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ADAPTIVE METHOD'S APPLICATION FOR THE IDENTIFICATION SYSTEMS IN DYNAMIC WEIGHING

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In this work the possibility of adaptive algorithm in Weight in Motion (WIM) systems, in which fibre optic sensors are used, is shown. Appointment of dynamic weighing device consists in determining the weight and type of vehicle. An algorithm for processing the input data and fibre optic sensor to create the database using in the algorithm is presented. The results of the algorithm for the identification of vehicles are given. The conclusions are made and options of increasing the accuracy of the identification algorithm are considered.

Keywords: dynamic weighing, adaptive filtering, digital data processing

1. Introduction

Thanks to scientific research progress today, intelligent transportation systems (ITS) are a major component of any strategy aimed at ensuring smooth traffic in European cities. However, the current state of transport networks in European countries and the problems associated with the need to maintain the quality of road surface, suggest the presence of measurement systems weighing vehicles in the existing ITS [1].

There is static and dynamic weighing. For static weighing systems a special area, designed to determine the total mass of the vehicle and the mass of the vehicle axles, should be equipped. The procedure requires a static weighing cessation of movement in this direction and passing to a special area for weighing vehicles.

Dynamic weighing system (DWS) allows us to weigh a vehicle in motion that significantly expands its range of applications. However, today, dynamic weighing systems are expensive, mainly due to the nature of electronic sensors in use [2].

The existing vehicle weighing systems various electronic sensors are used [3], the main ones are:

- Capacitance (Capacitive pad, capacitive strip);
- Piezoelectric (Piezo-electric cable);
- Strain (Bending plate, Load cell).

Existing sensors used for weighing vehicles in motion, are either high cost of installation and maintenance, or have a low accuracy of determining the mass of the vehicle [2]. The latter is typical for systems using capacitive sensors.

Regardless of the type of sensor, as a parameter characterizing the weight of the vehicle, changes of the electrical signals, recorded by the sensor (as a result of a special strain of the working part of the sensor under the weight of a passing vehicle), are used [3,4].

In recent years, as alternative sensors, the possibility of using fibre optic sensors is studied [1]. The main advantages of fibre optic sensors are long-term service life (about 12 years) and low cost of the system as a whole, both at installation and during maintenance in subsequent years [5,6]. However, materials processing signals from the output of fibre optic sensors are currently not sufficient for full implementation of such sensors in the dynamic weighing system.

2. Dynamic Weighing Systems and Factors Affecting their Parameters

DWS is positioned as a device to measure the dynamical mass of the axis or a moving vehicle. According to the measurements the corresponding static axle or the entire vehicle weight is determined.

DWS can be divided into two groups depending on the allowable speed of the vehicle weighing:

- low speed (less than or equal to 15 km/h);
- high speed (more than 15 km/h).

WIM parting by the speed of the vehicle is due to the limitations in terms of functionality and accuracy[5].Various factors can affect low and high speed WIM systems' functioning. Some of these factors are inherent in certain selected DWS, in particular, the use of force sensors. Other and equally important factors affecting the ability of DWS, are common to the DWS-technology in general.

Particular attention is caused by the following factors:

- characteristics of the installation location of DWS;
- vehicle characteristics;
- environmental characteristics.

The first type of parameters affecting DWS includes: the slope of the vehicle at the time of weighing (both longitudinal and transverse) and slope of the sensor.

The second type of parameters is: type of suspension, the distribution of forces during braking of the vehicle, the natural oscillations of the vehicle [7].

The third type of parameters, primarily includes temperature fluctuations. Because of the changes in ambient temperature sensor, its characteristics change as well.

The first two types of parameters are more affected by changes in the centre of mass of the vehicle weighing, while the temperature changes affect the entire result of the weighing process as a whole.

The lateral inclination of the vehicle leads to a shift in the centre of gravity and thus to shift the load towards the "lower" wheel. The slope in the direction of motion leads to the transfer of the load on the "lower" axle(s). Therefore, weighing on the side shows different results compared to the weighing on a flat surface.

The maximum possible error for the DWS is caused by fluctuation of the car. There are two fundamental vibration motions in relation to fluctuations of the vehicle: the vibration chassis of the vehicle with the natural frequency of 1 to 3 Hz, according to the load and the axis of oscillation with a frequency of approximately 10 Hz [7,8]. In terms of the current amplitude of the vibrations during the passage of time through the sensor DWS, measured the pressure will be higher or lower than the actual static weight. Due to the fact that the frequency axis is almost constant, its effect can be reduced by shifting the left and right sensor to half the wavelength. This measure is useful if the vehicle speed is constant. The shift is calculated as follows:

$$\Delta l = v / (2 * f_{axle}) , \qquad (1)$$

where v – speed of the moving vehicle;

f_{axle} – the frequency of the axis of the vehicle.

