages of output signal strength, simple signal processing circuit and obvious characteristics for output waveform corresponding vehicle feature. Based on the introduction of the sensor working principle, the construction of hardware and signal processing circuit for the traffic survey system is described in detail in the paper. Combined with the characteristics of the sensor output waveform, adaptive nearest neighbor clustering RBF neural network algorithm used to classify the vehicles is proposed and verified by experimental method. The result has a high vehicle classification rate and demonstrates the feasibility of the system. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Traffic survey, Micro ferromagnetic inductive coil, Signal processing circuit, Radial Basis Function, Vehicle recognition.

1. Introduction

The development of roads has entered into the management, control and optimization time from the large-scale construction. The factors including traffic flow, vehicle type, speed, lane occupancy and the traffic density and other parameters of road traffic information are the main bases of achieving traffic optimization and intelligent traffic management [1]. By accurate real-time road traffic information, not only can fully acquaint and grasp the current traffic information, but also can conduct effective traffic control and traffic guidance using the means of intelligent control and prediction, to ensure the unimpeded road traffic and optimal utilization of existing roads.

According to the difference of sensors adopted, traffic survey systems can be divided into induction coil detection, ultrasonic detection, microwave detection, infrared detection, video detection, etc. [2]. Induction coil is one of the most widely used methods in the traffic survey system which can get the vehicle appearance, go though, count, occupancy and other basic traffic information [3-4]. Its highlight advantage is relatively mature technology and precise vehicle counting, but the major shortages are serious disruptive in installing, interrupting traffic, affecting life span and will be easily destroyed by the heavy

vehicles and pavement repaired at work, meanwhile there is the problem of low vehicle recognition. For traffic survey system based on the ultrasonic, microwave, infrared, video and other means [5-8], in terms of detection principle, it has some advancement and realizability, but there are some issues such as high requirements for installation conditions, seriously affected by environmental conditions, high cost and low reliability, so it is astricted in practical application.

The traffic survey system proposed in this paper, which adopts micro ferromagnetic inductive sensor, has the features of small size (diameter is 10 mm, length is 120 mm), simple installation (all the work is embed in equal length hole drilled in the middle road and lead out line). Due to the special design of the sensor, the signal output is strength and the vehicle characteristics detected is obvious. Different from the conventional induction coil, it doesn't need high-frequency shock wave and the output is voltage value, through the processed circuit which is simple and has high anti-interference ability. After study of RBF neural network for the different vehicles characteristic signal curve whose difference is from chassis structure, height and other factors, complete the vehicle identification. At the same time, according to the features of system, combine with the ARM embedded system and 3G network configuration, realize the wireless transmission from real-time traffic data to the control center, which provide the foundation to acquaint and control traffic. After the actual testing and verification, the system meets the design requirements.

2. Sensor Structure and Principle

Different from conventional induction coil detectors, micro ferromagnetic core inductive sensor is composed of two same wire distribution series coils and a specially designed magnetic core, the main structure is shown in Fig. 1:

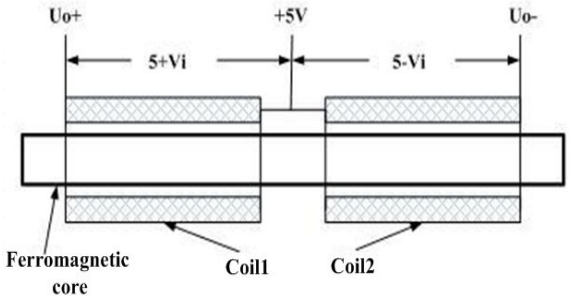


Fig. 1. The structure of micro ferromagnetic inductive sensor.

