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Neural Network and Single Magnetic Detector based Intelligent Sensor for Vehicle Classification

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***Abstract*—Vehicle detection and classification is a very actual problem, because vehicle count and classification data are important inputs for traffic operation, pavement design, transportation planning and other applications. In this work the results of a new detection and classification method using a single magnetic sensor based system are presented. Vehicle classes are determined using a feedforward neural network which is implemented in the microcontroller of the detector, together with the detection algorithm and the algorithm used for determining the neural network inputs. The gathering of training samples and testing of the trained neural network have been done in real environment. For the training of the neural network the back-propagation algorithm has been used with different training parameters.**

***Keywords*—vehicle detection, vehicle classification, magnetic sensors, neural networks**

I. Introduction

The need for automatic traffic monitoring is increasing, which urges the manufacturers and researchers to develop new technologies and improve the existing ones, to provide speed monitoring, traffic counting, presence detection, headway measurement, vehicle classification, and weigh-in-motion data.

Vehicle count and classification data are important inputs for traffic operation, pavement design, and transportation planning. In traffic control, signal priority can be given to vehicles classified as bus or an emergency vehicle.

In this work, a new detection and classification method for a single magnetic sensor based system is discussed.

Magnetic sensors measure the change in the Earth's magnetic field caused by the presence of metallic objects. Magnetic vehicle detectors use the changes generated by the metallic content of vehicles when they are near the sensor as written in Reference [1]. Two sensor nodes placed a few feet apart can estimate speed as described in Reference [2]. A vehicle's magnetic 'signature' can be processed for classification.

Advantages and disadvantages of magnetic detectors are shown in Table 1.

TABLE I.
ADVANTAGES AND DISADVANTAGES OF MAGNETIC SENSOR BASED VEHICLE DETECTORS

Advantages	Disadvantages
• Insensitive to inclement weather such as snow, rain, and fog • Less susceptible than loops to stresses of traffic • Some models transmit data over wireless RF link • Some models can be installed above roads, no need for pavement cuts	• Difficult to detect stopped vehicles • Installation requires pavement cut or tunneling under roadway • Decreases pavement life • Installation and maintenance require lane closure

II. The Used Sensor

The used magnetic sensor is an HMC5843 based unit developed by "SELMA" Ltd. and "SELMA Electronic Corp" Ltd., companies from Subotica, Serbia. Two types of magnetic detectors have been developed, one with cable and one with wireless communication.

For classification sample collection and detection and classification efficiency testing, a unit with cable communication has been mounted in Subotica, on the main road passing through the town. The place is ideal, because all vehicles classes can be found passing on that road. The sensor has been mounted 5 centimeters beneath the pavement surface. The direction of the axis is very important, because the network inputs are calculated by axis, and if changed, the waveforms will not be the same. The X axis points to the movement direction, the Y axis points to the neighboring lane, and Z is orthogonal with the pavement surface.

The Honeywell HMC5843 is a small (4x4x1.3 mm) surface mount multi-chip module designed for low field magnetic sensing. The 3-Axis Magnetoresistive Sensors feature precision in-axis sensitivity and linearity, solid-state construction with very low cross-axis sensitivity designed to measure both direction and magnitude of Earth's magnetic fields, from tens of micro-gauss to 6 gauss. The highest sampling frequency is 50Hz.

Wireless magnetic sensor networks offer an attractive, low-cost alternative to inductive loops, video and radar for traffic surveillance on freeways, at intersections and in parking lots as written in Reference [3].

III. VEHICLE DETECTION ALGORITHM

As written in References [4] and [5], magnetic detectors are capable of very high, above 97 percent detection accuracy with proper algorithms. In Reference [6] 97% of detection accuracy has been achieved using neural networks and fuzzy data fusion. Most of the algorithms use adaptive thresholds as used in Reference [7].

