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VEHICLE CLASSIFICATION BY PARAMETRIC IDENTIFICATION OF THE MEASURED SIGNALS

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Abstract: Traffic control requires measuring of road traffic parameters and vehicle parameters (velocity, length, number of vehicle, time distance between vehicles, etc.). One of very important parameters is the class of a vehicle. Up to date, video-camera systems, system with loop sensors, etc., have been used for classification. Unfortunately, the vehicle pattern were very complicated (picture from camera, time signal from loop, ...). Classification depends on the comparison of an actual signal to the reference pattern. It was very time-consuming and needed remembering the large reference pattern. This paper deals with a new method of vehicle classification. We have proposed the conversion of the measured signal into a vector of numerical parameters (only a few). The vehicle classification is being made by the comparison of such a very short vector with the vectors containing the values of parameters typical for the chosen class of a vehicle. Tests have been made on streets of Cracow (Poland). The classification efficiency for four predetermined vehicle classes is between 77% and 95%.

Keywords: Road traffic measurement, vehicle classification, inductive loop sensor

1 INTRODUCTION

A traffic control algorithm operated automatically depends on the measurement results of different traffic parameters on very wide area. Traffic parameters which are the object of direct measurement include the vehicle velocity, number of vehicles moving in the same direction, time distance between the vehicles, length of the traffic jam, time of access to the traffic, noise level, pollution level, etc. Important parameters are also the class and number of moving vehicles belonging to the specified class. The above parameters influence the implementation of the traffic control algorithm, but first of all the vehicle class is of primary importance for the access control (areas closed for some vehicle classes, limits of velocity and weight for different vehicle classes).

Vehicle classification can be performed by using various measurement systems and sensors. Very often video-camera systems, systems with inductive loop sensors [1,2] and systems with piezo-cable sensors [3] are used in road traffic measurements.

This paper deals with the vehicle classification based on the time signal analysis. The analysed signals are generated by moving objects in single inductive loop sensor placed under the surface of the road. Signals generated by different vehicles differ in their parameters such as e.g. the amplitude, frequency spectrum, statistical parameters, shape, etc. The shapes of typical signals versus time for some chosen classes of vehicles are presented in Fig. 1.

Recently [2], classification methods have been based on the comparison (in the sense of the analysed properties) of a signal generated by the tested object to the reference signal. The reference signals are generated as a result of averaging many measured signals corresponding to the selected vehicle class. The need for the independence of the classification results obtained from the road traffic and measurement system parameters causes the necessity of signal normalisation in time domain (elimination of vehicle velocity and sampling frequency influence) as well as in amplitude domain.

Unfortunately, normalisation eliminates from signal a part of useful information (e.g. the dependence of the signal amplitude on the vehicle class) and is time-consuming.

In this paper, we have proposed converting the measured signal into a vector of numerical parameters (only a few). Vehicle classification depends on the comparison of such a vector to the vectors containing the values of the parameters, which are typical for the predetermined vehicle classes. This way the necessity of storage of long vectors of reference signals is eliminated.

Typical parameters of signals measured with inductive loops, used for vehicle classification, are: mean value, variation, mean square value, higher order moments, and signal fluctuation.

The efficiency of the classification depends on the applied comparison criterion. The above mentioned signal parameters are tested as such criteria.