For the speed V up to10 km/h (2,8 m/sec) shift 0,14 m, for 100 km/h accordingly 1,4 m.

Figure 1 shows the load-unloading diagram obtained at different temperatures. The sensor was placed in the freezer for 4 hours at -20 ° C and then placed between the metal clamps of the testing machine through insulating spacers.

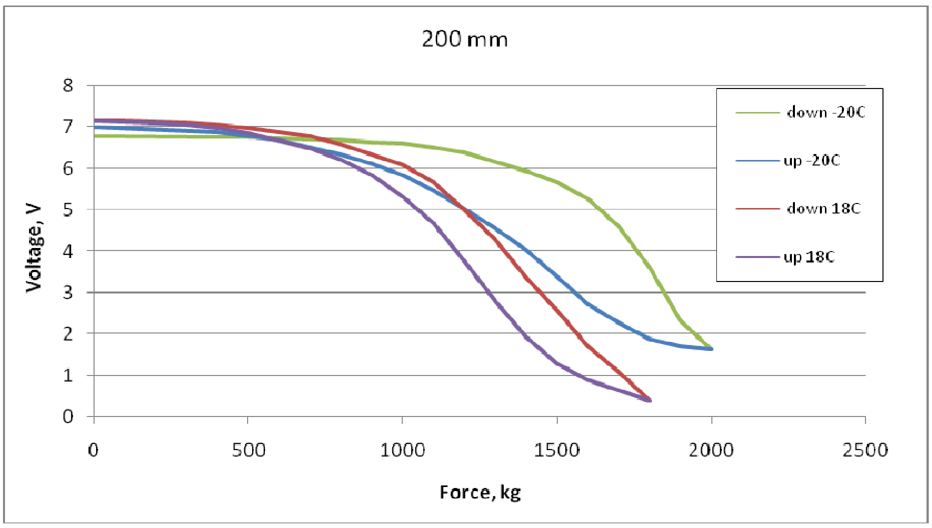

Figure1. The relation of the output voltage of the amplifier to the sensor of the applied force through the plate of 200 mm at various temperatures

The optical response of the sensor decreases with temperature falling due to the fact that the shell material of the sensor becomes less pliable at this. Increasing of the area of the hysteresis loop at low temperature is explained by the heating of the sensor during the test (about 20 min.).

Heterogeneity of the factors listed above, as well as their random nature, makes it virtually impossible to use direct methods of converting. The error converting signal levels from the outputs of optical fibre sensors in the vehicle weight ranges from 40 to 120% of the true weight of the vehicle.

3. The Method of Identification Systems in Decision-Making

One of the challenges is the task of weighing the dynamic allocation of overloaded vehicles from the flow of vehicles. In this case, the problem of weighing becomes the task of decision-making, if the vehicle is overloaded or not.

Decision problem is usually solved by comparing current events with a certain standard.

In electronic systems, a standard for comparison, can be specified either as signal or as a unit. The characteristics of this device include information on the standard signal.

In dynamic weighing systems using fibre optic sensors, the standard signal from the output of the sensor should correspond to the true weight of the vehicles. Due to the availability, random and regular destabilizing factors that distort the signal from the output of fibre optic sensor standard signal can only be formed by averaging signals from the output of the sensor. Averaging signals should occur with the same probe in multiple travels on it the standard vehicle laden weight.

Information on this signal is easier to represent in the form of a certain device (system). The signal at the output of such a system corresponds to the averaged response of the sensor on a multiple collision with the vehicle laden with standard weight.

In this work, as a standard device a digital filter is proposed. Weighted digital filter coefficients are determined by using an adaptive least squares algorithm.

Once the standard device is created, the compliance of the vehicle weight with allowable weight for a given line is determined by the method of system identification.

4. Signal Conversion Method Development

For the adaptive system identification method implement pre-processing the input data output from the fibre optic sensor is required. Consisting of the following:

- calculation of centre of mass of statically and dynamically weighed vehicles;
- change in peak (amplitude) of the input signals to the DWS, with the new calculated centre of gravity;
- calculate the factors taking into consideration thermal fluctuations of the environment;
- calculate correction factors for speed;
- formation of the reference.

