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ACOUSTIC SIGNALS PROCESSING AND APPLIANCE FOR THE PROBLEM OF TRAFFIC FLOW MONITORING

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The increase of road traffic in the European Union focuses for creating intelligent transportation systems of traffic control in local, urban and regional level. The possibility of using acoustic sensors for traffic intensity measurements are discussed in this article. Acoustic signal detector, such as an ordinary household microphone, is used as the most inexpensive sensor version for stationary and mobile traffic surveillance systems. The examples of the acoustic signals records from different types of road vehicles in various weather conditions are described here. The simplified modification of acoustic microphone's signals spectral processing algorithm and noise filtering are solved. Detection of moving road vehicles results, using records for their acoustic signals, is also discussed. The restrictions of using acoustic sensors to estimate traffic parameters are established.

Keywords: intelligent transport system, transport flow surveillance, vehicle detecting, acoustic signal, digital signal processing

1. Introduction

In the contemporary world the volume of traffic transportations has become one of the indicators of growth and regional development level. Due to this, the number of transport vehicles on roads is persistently increasing and the capacity of roads cannot cope with traffic, creating hours-long traffic jams. The permanent increase in the traffic intensity in urban areas leads to fading traffic flows, thus entirely paralysing the segment or the whole transport network. In order to solve this problem it is necessary to modernize the transport infrastructure (add an extra traffic lane or increase the width of the road), but this is often practically impossible because of the presence of a large number of closely located buildings, for example, in the historical centre of Riga (Fig. 1).

Figure 1. Traffic jam

At a first glance, it seems that the situation is completely desperate. However, this problem can be solved by creating new intelligent transportation systems of traffic control [1], but, for this purpose, a

detailed analysis of traffic flows in real-time mode under any weather conditions should be carried out, after which vulnerabilities in the transport network should be detected and eliminated. Structurally, these systems include networks of sensors of primary and indirect measurements of traffic flow parameters, controlling centre and the network of executive elements (traffic lights, managed road signs, reversible lanes etc.). The wider the network of sensors is, the more complete information is available for the intelligent control.

Currently, video surveillance, laser, radio, inductive and press-button sensors are mainly used as sensors of intelligent transport systems. The expansion of the network of such sensors requires considerable financial resources and sometimes even additional construction works. Installation, maintenance and protection of the network of costly sensors and their connection channels make the creation of full-scale intelligent transport systems rather expensive, which often cannot be financed by state.

With the development of methods and means of digital signal processing, an opportunity of using acoustic signals for detection of a passing-by transport vehicle appeared. This allows using a usual household microphone as a sensor, which makes possible to expand the acoustic network with minimum financial costs.

On the basis of spectral analysis of real records of acoustic signals of the transport vehicles passing by under different weather conditions, an algorithm of filtering noise components (wind gusts) and getting the useful signal letting to define the amount, speed and type of the vehicle (motor car, public or freight).

2. The Study of Intelligent Transport System's Sensors

As noted earlier, there are a large number of sensors, which have a number of significant advantages and disadvantages relative to each other. Use them in every segment of the transport network must be considered separately, and in some cases altogether excluded because of inability to properly fulfil the stated objectives [2].

2.1. Radio radars

Radio radars use the Doppler Effect and have a second name – Doppler radars. This radar measures the change in frequency of the signal reflected from the object. By changing the frequency of the signal, the radial velocity of the object (the projection of velocity on the straight line passing through the object and the radar) is calculated. Doppler radars are widely used in various fields: for determining the speed of aircraft, ships, cars, hydrometeor and other objects [2].

A major disadvantage of the radar is the feature that the speed of one moving vehicle only can be detected each time. Therefore, it is impossible to use the radio radar as traffic counter.

2.2. Laser radars

Laser radars, as well as radio radars, are used to determine the speed of vehicles. Abbreviation of the name is called as LIDAR [3]. LIDAR is the technology of obtaining and processing the information about remote objects by means of active optical systems utilizing the phenomenon of light reflection and dispersion in transparent and translucent media.