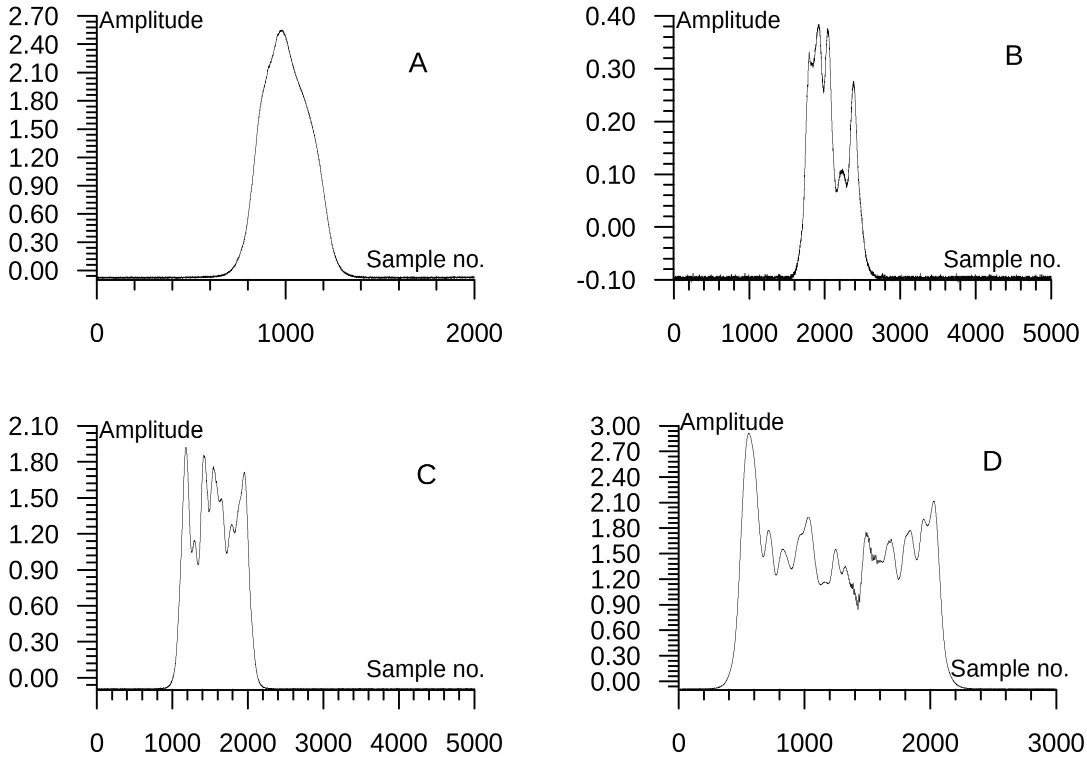

Figure 1. Signal from inductive loop sensor in time domain for different vehicle classes: A - cars, B - lorries, C - city bus, D - long bus.

The paper presents also the results of the study of the proposed vehicle classification method implemented under real road traffic conditions. The tests have been made in streets of Cracow (Poland). The drivers were not informed about the measurements to be made. No additional limitations, excluding those resulting from the traffic regulations, were imposed on the vehicle velocity and course.

2 SIGNAL PARAMETERS - CLASSIFICATION CRITERIA

Six signal parameters were defined as the classification criteria which were used to determine four vehicle classes. They are:

1) standard deviation

$$s_x = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(x_i - \overline{x}\right)^2} \tag{1}$$

where: x_i - i-th signal sample, $\overline{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$ - average, N - total number of samples.

2) mean square value

$$\Psi_x^2 = \frac{1}{N}\sum_{i=1}^{N} x_i^2 \tag{2}$$

3) third-order moment

$$m_{3x} = \frac{1}{N}\sum_{i=1}^{N} x_i^3 \tag{3}$$

4) third-order central moment

$$m_{3x}^c = \frac{1}{N}\sum_{i=1}^{N} \left(x_i - \overline{x}\right)^3 \tag{4}$$

5) signal fluctuation

$$x_h = \sum_{\ell=1}^{K-1} \left| x_{\ell+1} - x_\ell \right| \tag{5}$$

where: x_ℓ for $\ell = 1,2,...K$ - values of the signal at the ends of its monotony intervals, K - number of monotony intervals.

6) length of vehicle

$$x_L = \left(t_d - t_u\right)\cdot V \tag{6}$$

where: t_u, t_d - time instants at which the measuring signal crosses the adopted cut-off level when rising (t_u) and falling (t_d), V - vehicle velocity determined based on the registered signal according to the algorithm presented in [2].

Before particular criterial values are determined, the registered signals are being transformed to vehicle length domain.

3 ASSESSMENT OF CLASSIFICATION EFFICIENCY

The efficiency of the criteria employed for vehicle classification was tested through the analysis of measurement signals corresponding to vehicles out of the following four classes:

- cars (65 items),
- delivery trucks (65 items),
- lorries (58 items),
- buses (52 items).

At the same time a visual classification of vehicles was made assigning them one of the mentioned classes.