The works of the sensor which is based on Faraday Law of Electromagnetic Induction is relatively simple [9-10], according to the Faraday Electromagnetic Induction theorem:

$$V_i = d\Phi / dt , \quad (1)$$

where V_i is the voltage induced of the coil, Φ is the magnetic flux of the coil, the value is determined by the following formula.

$$\Phi = NA_c\mu_0\mu_c H , \quad (2)$$

where N is the turns, A_c is the cross section area of the coil, H is the magnetic field intensity, μ_c is the differential permeability of magnetic core. For a fixed structure sensor, the change of magnetic flux is only related to the magnetic field intensity.

In Application, the sensor vertically buried in the pavement, there is a constant excitation voltage whose value is 5 V in this system in the middle of the two series coils. The magnetic field intensity and the magnetic flux is fixed when no changes taken place in the electromagnetic environment, so that two outputs voltage value is both 5 V as the voltage of system. When magnetic conductive material such as a metal vehicle passes, owing to the changes in the magnetic circuit, the magnetic field intensity changes too in the coil which causes the changes of magnetic flux, then induced voltage is generated in the coil. Since the wire distribution is same which is equivalent to the intermediate 5 V voltage terminal, so the polarity of two outputs induced voltage is opposite. The magnitude of induced voltage the sensor generated in addition have a relationship with the speed, its features of continuous waveform is mainly related with the body and the chassis structure of the vehicle, by detecting the sensors output waveform the vehicles passing by, can determine the main type of the vehicle. Therefore, detection system adopting this sensor not only can detect the presence of vehicles but also can determine the type of the vehicle structure.

Ferromagnetic coil is composed of Air-core Coil and Ferromagnetic mandrel which plugged in the center of the Air-core Coil. Owing to the tiny structure, to produce high enough induced voltage, the core material which requires high permeability, low coercivity, high magnetic power etc. is essential to choose. The basic types of the core material of induction coil sensor are ferrite, permalloy and amorphous materials. The eddy current loss of ferrite is little, but the permeability is lower too so it isn't suitable for the low-frequency and middle-frequency system; The permeability of permalloy is higher and coercive force is lower, but there is the eddy current loss and the working process is complex; the differential permeability of Amorphous material is larger than the permalloy and the eddy current loss is more lower, therefore, for the same size of core, its inductance also larger. So the amorphous materials with rare earths are used in the system.

The differential permeability of the core in the system is so high that the voltage sensitivity of induction coil is μ_c times higher than the air-core coil, considering the effect of the demagnetization

coefficient, the actual value of the differential permeability μ_c is calculated by the formula (3).

$$\mu_c = \frac{\mu_r}{1 + N_d(\mu_r - 1)}, \quad (3)$$

where N_d is the demagnetization coefficient, which was gotten by the core shape. For the cylinder core, N_d can be calculated by the simplified Stoner equation (4).

$$N_d \approx \frac{d^2}{l^2}(\ln\frac{2l}{d} - 1), \quad (4)$$

where d is the diameter of the coil, l is the length of the coil.

In the basis of determining the optimum differential permeability μ_c of the core, by the theoretical calculation and experimental verification confirm that the half of the coil length is 25 mm, the diameter is 2.3 mm, and its output meets the requirements of detection system.

3. System Hardware Design

System hardware design includes sensors, signal processing circuits, signal acquisition circuits and the ARM Embedded computer processing system for signal acquisition, processing and results transmission. Meanwhile, his system as a terminal of network control uses 3G technology in communication with management center and real-time transfers back the traffic survey result to the network control center. The system hardware structure is shown in Fig. 2.

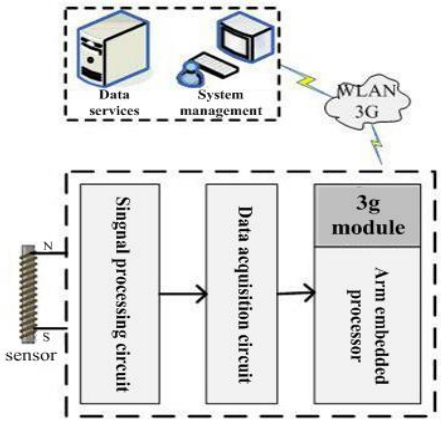


Fig. 2. System hardware structure.