In Reference [4] it is described that HMC magnetic sensor measurements are affected by temperature. As the temperature on the pavement can change a lot in the course of a day, but the changes in the measured values are very slow.

The developed vehicle detection algorithm uses thresholds which can change when no detection is available to avoid the effects of temperature changes. The principles of the algorithm:

- A calibration process is run when the unit is turned on. Maximum and minimum values are determined in a period of time at all three axis (if even at one axis the difference between the maximum and minimum exceeds a previously defined width, the calibration starts from the beginning). After this stage, the range is equally stretched to the previously defined width, and the upper and lower thresholds are now determined at all three axis. This method makes the further algorithm immune to noise.
- If the measures at all three axis exceed the range determined by the thresholds, a detection is generated (detection flag is "1"). If only one or two axis exceed the range, probably a vehicle is passing in the neighboring lane.
- In case of a detection, the detection flag goes back to "0" if measures in all three axis are between thresholds for a previously defined number of measures.
- If all three axis are in the range determined by the thresholds, and no detection is available, the algorithm calculates new thresholds.

The axis along the direction of travel can be used to determine the direction of the vehicle, what is shown in Reference [8]. When there is no car present, the sensor will output the background earth's magnetic field as its initial value. As the car approaches, the earth's magnetic field lines of flux will be drawn toward the ferrous vehicle.

A. Efficiency

For testing the efficiency of the algorithm a one hour test has been done. The results have been divided by vehicle classes, and are shown in Table 2. As seen, the algorithm is effective, only motorcycles can cause failures. The reason of failures in motorcycle detection can be the low metallic content, and the distance from the detector. Vehicles passing in the neighboring lane with high metallic content, usually trucks, can cause false detections. The filtering of these vehicles can be done by increasing the width of the detection ranges, but this can affect the motorcycle detection efficiency.

TABLE II.
EFFICIENCY OF THE DETECTION ALGORITHM DURING A ONE HOUR TEST

Vehicle class	Passed	Detected	Rate
Motorcycle	4	3	75%
Car	168	168	100%
Van	10	10	100%
Truck	15	15	100%
Bus	6	6	100%
Other	2	2	100%
False detections caused by vehicles passing in the neighboring lane		13	
Σ	205	217	94,15%

IV. CLASSIFICATION ALGORITHM

The basic idea was to collect the measurement values when the detection flag is "1", and calculate specific parameters from the magnetic signature, which can be applied to the inputs of the neural network.

A. Other classification algorithms

Classification stations with highly calibrated inductive loops are very popular. However, the infrastructure and maintenance costs of such a vehicle classification station are high.

In Reference [9] an artificial neural network based method was developed to estimate classified vehicle volumes directly from single-loop measurements. They used a simple three-layer neural network with back-propagation structure, which produced reliable estimates of classified vehicle volumes under various traffic conditions. In this study four classes (by ranges of length) were defined, and all classes had an own ANN. All networks had 19 nodes in the input layer, 1 node for the time stamp input and 9 pairs of nodes for inputting single-loop measurements (volume and lane occupancy). All networks had one output node (each was one class bin), but the number of hidden neurons differed for each class (35 for class1, 8 for class2, 5 for class3 and 21 for class4).

Sun, in Reference [10] studied the use of existing infrastructure of loop detectors for vehicle classification with two distinct methods. The seven-class scheme was used for the first method because it targets vehicle classes that are not differentiable with current techniques based on axle counting. Its first method uses a heuristic discriminant algorithm for classification and multi-objective optimization for training the heuristic algorithm. Feature vectors obtained by processing inductive signatures are used as inputs into the classification algorithm. Three different heuristic algorithms were developed and an overall classification rate of 90% was achieved. Its second method uses Self-Organizing Feature Maps (SOFM) with the inductive signature as input. An overall classification rate of 80% was achieved with the four-class scheme.

In the last few years a big number of studies have been made with classification algorithms using magnetic sensors.