The efficiency of the criteria used in the vehicle classification varies with the vehicle class (recognised visually) and can be assessed using the enclosed histograms (Fig. 2). They show a percent contribution of the vehicles classified to one of the four defined classes when the vehicles being classified belonged to a predetermined class.

The 100% efficiency of a criterion would be seen in these histograms as one bar of the 100% height assigned to the same class as was assumed based on the visual observation and located at the place denoted with the number of this criterion. The bars of this criterion in all other classes should be 0% high.

Regarding the car class, all tested criteria exhibit the similar efficiency. An exception is the criterion (5) which does not allow to distinguish cars from delivery trucks. The recognition efficiency of the vehicles belonging to the car class is not less than 95%.

The criterion (6) is the most effective in the delivery truck class: its efficiency is 75.4%. The observed erroneous classification cases were classifying delivery trucks as cars (23%) or buses (1.5%).

The lorry class classification efficiency is the lowest. Although criteria (2) and (3) make it possible to recognise 69% of vehicles, they do not distinguish lorries from buses. From this point of view the criterion (1) is the best as it recognises 56.9% of lorries. However, erroneous classification numbers are respectively: cars: 17.2%, delivery trucks: 20.7%, buses: 5.2%.

The most effective criterion in the bus class is (5) as using it resulted in the correct recognition of 82.7% of vehicles. Erroneous classification numbers are respectively: cars and delivery trucks: 11.5% (no possibility of distinguishing between them), lorries: 5.7%.

Closing the presented analysis it should be concluded that no criterion exists among the six tested whose efficiency is satisfying in all the four vehicle classes. However, applying different criteria to particular classes may result in the efficiency which is close to 70% in the worst case (lorries).

An improvement of the classification efficiency can therefore be obtained by using the multi-criterion classification, combining the results obtained with single criteria.