Where the signal processing circuit is the key part of the hardware design, according to the characteristics of the sensor and its output signal, the composition of the signal processing circuit is shown in Fig. 3.

The circuit design is shown in Fig. 4. Including filter, zero-adjustment, subtraction, integral, amplitude modulation and amplifier etc. Circuit (a) is the basic filter, zero-adjustment and subtraction circuit. The function of the RC circuits is low pass filter, zero potentiometer is used for output zero adjust when no signal input. Two transistor take differential input for the signal, high precision operational amplifier take subtraction and some signal amplifier, with it, while eliminate the 5 V excitation voltage of the system, provide initially amplified output signal for the subsequent conditioning circuit; (b) is the integral circuit. With this circuit, the input signal is integrated to increase the signal strength, at the same time react the signal trend while different parts of the vehicle passing by; (c) is the amplitude modulation circuit. All circuit voltage magnitude must limit under 5 V, on the basis of different models experiments, the appropriate amplitude is selected by adjusting the magnification of the amplifier circuit, while add the voltage follower matching with the subsequent conditioning circuit in impedance; (d) is the last amplifier circuit which is for further amplification for the former input signal. The protection circuit and limiter circuit are configured in the design.

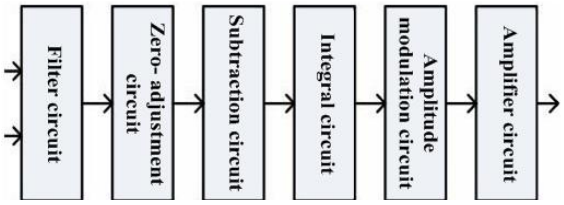


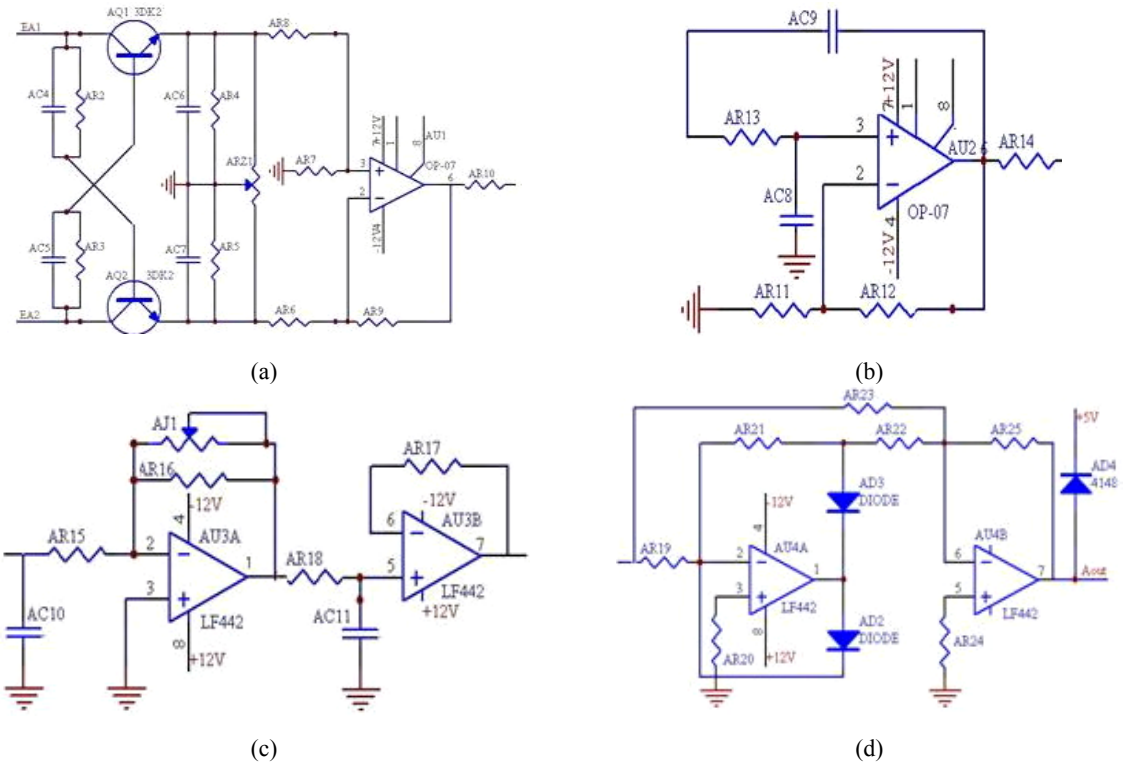
Fig. 3. Signal processing circuit diagram.