LIDAR is significantly smaller than traditional radar, but less reliable in determining the speed of modern cars: reflections from the inclined plane of complex shape distorted signal to the receiver LIDAR.

Disadvantages of laser radars are similar to radio radar.

2.3. Photo radars

Photo radar has a number of opportunities for the registration of moving vehicles. This is the best method for measuring traffic flows and speeds. This type of radar can store information in some cases to pass this information via radio to a remote mobile post. There are problems with taking pictures at night, but the problem is solved by using infrared illumination.

In the second generation of photo sensors installed new hardware and software that solves the problem of mathematical processing of data from radar and cameras, image analysis and pattern recognition to personnel numbers, self-diagnostics, climate control, and performs communication functions. As a result of data processing and image analysis photo sensor gives one fixed frame with the velocity and recognized car number [2].

Despite the large number of possibilities, this method has its own disadvantages. To obtain a clear picture visibility and wet weather should be moderate. It is also possible to solve problems with the fixation of several vehicles simultaneously. These photo radars are not designed to count the number of vehicles, but could be upgraded. The processing of acoustic signal can be added to it. Photo radar is inherently unidirectional, meaning it can fix the vehicles in both directions.

2.4. Induction sensors

Inductive sensors are designed to detecting the moving vehicles. Proximity sensors are designed to control the position of objects made of metal (other materials are not case sensitive); performed with normally open or normally closed contact [4].

In a simplified form the inductive sensor is a wire which is placed under the asphalt surface and is connected to the controller. The sensor works on the principle of inductance while driving the car through it. The signal is processed by the controller and at the same counter the number of vehicles increases. In order to be able to determine the direction it is necessary to use two wires. Depending on which of them will cross first, the direction of car is determined [4].

The disadvantage of this method is that it requires the destruction of the road surface for laying inductive loops. It requires special permission and time.

2.5. Pressure sensors

Pressure sensors are composed of two screw elements, which are separated by some distance. Once the transport front wheels crossed the first push element, the receiver gives the signal of start of timer. Once the front wheels reached the second transport screw element, the receiver command is ending the countdown. At the time and known a certain distance between sensors it is simply to calculate the values of a passing transport. It may be the speed, quantity and direction [4].

The disadvantage of such sensors is that not any road surface can be installed. Most of these installations can be found at the entrance/exit to/from the car parking. From other hand, the sensors of this type very quickly become clogged, and it can lead to their frequent breakdowns.

2.6. Sensor's network combination

For the full solutions of increasing transportation problems should be combined and set a large number of sensors on one segment of the transport network that leads to processing of huge amounts of data, thereby reducing the reliability of the system.

It is becoming actual problem of minimizing the number of sensors using alternative methods of traffic flows monitoring. One such a method is based on digital processing of acoustic signals from passing vehicles, but at first we consider the most common types of acoustic sensors.

3. The Use of Acoustic Sensors

It is possible to use one of the 3 types of microphone (ribbon, dynamic or condenser), which the best solution to the task of sound record.

The principle of the ribbon microphone consists of the following: a very thin aluminium tape almost freely suspended in a magnetic field. Its fluctuations depend on the sound pressure on both sides.

Dynamic microphones are composed of membrane and attached to it a small coil placed in the field of a permanent ring magnet. Membrane, oscillating under the influence of sound pressure moves the coil, which when crossing the sound of magnetic field lines are the currents corresponding to the sound vibrations. These microphones are easy to assemble, inexpensive, accessible and perfectly suited to the role of the acoustic sensor.

Condenser (capacity) microphone consists of a very thin membrane and located very close parallel to the electrode. In order for this system has become a capacitor, the power supply is needed. Fluctuations of the membrane lead to changes in the capacity of the condenser and the appearance of the signal. This signal is weak, and the built-in preamplifier is need for the signal increasing [5]. The membrane is very thin and agile, so condenser microphones are more sensitive than dynamic. They need their own power supply. Condenser microphones are usually more sensitive than dynamic microphones; there is less resistance against mechanical damage. These microphones are mainly used in recording studios and are not suitable for recording the signal on the street.