The rate of change of consecutive samples was compared with a threshold in Reference [11] and declared to be +1 (–1) if it is positive and larger than (negative with magnitude larger than) the threshold, or 0 if the magnitude of the rate is smaller than the threshold. The second piece of information was the magnetic length of the vehicle. 82% efficiency was achieved, with vehicles classified into five classes.

Reference [12] achieved a vehicle detection rate better than 99 percent (100 percent for vehicles other than motorcycles), estimates of average vehicle length and speed better than 90 percent, and correct classification into six types with around 60 percent, when length was not used as a feature.

In Reference [13], with x and z dimension data and without vehicle length information, a single magnetic sensor system, with a Multi-Layer Perceptron Neural Network, 93.5 percent classification efficiency was achieved, but vehicles were only separated into two classes. In a double sensor system 10 classes were selected for development, and 73.6 percent was achieved with length estimation and a methodology using K-means Clustering and Discriminant Analysis.

B. The used neural network and the input parameters

A three-layer feedforward neural network has been used for vehicle class estimation. The neurons in the hidden layer have logarithmic sigmoid transfer functions, while the output layer neurons use saturating linear functions. The structure of the used neural network can be seen on Figure 1. Bias values have not been used in the network because the network has to be implementable in a neural network, and the bias values would need big memory space.

The networks have been trained using the backpropagation algorithm. During the training, weights have been modified after every sample. Using this network the error of the output layer output can be calculated with the next formula:

$$\delta_\alpha = Target_\alpha - out_\alpha \quad (1)$$

where δ_α is the error of α output neuron, $Target_\alpha$ is the target value, and out_α is the current output of the neuron.

The output neuron weights have to be modified the next way:

$$W_{A\alpha}^{+} = W_{A\alpha} + \eta * \delta_\alpha * out_A \quad (2)$$

where $W_{A\alpha}^{+}$ is the modified weight between A hidden and α output neuron, and η is the learning rate.

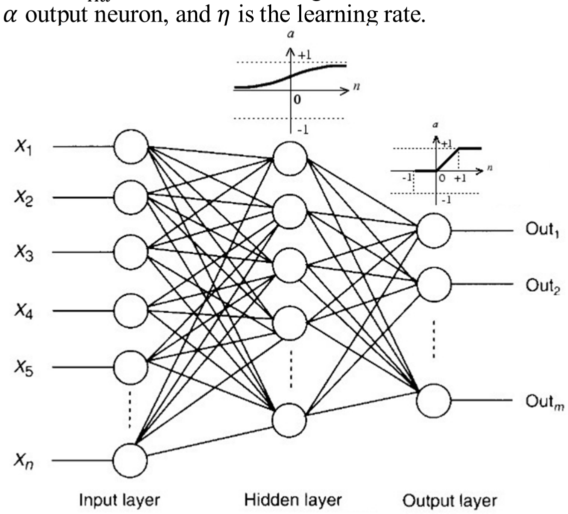

Figure 1. The structure of the used neural network

The error of the hidden layer neurons can be calculated using the errors of the output neurons, the weights between the hidden neuron and each output neuron, and the output of the hidden neuron:

$$\delta_A = out_A * (1 - out_A) * (\delta_\alpha * W_{A\alpha} + \delta_\beta * W_{A\beta}) \quad (3)$$

The modifications of the weights between the input and the hidden layer can be done with the next formula:

$$W_{\lambda A}^{+} = W_{\lambda A} + \eta * \delta_A * in_\lambda \quad (4)$$

where in_λ is the input of the λ input neuron.

Network training has been done with different number of neurons in the hidden layer, and different learning rates.

The network has 6 outputs, because 6 vehicle classes had been defined to be classified: motorcycles, cars, vans, trucks, buses and other. The class with the biggest output will be declared as the class of the passed vehicle.