After above processing circuit, the input signal through data acquisition card is sent to the ARM system for the data processing and vehicle identification, the processing results includes flow, vehicle type, speed and other information are send to road traffic control center by 3G network.

4. Vehicle Identification Methods and Results

4.1. System Output Waveform Analysis

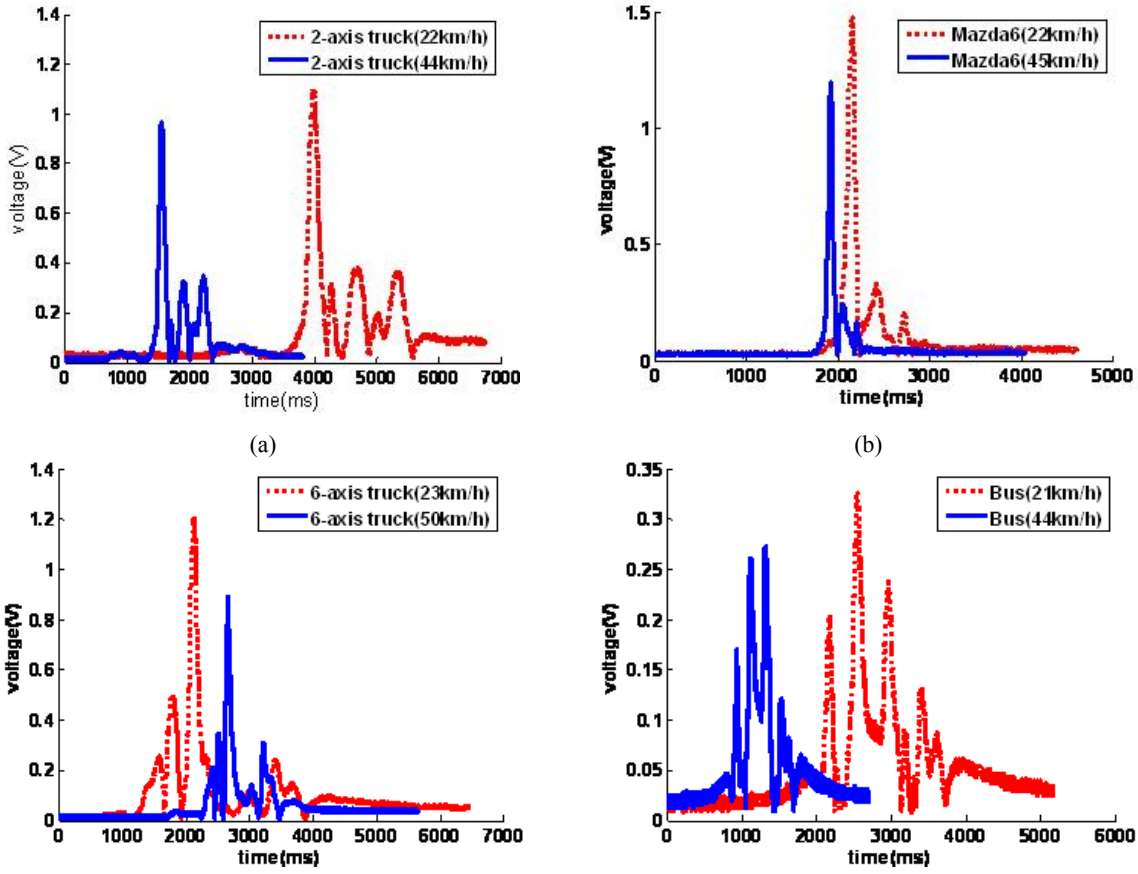
In Fig. 5, the waveform is obtained by the actual measurement of different vehicles passing by the sensor, including two axle trucks, six axle trucks, Mazda6 and buses, each vehicle is given two velocity waveform, as can be seen, for the same vehicles with different speed, the output waveform shape is highly similar, simply because of the velocity change, the waveform width changes too, the amplitude is also different because of the change of the magnetic flux. But for different vehicle type, the difference of waveform shape is quite obvious, which is the main character that we identified by the RBF neural network.