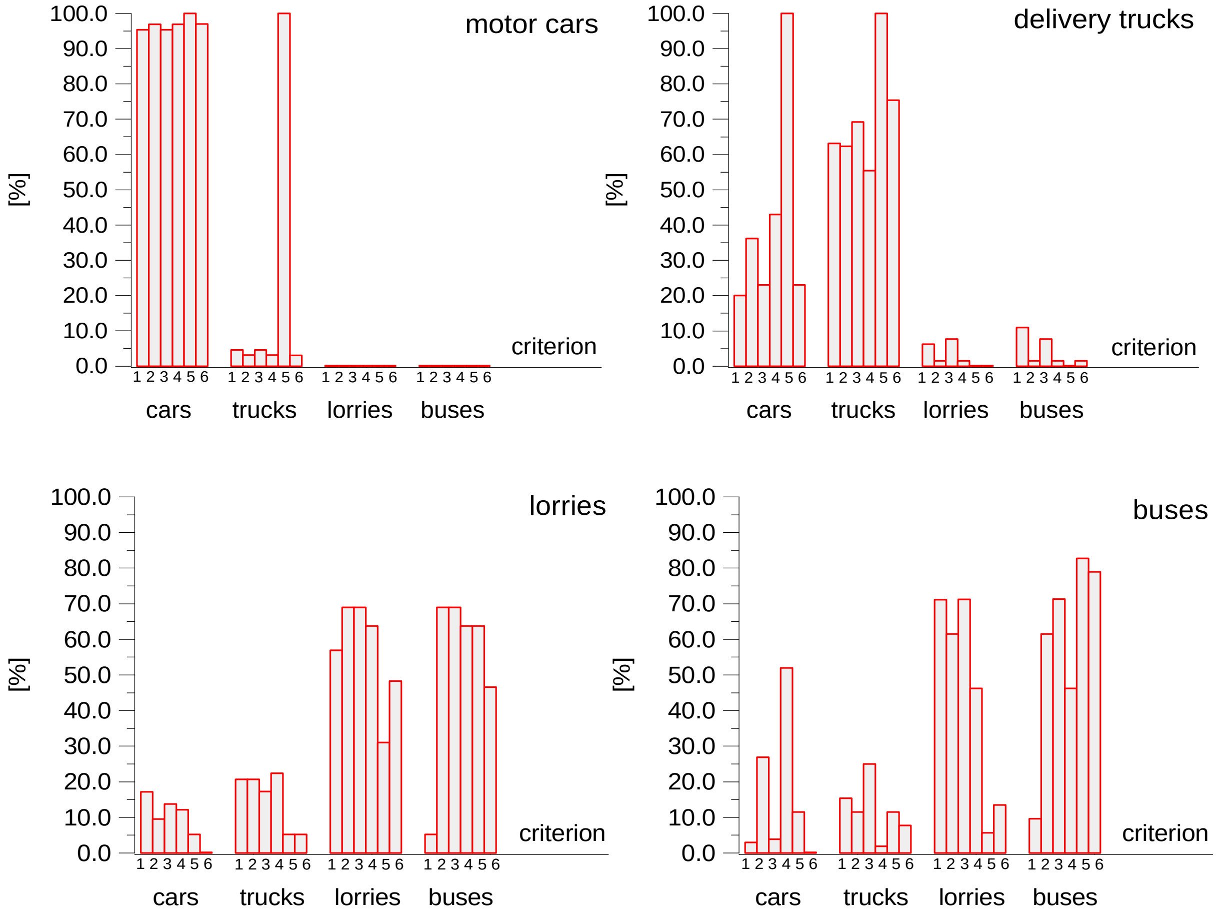

Figure 2. Assessment of the efficiency of criteria (1) - (6) of automotive vehicle classification where four vehicle classes are defined (cars, delivery trucks, lorries, and buses). 1,2,3,4,5,6 - numbers of classification criteria according to description in the text

4 MULTI-CRITERION CLASSIFICATION

Multi-criterion classification can be implemented as one out of two methods: as a „voting" method and as a hierarchical classification method.

According to the „voting" method, vehicle classification is being made successively according to each of the applied criteria. The final result of classification is that which met the greatest number of criteria (gained the greatest number of votes). If a few results gained the same number of votes then the classification result is not definite and more than one class is assigned to the vehicle. A modification of the „voting" method is a method where the „votes" of individual criteria are weighted by the coefficients assuming the values from the (0,1) interval. The efficiency of classification without and with weighting votes is presented in Fig. 3. All the mentioned criteria were the „voting" criteria.

Weighting of the votes increases substantially the efficiency of vehicle division into two groups, i.e. the group of cars and delivery trucks and the group of lorries and buses. This is why the method of voting with weighting can be the primary criterion in the hierarchical classification. The improvement in efficiency of dividing the vehicles into the two groups obtained as the result of applying weighting of votes is particularly visible in the lorries group. The application of weighting resulted also in an improvement in the classification definition.

In the hierarchical method primary and secondary criteria are defined. The primary criterion is used to make an initial classification of vehicles into groups containing usually two or more classes (when the total number of classes is large). The secondary criteria are used to make classification within particular groups, dividing the vehicles into classes. Different criteria can be used in individual groups. Some typical schemes of the process of classification with a hierarchical method are shown in Fig. 4.

The efficiency of the hierarchical classification method is substantially higher than that with application of single criterion (Fig. 5). Particularly significant improvement was obtained in the lorries group. If the **b** scheme was applied, the classification efficiency in the individual classes was respectively: cars: 95.4%, delivery trucks: 83.1%, lorries: 87.9%, buses: 76.9%. The erroneous classifications which usually were from a few to more than ten per cent occur between classes exclusively.