The input layer consists 16 neurons. These are parameters calculated of the waveforms at each axis. The network inputs are the next:

- 1 input – Detection length (number of measures made while the detection flag is "1")
- 6 inputs - The biggest differences between measured values and thresholds at each axis (the difference between the highest measured value and the upper threshold (5), and the difference between the lower threshold and the smallest measured value (6))

$$X_{upper\_diff} = X_{highest\_val} - X_{upper\_thr} \quad (5)$$

$$X_{lower\_diff} = X_{lower\_thr} - X_{lowest\_val} \quad (6)$$

- 6 inputs – Number of local maximums (if the measured values are above the upper threshold), and local minimums (if the values are under the lower threshold) at each axis.
- Range changes at each axis. The thresholds define three ranges, one above the upper threshold, one under the lower, and one between them.

C. Sample collection

Measurement data for 130 samples per class have been collected for network training. The measurement values and a detection number, which has been incremented at every rising edge of the detection flag, have been saved into a database.

The classes (network targets) of the samples have been defined using images made by a camera mounted beside the road. The images have been saved at every falling edge of the detection flag, and have been named using the detection number.

D. Neural network training

The network training has been done in three series depending on the learning rates of the layers. The used rates were the next:

- 0.11 at the output and 0.1 at the hidden layer
- 0.08 at the output and 0.06 at the hidden layer
- 0.05 at the output and 0.04 at the hidden layer

Every learning rate pair has been tested with 1 to 25 hidden layer neurons. Every of the 75 trainings has been done in 1000 epochs.

Of 130 samples per class, 90 have been used for training, and 40 for validation.

During the training process the matching rates and the mean squared errors at training and validation samples have been calculated after every sample in the epoch. The highest matching rates and the smallest mean squared errors have been saved. When finding a better value of each parameter, all current values of other performance parameters have also been saved together with a matrix containing the current places of the misses. The current number of the iteration and the sample number have also been recorded to see are more iterations needed.

The highest matching rates with all learning rate pares depending on the number of hidden layer neurons can be viewed on Figure 2. The efficiency of the network both on training and validation samples has improved when learning rates have been reduced. The highest matching rate on training samples, 88.44%, has been recorded with 18 hidden layer neurons. The highest efficiency on validation samples was 70.83%. The rate at training samples can be improved by increasing the number of iterations, because at most cases the biggest value was achieved near to the end of the training process. But this is not true for the validation samples, where in most of the cases the maximums were recorded around 300 epochs.

On Figure 3 the smallest mean squared errors are shown found during the trainings. As seen, the smallest values were achieved also with the smallest learning rate pair. The values similarly as at matching rates, could have been improved at training samples by using a longer training process, but the smallest values at validation samples were also recorded around 300 iterations.

The number of misses by classes in the case when the highest matching rate at training samples has been found are shown in Table 3 for training samples and Table 4 for validation samples. The places with most misses are very similar. The most misses are were made between classes 2, 3 and 4. A possible reason can be that cars, vans and smaller trucks are almost the same length, the number of axles is also the same, and the distance between them is also similar.

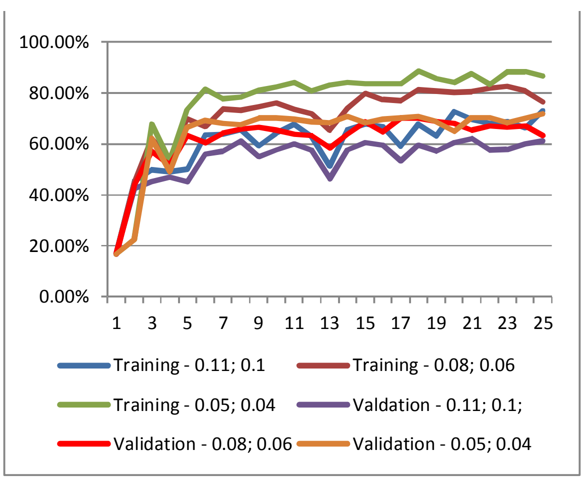

Figure 2. Highest matching rates achieved at training and validation samples with different number of hidden layer neurons and different learning rates.