(a) (b)

(c) (d)

Fig. 4. Signal processing circuit schematics. (a) Filter, Zero-adjustment and Subtraction circuit, (b) Integral circuit, (c) Amplitude modulation circuit, (d) Amplifier and limiter circuit.



(a) (b)

(c) (d)

Fig. 5. Measured waveforms: (a) Two axle truck, (b) Mazda6, (c) Six axle truck, (d) Bus.

In practical application, in order to obtain the speed and the length of the vehicle, two sensors need to be installed in a certain interval distance shown in Fig. 6, that can obtain the time interval that one axle passed by the two sensors, then calculate the speed combine with the distance of the two sensors, and according to the time that the vehicle passes a single sensor can obtained the information of vehicle length. Fig. 7 is the signal waveform that Mazda6 with speed of 44 km/h passing by the two sensors, the waveform have been processed by digital filter that the characteristics of origination and terminus are distinct, according to the characteristics, the waveform of the whole vehicle can be obtained.

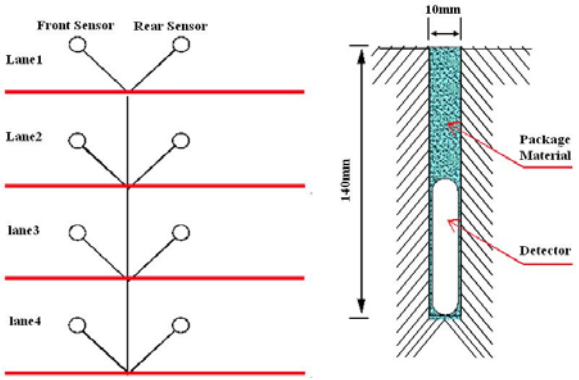


Fig. 6. Installation Schematic.

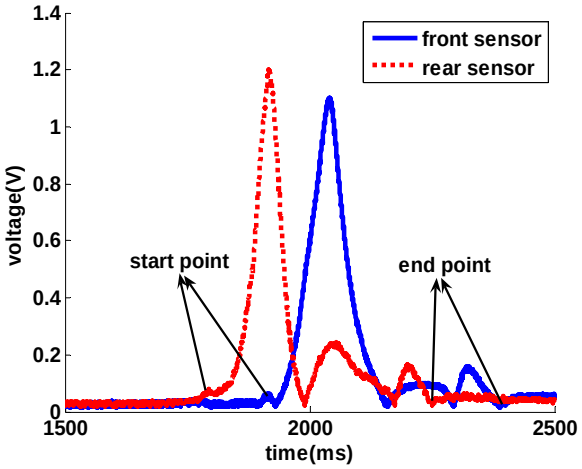


Fig. 7. Output waveform of Mazda6 with speed of 44 km/h.