4. Development of Moving Road Vehicles Algorithm Detections Using Digital Processing for Its Acoustic Signals

To develop the algorithm for detecting road vehicles was used the real acoustic signal recorded from the streets of Riga (Fig. 2).

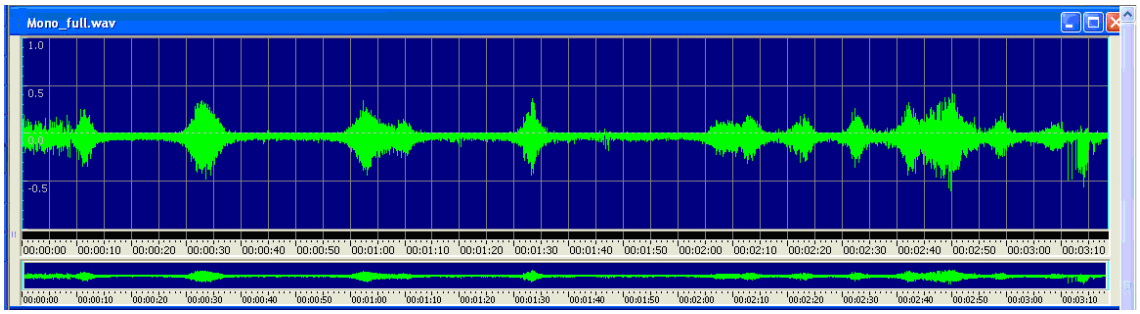

Figure 2. Example of acoustic signal

In areas where the signal increases and then decreases, there is passing road vehicles, after that these areas are cutting out and using for calculations.

During the experiment, acoustic signals were recorded under different weather conditions (Fig. 3-6). Analysing the Figures 3-6 we can conclude that each signal has its own specific form. Road vehicles have a common feature: the increasing signal, and then gradually decreasing. At last acoustic signal is clearly observed chaotic bursts indicating the noise which should be filtered. All these signals brings together that their maximum is attained at the points from 0.4 to 1. Moreover, the maximum mark of the road vehicle is in the range from 0.5 to 0.6 and 0.5 to 1 for wind.