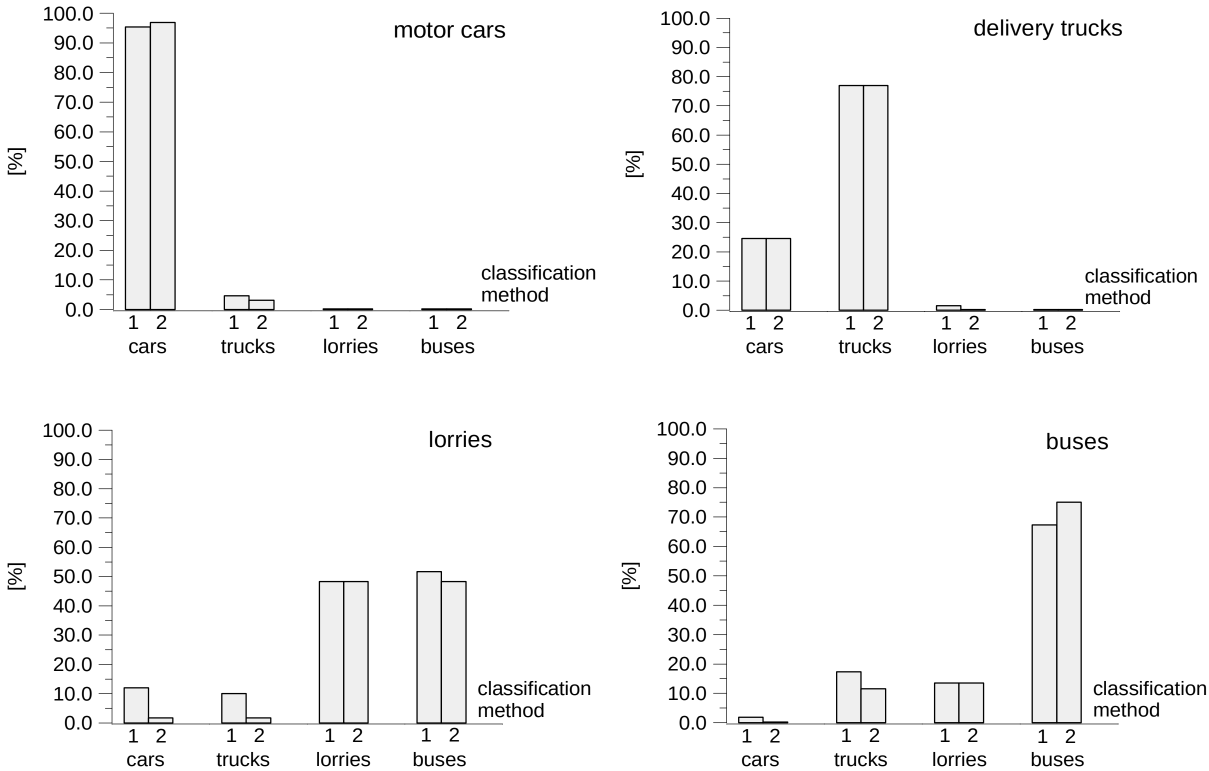

Figure 3. Efficiency of the automotive vehicle classification with voting: (1) without weighting; (2) with weighting of votes.

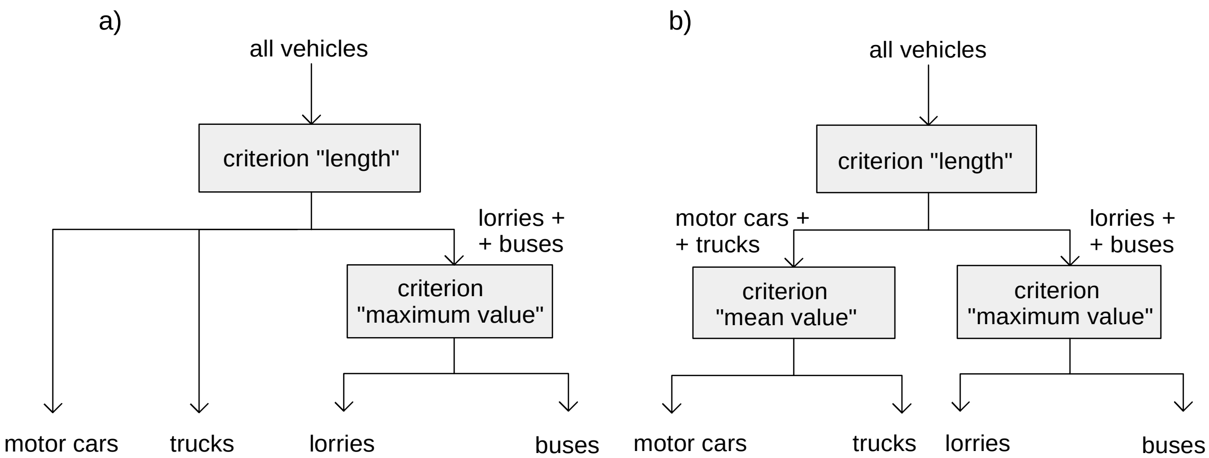

Figure 4. Typical schemes of a hierarchical classification process.