4.1. Calculation and Changes of Mass Centre

The centre of mass of dynamically weighed vehicle is calculated on one assumption: the weight of the first axis of the standard wagon was equal to the mV corresponding to the first axis of a standard weight truck. This assumption was made based on the fact that the first axis of the standard wagon «MANFH12» doesn't practically affect the weight at full load or unload of the vehicle. From that we can conclude that the external influences on it have the least effect.

Figure 2 and Figure 3 shows the signals obtained from the output of fibre optic sensors installed in the roadway when passing through it empty and full five-axes reference wagons «MANFH12».

From the graphs shown, it is clear that some of the dynamic additional forces have impact on the process of weighing and it can be seen by comparing the results obtained with the last three axes. Weight of each of the last three axes in dynamic changes according to the number of additional forces applied, that were considered earlier.

In this case to calculate mass centre (gravity), the vehicle can be represented as a lever to the centre of mass at some point. Figure 4 shows a diagram of the classical lever [9], but applied to our case - where the dotted line shows the desired mass centre. Legend $F_{1,2,3,4,5}$ – axis pressure factor of the vehicle in mV on the measuring probe, and $l_{1,2,3,4,5}$ – shoulder of the load.

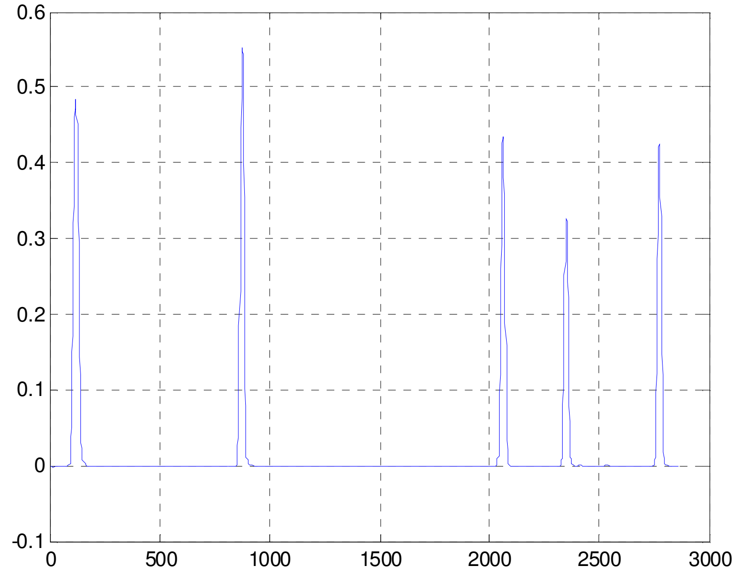

Figure 2. The response of the sensor when driving an empty reference wagons of 90 km / h on it

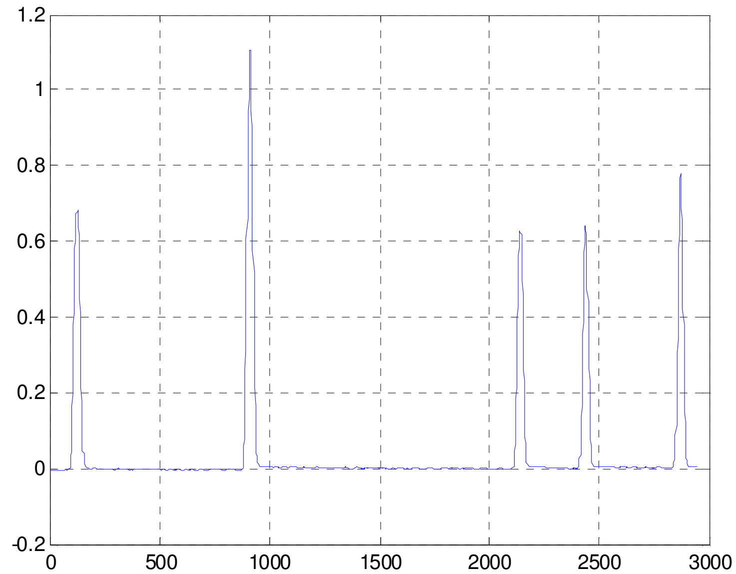

Figure 3. The response of the sensor when driving laden standard truck 90 km / h on it

In this case, balancing the forces will be equal to:

$$F_1(l_1 + l_2) + F_2 l_2 = F_3 l_3 + F_4(l_3 + l_4) + F_5(l_5 + l_4 + l_3); \tag{2}$$