4.2. RBF Neural Network

The vehicle identification system based on the pattern recognition that according to the characteristics of the detector output waveform includes fuzzy algorithm [11], BP neural network [12], wavelet analysis [13] and other methods, each method has its own advantages and disadvantages and adaptation range. As the market models increasing, the waveform obtained by the detector also various, using fuzzy algorithm have some problems in determining the fuzzy rules more comprehensively; BP neural network can be obtained the optimal matching in theory, but the premise is that the exhaustivity of samples need to meet the requirements; Modern signal processing means such as wavelet analysis can achieve the same functionality, but the problem is the complexity of the algorithm causes the real-time problems of the system. Based on the analysis and comparison, he RBF (radial basis function) neural network is used as recognition algorithm in this system, which can not only realize offline training, but also online learning and improvement. The algorithm is relatively simple and fast speed, overcome some shortcomings the above algorithm has.

RBF neural network is an artificial neural network which uses topical receptive field to implement the function mapping. It is a single hidden layer feed forward neural network, has optimal approximation and universal approximation properties [14]. Its topology is shown in the following Fig. 8.

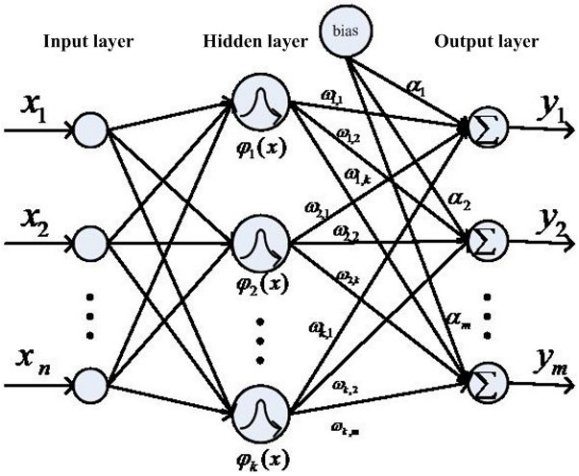


Fig. 8. RBF neural network topology structure.

Where: $X = [x_1, x_1, ..., x_n]^T$ is the network input vector; k is the number of the hidden layer nodes (receptive field);

$$\phi_i(X) = exp(-\frac{||X - C_i||^2}{2\sigma_i^2}), \quad (5)$$

$\varphi_i(X)$ is the Gauss kernel function of receptive field i, $\|\bullet\|$ is the euclidean norm; $C_i = [c_{i,1}, c_{i,2} \cdots c_{i,n}]^T$ is the data center of the receptive field i; σ_i is the width of i-th nonlinear transform unit; ω_{ij} is the weight between the i-th hidden layer node and the j-th output node, RBF net

output is the linear weighted of the output of the receptive field kernel function, is as follows.

$$y_j = \sum_{i=1}^{k} \omega_{ij} \varphi_i(x), 1 \le j \le m \quad (6)$$

As long as set the center and the width of data, the output weight can be ready by solving linear equation. Therefore, the main task of RBF network design is to determine its data center and width.

RBF neural network whose purpose is to select the center of the RBF includes several forms, such as random algorithm, self-organizing learning algorithm and the nearest neighbor-clustering algorithm. random algorithm and self-organizing learning algorithm is mainly used for static model offline learning, not only need to get all possible samples, but also determine beforehand the number of center, combined with the actual demand of the system, these two methods are not suitable for using. Dynamic adaptation RBF neural network model [15] is used in this paper, which is based on the nearest neighbor-clustering algorithm, is an adaptive clustering learning algorithm, do not need to determine beforehand the number of hidden layer units, after clustering, the RBF network is the optimal, and can be online learning, this will ensure that through collecting samples on the road and online learning obtains the optimal capability of the RBF network in the case of the Multi-type vehicle and not all the samples of models can be collected in advance.