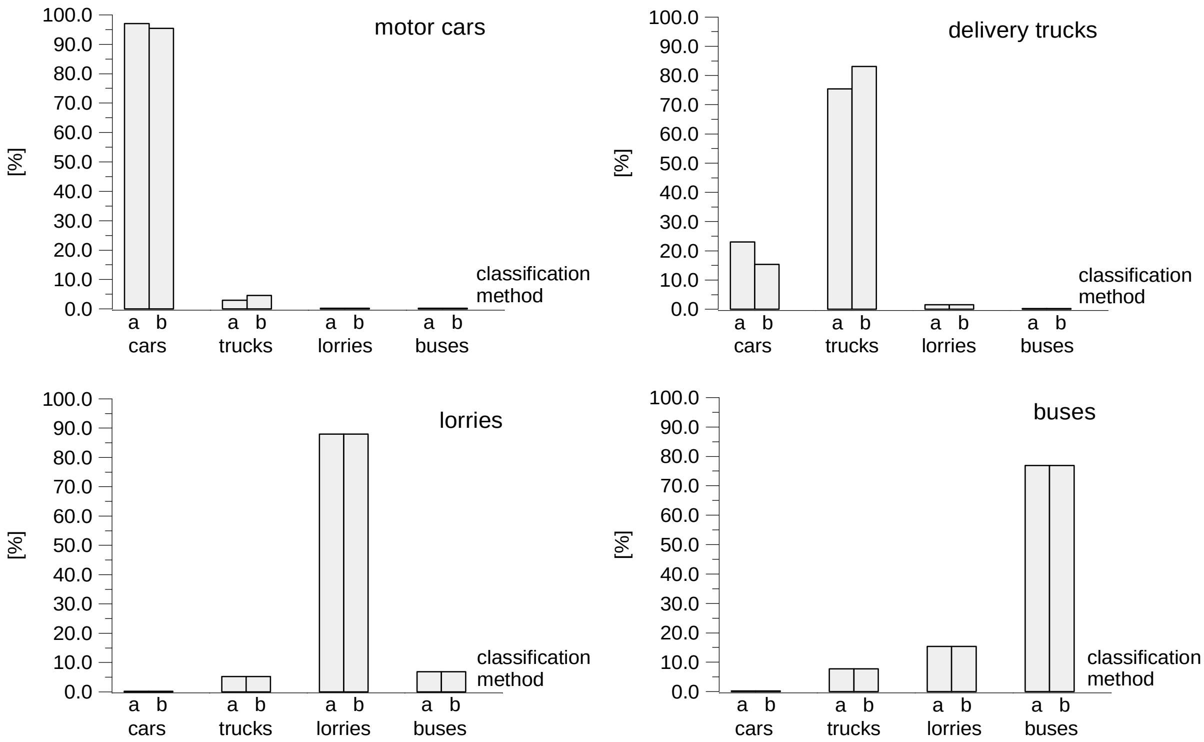

Figure 5. Efficiency of the hierarchical classification according to schemes **a** and **b**. Scheme **b** is better in the delivery trucks class.

5 CONCLUSIONS

It should be stated that the proposed algorithms could be applied to classify vehicles with sufficiently good efficiency.

The obtained classification results make it possible to formulate the following conclusions:

- all remarks presented in sections 3 and 4 on the efficiency of the tested automotive vehicle classification criteria are valid at the accepted boundary values separating the defined classes of vehicles and for the weights of votes of individual criteria. The correct selection of these values made e.g. by the method of maximisation of a chosen criterion being a total estimation of the classification efficiencies in the all defined classes can result in the further improvement of this efficiency
- no criterion exists among the six tested whose efficiency is satisfying in all the four vehicle classes. However, applying different criteria to particular classes may result in the efficiency which in the worst case (lorries) is close to 70%.
- the hierarchical method classification efficiency is substantially higher than that for the single-criterion method (Fig. 5). Particular large improvement was obtained in the lorry class.

The research towards the development of the vehicle classification strategy will be continued.

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