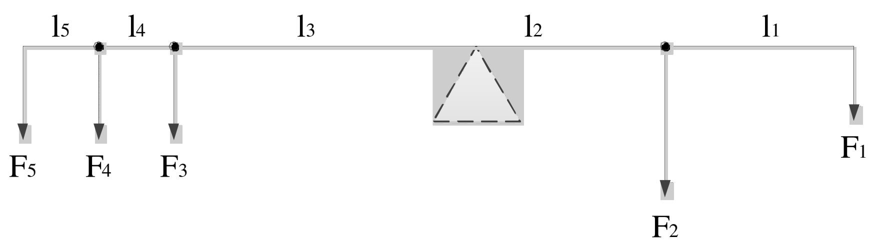

Figure 4. The scheme of the lever considering the acting forces of model wagon

Then we need to find the distance from the wheel base to the point of balance of forces, under the assumption that the balance point is located between the second and third axis.

The formula by which to determine the distance of the mass centre of the second wheel axis is derived from equation (2) and has the following form:

$$l_3 = \frac{F_1(l_1+k)+kF_2-F_4l_4-F_5l_5-F_5l_4}{F_3+F_4+F_5+F_1+F_2}; \qquad (3)$$
$$k = l_2 + l_3.$$

Table 1 shows the values of the centre of mass calculations for different speeds of travel of the sensor. At that you may notice a tendency of the centre of mass shifting to the distant axes for dynamic weighing, which does not disappear in the next travels. In the case of empty and full trucks, centre of gravity is not the same. In the case of fully loaded trucks the centre of mass is deflected to the far more significant axes of the vehicle than with empty trucks.

Table 1. Table of changes in the mass centre from speed and load

The speed and load of the vehicle	The centre of mass in the static (distance in meters from the second axis)	The centre of mass in the dynamic (distance in meters from the second axis)
~50 km / h, empty	2,28	2,49
~70 km / h, empty	2,28	2,32
~90 km / h, empty	2,28	2,28
~50 km / h, loaded	3,34	3,95
~70 km / h, loaded	3,34	3,45
~90 km / h, loaded	3,34	3,43

After the results were obtained from the shift of mass centre, you must change the input signal to the DWS in such a way that the mass centre in a dynamic weighting was equal to the static mass centre.

Due to the assumptions made, for calculating the new amplitude balancing the dynamic mass centre with the static mass centre, it is necessary to recalculate the value of the first peak and for this we derive the formula (2), the formula for calculating the new value of F_1:

$$F_1 = \frac{F_2(k-l_3)-F_4(l_4+l_3)-F_5(l_3+l_4+l_5)-F_3l_3}{l_3-l_1-k}. \qquad (4)$$

The value obtained in the calculation of the formula (4) will be the maximum value of the first peak of the input signal to the DWS system, which will lead to a change in the mass centre to static.

4.2. The Adjustment Coefficients

To calculate the adjustment coefficients, data obtained during the test of the fibre optic sensor was used.

The adjustment coefficients to adjust the signal when the ambient temperature is different from the temperature at which the sensor calibration is performed, as well as factors for the normalization of the reference signal at different speeds of travel on the sensor were calculated.

Adjustment of the signal is performed by determining the current temperature of the sensor and multiplying it by the case other than the temperature of the temperature calibration, for the calculated correction factor. Where the adjustment coefficients are calculated on the basis of the obtained dependences of the two curves of temperature of the sensor on the pressure, recorded at 18 °C and -20 °C on Figure 5.

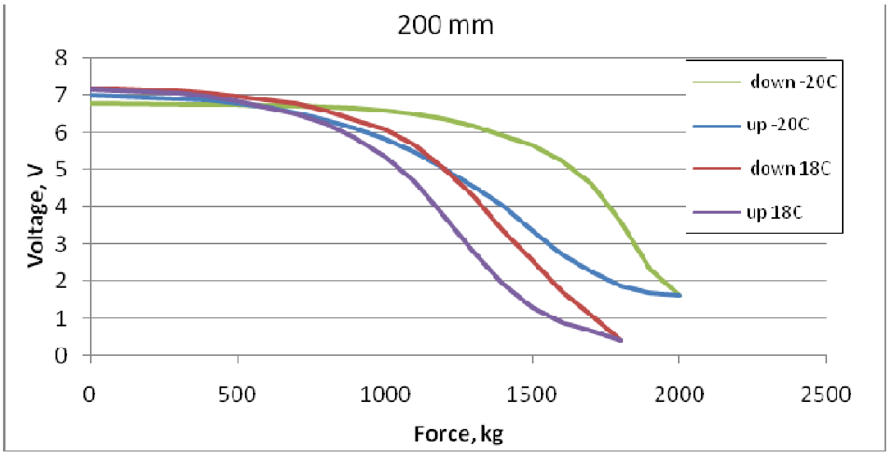

Figure 5. Relation of the output voltage amplifier from the force applied to the PUR sensor through the plate length of 200 mm at various temperatures