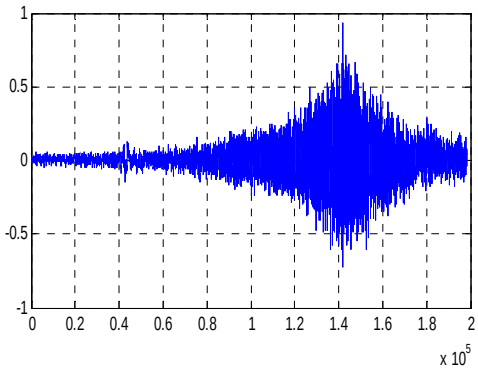

Figure 3. Car signal

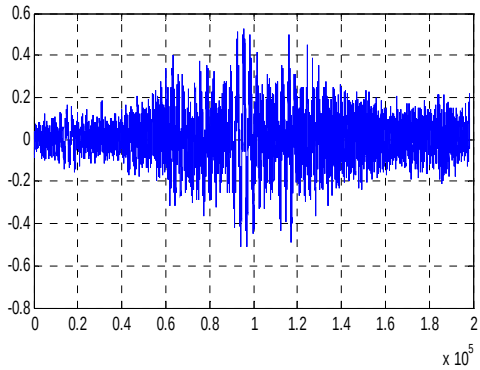

Figure 4. Signal of public transport

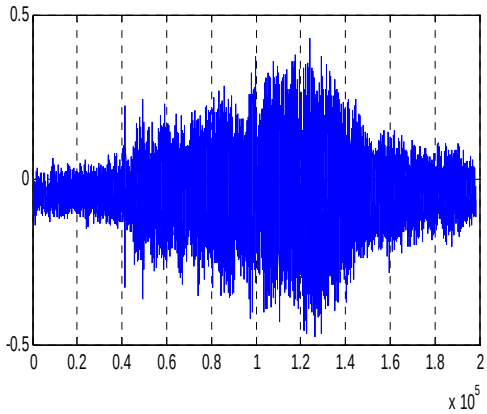

Figure 5. Car signal at rain

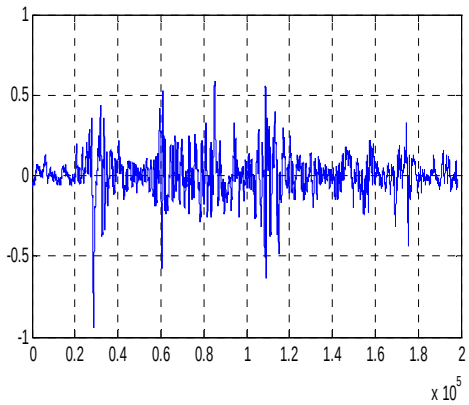

Figure 6. Wind signal

Each record was divided into fragments of 5 seconds length, since all the pulses of signals from vehicles travelling at a speed of about 60 km / h, fit in this time period (Fig. 2). The peculiarity of

acoustic recording is almost three times the redundancy of the sampling frequency: quantization and recording occur with a maximum sampling rate of 44100 Hz and a microphone used in the experiment has a bandwidth of only 16000 Hz. To eliminate redundancy and reduce the processing time the quantization of the signal has been carried out with a frequency corresponding to the conditions of registration (microphone), i.e. 16 kHz. The result has been obtained as discrete sequence of 80000 samples length.

Then the signal was subjected to decimation, where every tenth sample was kept, retaining the basic properties of the signal unchanged, resulting in a signal of 8000 samples length.

On the basis of numerous of experiments it is established the optimum in terms of minimum-time of data processing, as the acoustic signal processing algorithm. It consists of 3 stages:

- Filtering in the spectral domain [6] for lower and upper frequencies of the acoustic signal using the function developed by ***filtering (x, lb, ub)*** in the Matlab software. The parameters of function are: ***x*** – input array of points of the signal, ***lb*** – lower limit of the filter, ***ub*** – upper limit of the filter;
- Square power of the filtered signal;
- Calculation of the moving average of the window length 8000 points, with a given step 10 samples with the help of the developed functions ***mean_vals (x, winSize, step)*** in the environment of Matlab. The parameters of function are: ***x*** – input an array of the signal, ***winSize*** – the length of the window, ***step*** – step.

The example of block diagram of an acoustic signal of the car (Fig. 7) and wind (Fig. 8) phase-out processing is presented below.