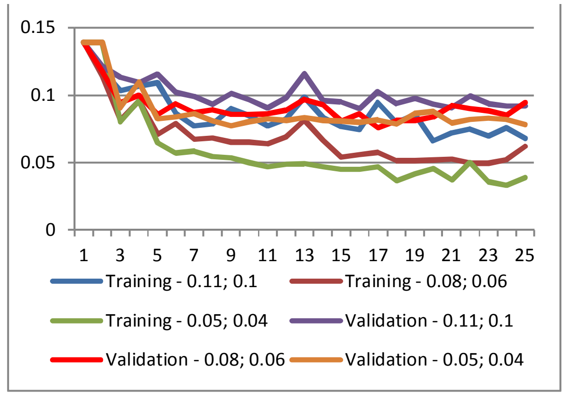

Figure 3. Smallest mean squared errors achieved at training and validation samples with different number of hidden layer neurons and different learning rates.

E. Neural network implementation and testing

During the implementation a very important factor was not to stop the measuring for the time of the network output calculating. The network input calculation and updating has been done after every measurement when the detection flag was “1”.

After a falling edge on the detection flag, the network outputs are calculated, and the vehicle class is determined. This process is done until the next measurement is made, so the class is determined in 20ms, what is a measurement cycle.

For testing, the weights of the 18 hidden neuron network has been implemented which achieved the highest matching rate on training samples. This network had 64.17% efficiency on validation data, the mean squared error of the training samples was 0.041736, and 0.096034 of the validation samples.

TABLE III.
PLACES AND NUMBER OF MISSES AT TRAINING SAMPLES

Output \ Target	1.	2.	3.	4.	5.	6.	Rate
1.	0	1	1	0	0	0	97,33%
2.	1	0	9	7	0	0	77,33%
3.	1	7	0	6	1	0	80%
4.	2	4	4	0	4	1	80%
5.	0	2	1	0	0	0	96%
6.	0	0	0	0	0	0	100%

TABLE IV.
PLACES AND NUMBER OF MISSES AT VALIDATION SAMPLES

Output \ Target	1.	2.	3.	4.	5.	6.	Rate
1.	0	1	1	0	0	3	87,5%
2.	1	0	9	9	0	0	52,5%
3.	0	11	0	10	1	1	42,5%
4.	3	7	5	0	9	1	37,5%
5.	0	4	2	6	0	0	70%
6.	2	0	0	0	0	0	95%

TABLE V.
TEST RESULTS OF THE IMPLEMENTED NEURAL NETWORK

	1.	2.	3.	4.	5.	6.	Σ	Recognition rate
1.	2	0	0	0	0	0	2	100%
2.	18	99	48	55	5	4	229	43,23%
3.	0	1	6	5	0	0	12	50%
4.	0	4	1	13	2	0	20	65%
5.	0	1	0	2	3	1	7	42,86%
6.	0	0	0	0	0	0	0	0%
False Detection	11	1	1	6	0	11	30	
Σ	31	106	56	81	10	16	300	

The network was tested for 300 detections, and the results are shown in Table 5. As seen, the recognition rates are very similar to the values calculated on validation samples during training (Table 4). The testing was not ideal, because some classes had very small number of vehicles passing in this testing interval.

V. CONCLUSION

In this work a detection and neural network based vehicle classification method was presented. Measurement data had been collected for neural network training. Training has been done with different number of hidden layer neurons, and different learning rates.

Training results showed that the recognition rates are not usable in real-life applications, but the results are perspective. For better recognition rates, changes are needed.

Increasing the number of training samples could lead to better results.

Another possible modification is to change the classification. Dividing the vehicles into more classes, or dividing them by length and axle number could also improve the accuracy.

But probably the most efficient modification could be to include the changes of waveforms in time.

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