4.3. Formation of a Reference Signal

Standard signal is the value of the amplitude of axis of the vehicle formed while the vehicle is passing on the measuring sensor. The standard is formed by averaging the values of the races as blank test standard trucks, the standard for the formation of an empty wagon, and value is fully loaded test truck, a standard for the formation of a full truck.

In this case, the number of sensors, on which the vehicle is moving or the number of rounds over which the averaging is made, is of great importance.

5. The Algorithm of the Adaptive System Identification Functioning

The principle of operation of the adaptive system identification of vehicles, using fibre optic sensors in the DWS is following.

The input signal from the output of WIM sensors (a simple dynamic weighing system consists of an inductive loop sensors and two inductive sensors) goes on a portable computer or signal processor, where out of the received signal we determine:

- speed of the vehicle;
- type of vehicle (by the quantity of axes driving on the sensor, by the distance between the axles and the number of pairs of wheels);
- and the weight of the vehicle.

5.1. Description of the Algorithm Scheme

Figure 6 shows a diagram of the algorithm for the identification of systems consisting of independent blocks: calculating the centre of mass, power shift, standard form, the block of estimating the mass of the axes, the filter blocks, as well as the database block.

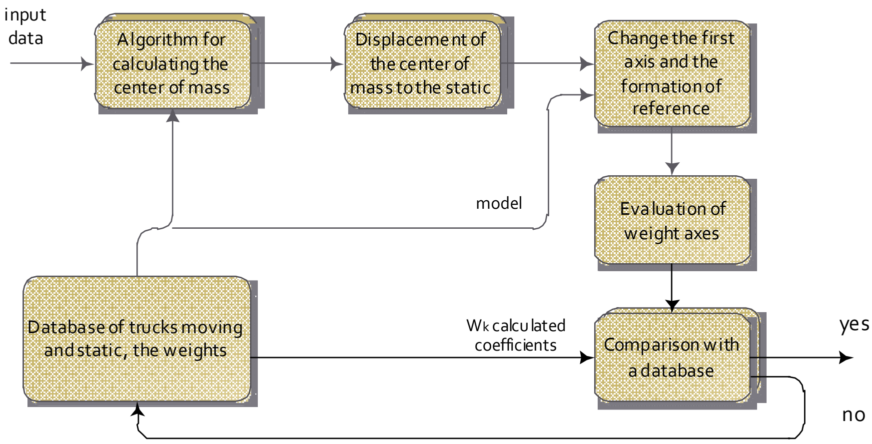

Figure 6. The scheme of the algorithm of identification systems

The input of the first block of data fed from the output of the DAC fibre-optic sensor. In this block the identification (determination) of the vehicle is defined in order to select the desired pattern and identifiable parameters (i.e. weight) from the database. Further action after identifying this block is the centre of mass calculations in static and dynamics. In the first case, the centre of mass is calculated for a vehicle, which has been identified by the system, with different weights (e.g., 5-axle wagon with weights: a fully laden, empty). In the second case, the centre of mass is calculated directly from the data obtained from the WIM sensor. Once the centres of mass are found in static and dynamics, it is necessary to dynamically change the received signal to the static centre of mass. Thus we get some signals from the various centres of mass.

In the next block, there is a formation of a reference signal to be fed to the digital filter for system identification. From the database supplied reference signal obtained for certain parameters (speed, temperature, etc.) that need to be adapted (converted) to the current conditions of measurement. After changing the centre of mass and the formation of a reference signal is the weight rating of axes, i.e. determined by the weight of each axle.

In the last block, the received signal is compared with the reference signal. It uses the discrete filter with certain weights, which were pre-computed and loaded from the database. If after the comparison with a standard, we have a large error, then the database is loaded a new reference signal and new weightings come to a discrete filter. Everything is repeated until we find the result with the least error. In particular, comparing the procedure consists of an array of discrete filters, that are loaded in the specified weights and the corresponding standard signals. After comparison, we obtain the comparison results and choose the option with the least error.