4.3. Learning Methods and Results Analysis

According to the system output waveform, reflecting models feature should include amplitude, pulse width, maximum point, minimum point and other parameters, however, we found in the analysis that for the same type of vehicle such as both compact cars or the trucks whose number of axles is the same, their eigenvalues will be different, only the overall shape of the waveform is similar. In conjunction with this trait, area normalization method is taken in selecting waveform parameters of vehicle, namely, the area which is formed by the whole car curve and the abscissa of time axis is divided in equi-spaced along time axis, after calculated of each part of the area and normalized, act as the input of the RBF. Such division method, not influenced by the velocity of the vehicles, as long as the division is fine enough, it can accurately reflect the characteristics of the waveform shape.

7 kinds of models include minivan and from two axle to six axle truck or bus had been chosen to train, input is the equal division normalized area of each model, output is the corresponding models whose value is 1, kernel function is Gaussian function, training method is adaptive nearest neighbor clustering algorithm. After 25 cycles training, a network with 28 hidden layers is formed, its accuracy is 0.01. Simultaneously, the training results have been verified by seven categories 29 vehicles, the training process and the comparison results are shown in Fig. 9 and Fig. 10. From the comparison results, the recognition rate of the network is very high, it is over 95 %. According to the requirements of ministry in the Highway Traffic Survey and the characteristics of actual traffic flow composition in the detection, divided vehicles into medium bus, large bus, jubilee truck, medium truck, large freight car, motorcycle and other several forms, combined with the vehicle length, these models can be classified accurately.

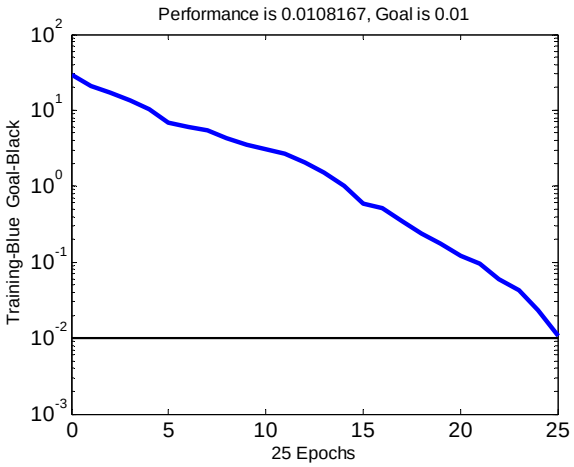


Fig. 9. RBF network training process.

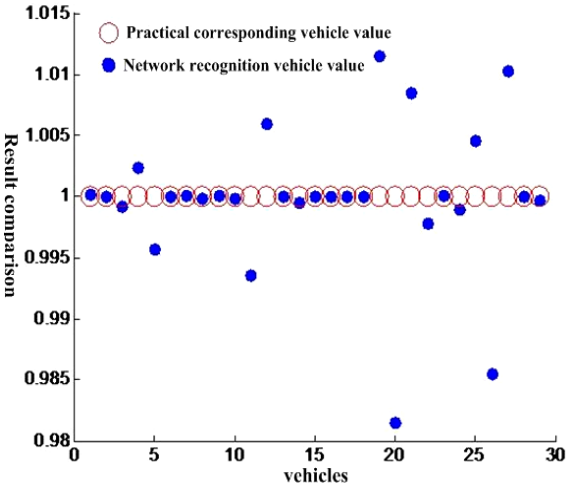


Fig. 10. Results compare of actual models and network computing.

5. Conclusions

The principle of micro ferromagnetic inductive coil which has the features of small size, simple installation and little road surface damage is different with traditional ring induction coil vehicle detectors,

through the special design of the ferromagnetic core and coil, the sensor has the advantages of output signal strength, without loading the excitation circuit and simple signal processing circuit. Traffic survey system with this sensor, the characteristics of output waveform is obvious and is conducive to models identification by pattern recognition algorithms. With RBF neural network, different models have been trained and recognized, the result is accurate and the recognition rate is high. While the ARM embedded processing system and 3G wireless network transmission system is used in system hardware design by which the real-time collected and synchronous processed traffic information can be sent to traffic control center to achieve the real-time traffic monitoring and traffic management.

Acknowledgements

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