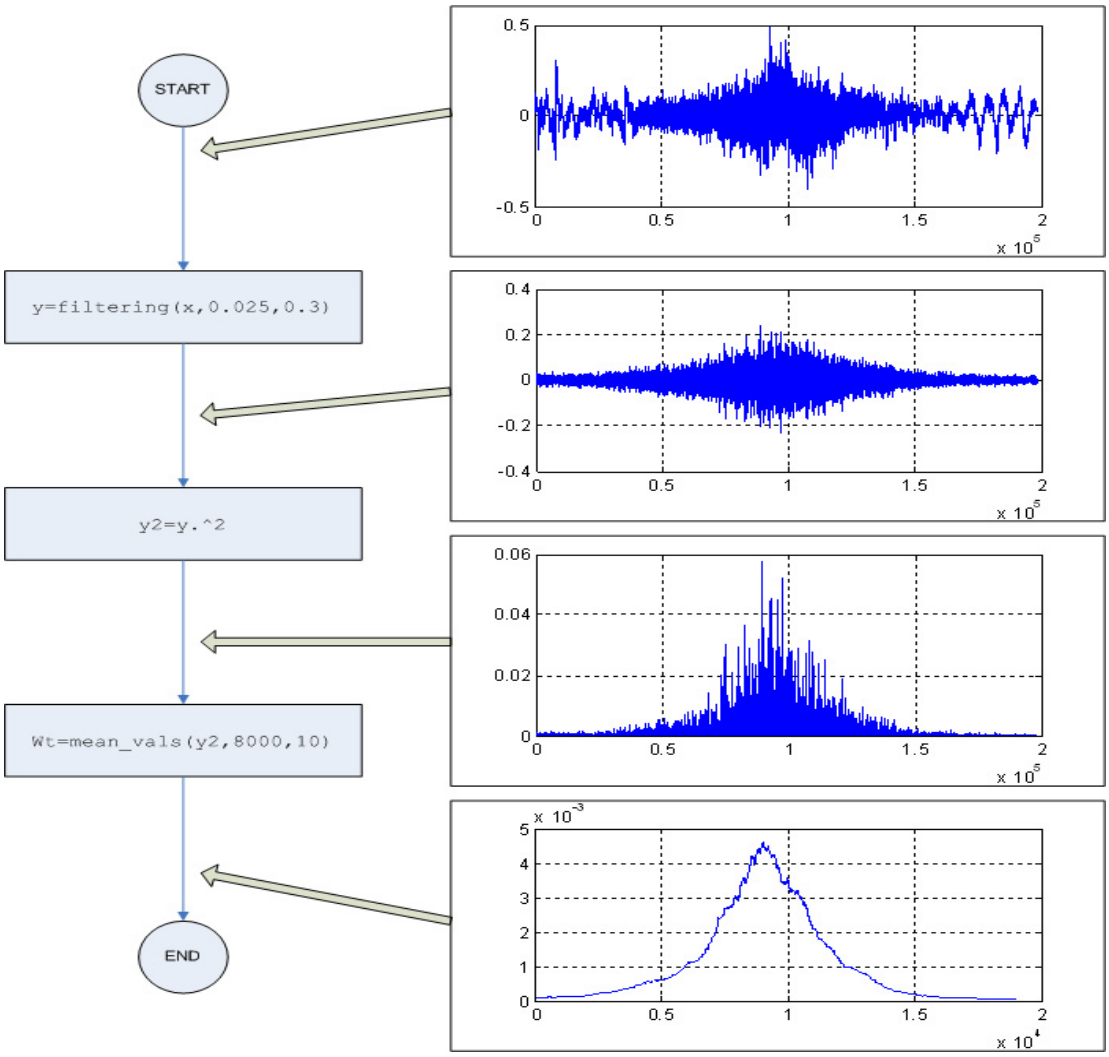

Figure 7. Block-scheme of acoustic car signal processing

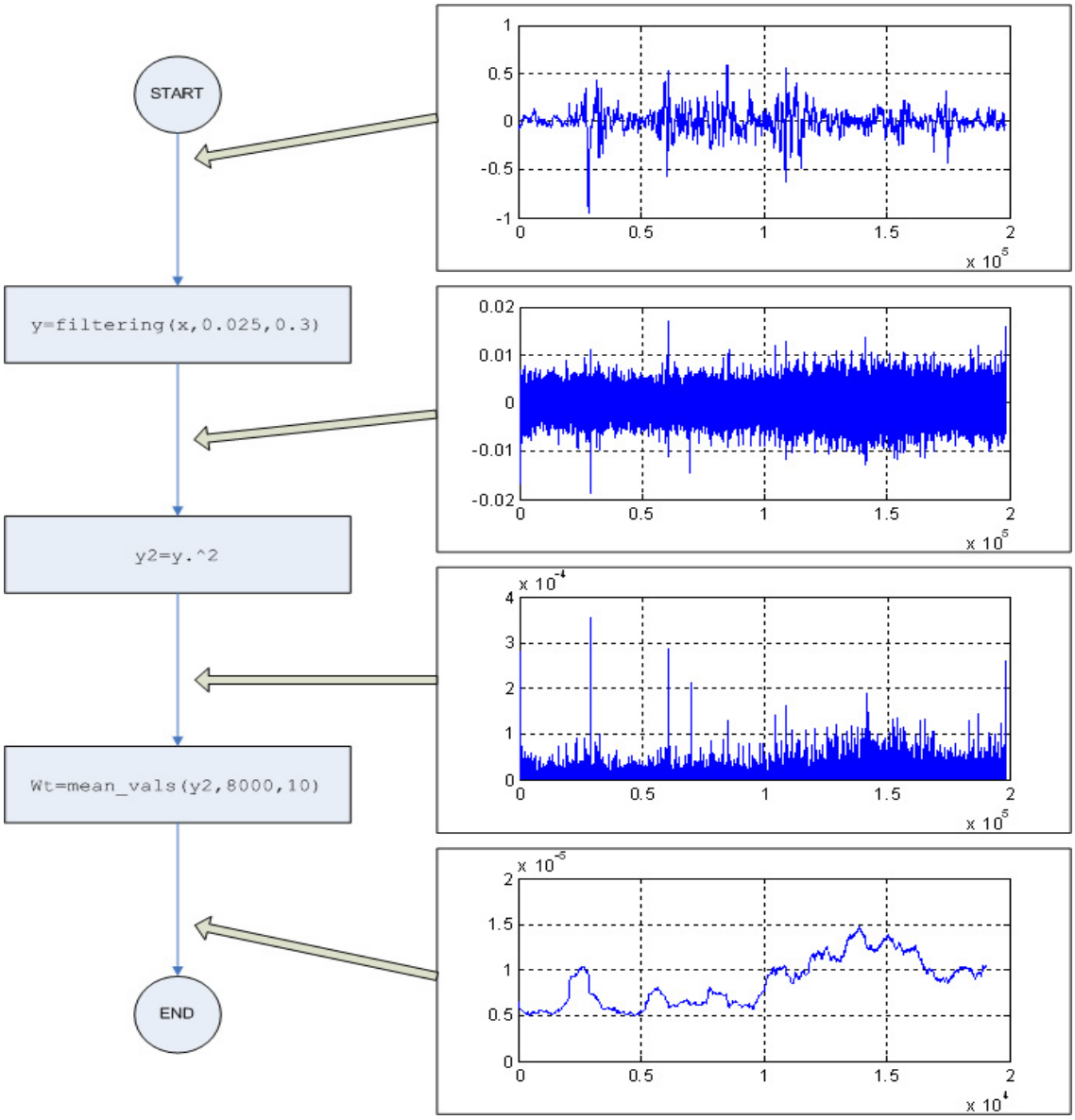

Figure 8. Block-scheme of acoustic wind signal processing

After performing such operations the ratio between the signal of wind and the signal of the car has very low settings, though the pulse of the wind signal before the processing is several times greater. Maximum of signal of the car is now 300 times higher than the highest point of the wind that makes it possible to state certainly the presence or absence of a vehicle in the segment of the transport network, i.e. use the elementary amplitude detector.

We must pay attention to the fact that the signals have been registered in the absence of pedestrians on the free stretch of road one-way traffic, where vehicles are moving at the maximum permissible speed. The effects of extraneous sources of sound, motion with low velocity dense mass of vehicles in traffic "bottleneck" and the noise from vehicles in opposite directions – these all are the factors of effectiveness of the acoustic method, which is expected to detail study in future.

5. Conclusions

As the result of studies it has been found that the acoustic method can be used for detecting of moving vehicles, therefore, the algorithm for determining the moving vehicles based on digital processing of acoustic signals is useful for surveillance. The advantages of this method are as follows:

- Low cost of equipment, what helps to minimize the financial cost for full-scale implementation;
- Autonomy of the system;
- Mobility and flexibility of the system;
- Ability to work in all weather conditions.

Unfortunately, this method is working well on the road with one lane in only one direction at absence of interferences. The most perspective creation of mobile and low-cost measurement system is a combination of acoustic sensors, longitudinal and transverse directions with observation data from WEB-camera making an additional influence research of various interferences. Also, the entire system must be completely manipulated (with the possibility of full control), which requires additional studies to determine the necessary protection level of data and all transmission channels.

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