To obtain the weight coefficients of adaptive filter, the method of least squares is used [10].This adaptive algorithm has been selected due to the fact that it works in real time, i.e. no need in accumulation of errors from the sensors. Using other adaptive algorithms such as Normalized LMS, Variable step size LMS and sign algorithm LMS it doesn't lead to significant improvements in calculating the weights.

The general structure of an adaptive filter is shown on Figure 7. The task of an adaptive filter is to minimize the error signal reproduction model. For this purpose, a block of adaptation after processing each sample analyses the error signal and additional data coming from the filter. Analysis' results are used for the adjustment of the filter's parameters (coefficients). Later, these coefficients are entered into the database and are assigned to a certain type of car with a certain load.

Coefficients are calculated by the formula (5).

$$w(k+1) = w(k) + \mu e(k)u(k)2\,, \tag{5}$$

where μ – positive coefficient, called the step size;

$e(k)$ – error at rendering an exemplary signal;

$u(k)$ – vector of the contents of the delay line filter at the k step.

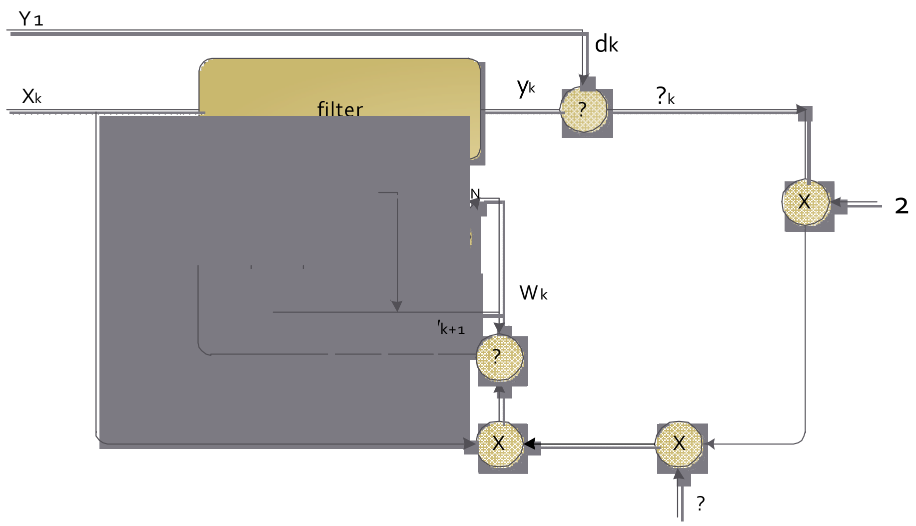

Figure 7. The scheme of calculating the adaptive filter weight factors

Figure 8 is a schematic diagram of the block "compared with the database" system identification algorithm. This scheme is a link of a database and digital filters. Thus the number of discrete filters depending on the number of types of weights one moving vehicle available in the database. The input $Y_{1,2,...,N}$ fed the standard signals corresponding to the selected weighting coefficients. The input X_k simultaneously on all the digital filters is fed from the output signal of the modified fibre-optic sensor. On the output of these filters, we obtain ε_k values error, after filtering the input signal and the comparison with the standard signal. As a result of this, the mass of the vehicle is determined.

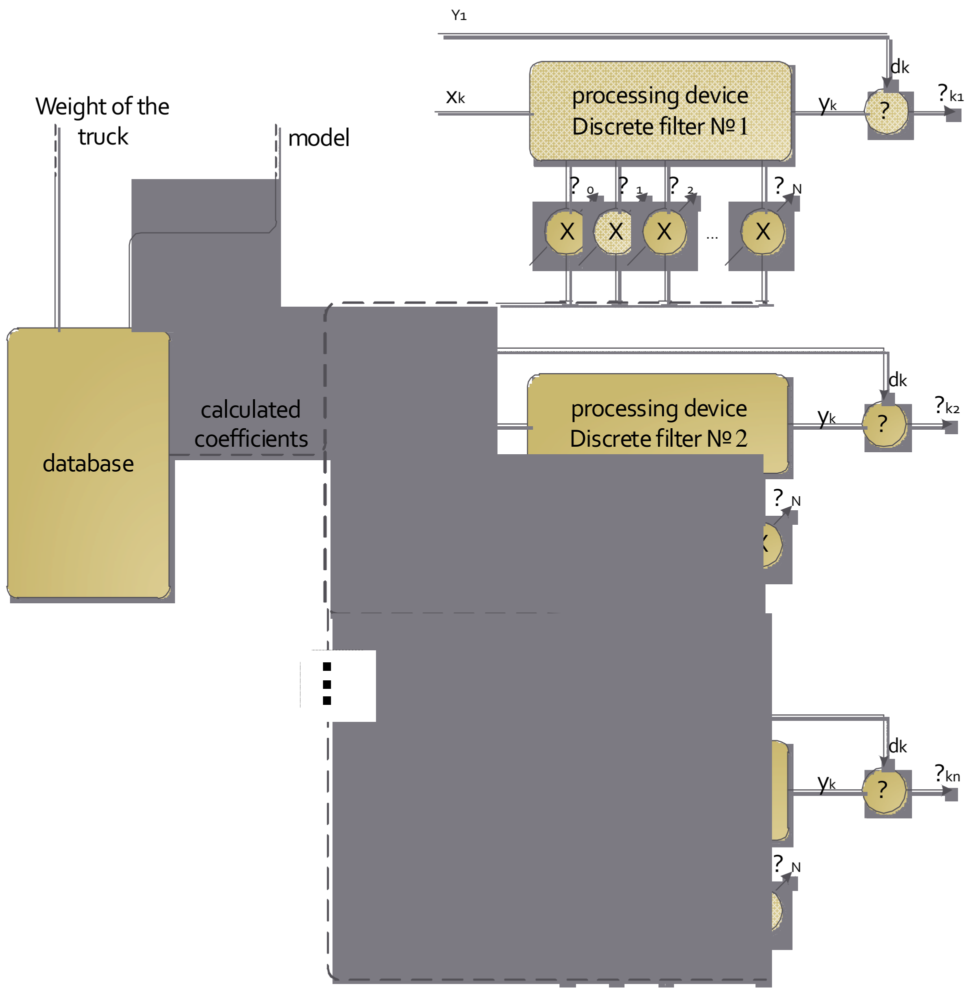

Figure 8. The scheme of interaction databases with discrete filters

5.2. Database Formation

As it can be seen in the proposed algorithm, the database is very important and integral part of the algorithm. This is due primarily to the fact that the database contains a large amount of sensitive and accurate enough information in connection with which, at its formation may have some difficulties.

The database is formed by the rounds of standard vehicles with certain weight of fibre-optic sensor, which is why the difficulty of developing a database of a large number of vehicles occurs.

5.3. The Results of the Algorithm

During the experimental operation of the algorithm for system identification, the algorithm has shown good results for the determination of the mass of a passing vehicle, which can be seen on Figure 9 and Figure 10.

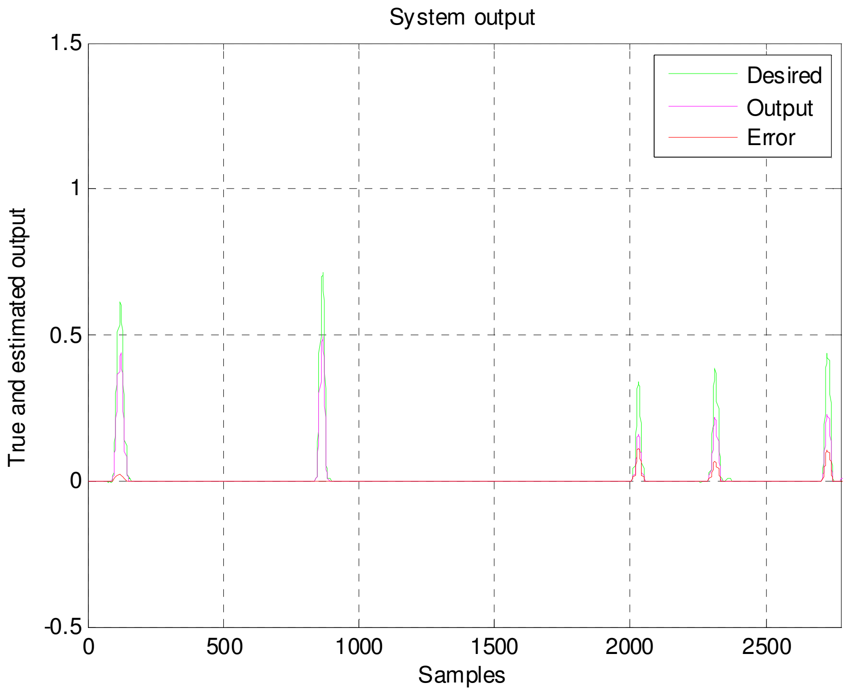

Figure 9. The results of weighting identification algorithm from the output of digital filter. An empty wagon 90km/h

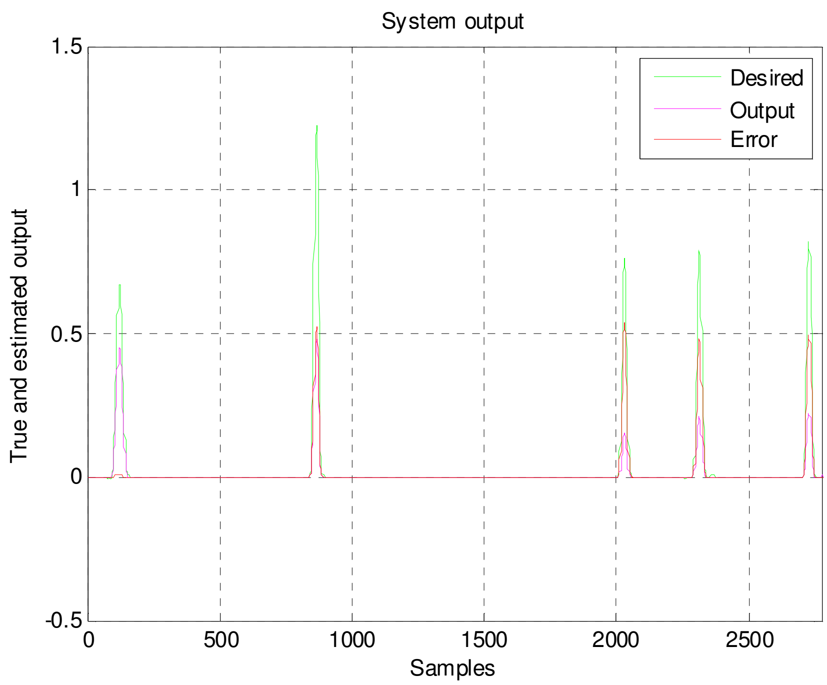

Figure 10. The results of weighting identification algorithm from the output of digital filter. Ladenwagon 90km/h

In the course of the proposed algorithm two standard wagons (fully laden and empty) have been created and submitted in the database. The converted signal is output from the fibre optic sensor as digital filter, where it has been compared with the standard. In the first case, when the signal is compared with the standard of the empty truck, the result of the comparison of error is 7.19% of total weight. In the second case, when the signal is compared with a standard laden truck, comparison the error is 43.48% of the total weight. Table 2 shows the results obtained in the course of the algorithm of identification systems.

Table 2. Results of the algorithm application in vehicle identification in %

Options of arrivals of vehicles with different weights		The discrete filter #1 (the coefficients of an empty vehicle)		The discrete filter #2 (the coefficients of laden vehicle)	
		70 km/h	90km/h	70km/h	90km/h
Arrival sequence number of an empty vehicle	1	9.83	10.44	54.99	44.44
	2	12.73	7.40	59.23	40.93
	3	10.51	7.25	56.05	40.84
	4	6.02	7.19	50.23	40.81
Arrival sequence number of laden vehicle	1	42.94	24.10	20.18	21.86
	2	38.64	34.36	14.83	5.68
	3	32.50	32.63	22.04	8.78
	4	51.13	34.36	11.67	5.68

Table 2 presents the comparison of error. As it is shown, not all results are optimal. This may be due to the fact that the fibre-optic sensors tested haven't been checked on the spatial uniformity of response of the sensor throughout the working area. In the data used there are possible errors related to the fact that the signals have been recorded in one day, and within a certain period of time with the connection and disconnection of equipment from the sensors. As a result, technical errors are possible (dust, changing micro bending (varies micro bend) ...).

According to the results it can be concluded that system is designed to cope with the task of identifying vehicles permitted to exceed the maximum load on the highway.

6. Conclusions

The possibility of using an adaptive system identification method for dynamic weighing has been studied.

As the results of work prove, this way is relevant and prospective, as currently there are no existing WIM systems that use fibre optic sensors. Obtained results allow us to use the system to determine the overloaded vehicles in the automotive stream.

As experience shows, it is necessary to use more than one fibre optic sensor to improve the algorithm's work. One of the main problems is the development of the database for the algorithm of the identification systems. Development of a database for a large number of vehicles is quite expensive. That is why the confines of the possibility of use of this algorithm in the near future occur.

Acknowledgements

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