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INTELLIGENT TRANSPORT SUBSYSTEM FOR ESTIMATING THE TRAFFIC DENSITY AND ITS COMPOSITION BASED ON ARTIFICIAL NEURAL NETWORKS AND PARALLEL COMPUTING

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ABSTRACT

The article describes the intelligent transport systems trends and identifies their perspective directions. Special attention is paid to the function principle of the intelligent traffic density estimation and vehicle classification subsystem. A new approach for improving the speed of this subsystem by the instrumentality of the GPUs (Graphics Processing Unit) and parallel computing is suggested. Different transport detectors were analyzed to select the most useful one for further use in the subsystem. The intelligent subsystem has been developed to estimate the traffic density and its composition in order to integrate it with conventional video surveillance systems used for violations video recording.

1. INTRODUCTION

The continuous population growth, coupled with the automotive industry development made it necessary for the implementation of Intelligent Transport Systems (ITS). ITS is a core part of intelligent logistics and IoV (Internet of Vehicles). Previous approaches, such as widening roads, increasing their number, have become useless. This is especially evident in the large cities of the United States of America (USA) and China [1]. The efficient service of the existing road networks and their optimal development required the introduction of modern high-tech solutions. The integrated implementation of technologies and automation tools focused on providing optimal transport services to traffic participants has become increasingly used in the world. ITSs are widely implemented today and continue to develop in Korea, Japan, the USA, Germany, Australia, and other countries [1, 2].

The mathematical models and algorithms that underlie the ITS began to be developed in the middle of the 20th century. However, the widespread and integrated implementation of automation has required technologies that have become available only recently. Nowadays ITS are widely used for road safety. Here the leading position is occupied by complexes of photo and video recording of traffic rules violations. The second actively developing area of ITS is the automatic traffic control system (ATCS) [3-8].

The next stage in the development of ITSs is solutions in the field of management and dispatching of public transport and multimodal passenger transportation. The purpose of such systems is to provide comfortable travel on public transport. This will reduce the number of vehicles on the streets, minimize congestion, create comfortable conditions for residents, and the development of the large cities economy.

Recently, much attention has been paid to safety in transport systems. For example perimeter defender (protecting the perimeter of the object)， aggression detection, gunshot sounds, glass breakage， smoke and fire detection， inspection and response to incidents in real-time, etc. Such systems can be used both independently and as part of the ATCS. The latter can significantly improve the efficiency of traffic management with a rapidly growing vehicles fleet.

Currently, a large number of automated transport systems are in use that allow traffic control. These systems make it possible to effectively manage traffic, but they need continuous information about the traffic density in real-time and its identification (for example, the composition of traffic: trucks, minibusses, cars, motorcycles, bicycles, pedestrians, etc.). Information is collected mainly based on infrared and radar detectors, which have certain disadvantages. At the same time, more and more video surveillance systems appear on the roads, which are used mainly for violations video recording. However, the potential of such systems is much greater: they can be integrated in smart city applications and IoV or used for automated analysis of the traffic situation with statistical information collecting, which is very necessary for rapidly growing cities. Therefore, there is a need to ensure continuous moving objects monitoring/control on various road sections, regardless of weather conditions and time of day, which is also a far from solved problem in many cities.

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The objective of this work is to develop ITS for estimating the density and composition of the traffic in order to integrate it with conventional video surveillance systems used for violations video recording.

2. GLOBAL TRENDS OF THE ITS DEVELOPMENT

The traffic congestion problem and optimization of urban and suburban traffic are similar only at first glance. If we study the sources of problems, then each city will reveal its unique specifics. It includes the current traffic structure, the locations of the attraction centers of citizens (workplaces, sports and cultural complexes, train stations, other places of mass stay of people), the population income level, the seasonality factor, especially for cities located in tourist zones and pilgrimage places, and the current level of region automation development. As for the latter, the process of creating ITS in the city cannot be separated from the process of automation and informatization of other city services, and it differs very much in different cities, even within the same country [1, 2].

Recently, the following general trends have been observed in the ITS development:

- providing city services with up-to-date information about the current state of the transport infrastructure by creating a measurement system based on Internet of Things (IoT), Industrial Internet of Things (IIoT), and IoV technologies;
- adaptive control systems implementation for traffic lights, bollards, and other road infrastructure devices based on information about traffic congestion in order to redirect and synchronize traffic flows, prevent the traffic jams formation;
- intelligent systems implementation for: forecasting the transport situation in the city, costs optimization of the transport infrastructure development by predicting possible results of decision-making;
- the use of intelligent systems for modeling the transport situation in the design of roads, intersections, crossings, traffic lights, and other tasks;
- monitoring systems implementation in order to detect the location and current state of urban transport, creation of "smart" stops;
- informing citizens systems creation about the current roads congestion and the condition of parking lots (free places availability), including mobile applications;
- transport flows synchronization of various types (buses, subways, trams, etc.), to reduce the time that passengers spend on transfers;
- introduction of unmanned road transport and railway systems, including the metro;
- automation of management processes and accounting of the work of contractors engaged in snow removal on roads, crossings, and stops, adaptive management of cleaning taking into account the current weather and transport situation;
- the use of unmanned aerial vehicles/drones for traffic monitoring, the snow removal quality on roads and crossings, the quality of road surface, etc.;
- the transition to the use of wireless technologies (communications, power supply).

All the above trends in the ITS development require obtaining information about the density and composition of vehicles and pedestrians, which confirms the relevance of this work.

3. COLLECTING INFORMATION FACILITIES OF THE TRAFFIC. VIDEO SURVEILLANCE SYSTEMS

Various types of transport detectors are actively used in ATCS to collect information: contact, photoelectric, ultrasonic, magnetic, etc. A very interesting analytical review of transport detectors was conducted by AGA Group (Boston, USA) [1, 2]. The tests were carried out on video cameras as well. Table 1 shows the advantages and disadvantages of the most commonly used types of detectors.

As can be seen from Table 1, each technology has its advantages and disadvantages. And video surveillance technology looks pretty promising. It has great advantages over other types of detectors, and some disadvantages can be successfully eliminated. So, today there are quite effective algorithms [9 - 11] that allow you to neutralize the negative effect of the external environment on the camera, and modern IP cameras allow continuous monitoring day and night and simplify the video signal processing.

Table 1 *Advantages and disadvantages of some measurement technologies*

Technology	*Advantages*	*Disadvantages*
Passive/active infrared	*Easy to install* *Reliability* *Resistant to environmental influences*	*It Covers 1-2 lanes* *Weather limiting for active infrared sensors is usually similar to the human eye* *The classification is based on the study of the height of the object, not the length.* *Passive sensors are impaired by rain and snow*
Radar	*Severe climatic conditions do not affect the detector's performance* *Direct speed measurement* *Serves several lanes at the same time*	*Poorly works at intersections when calculating the volume of traffic*
Ultrasonic	*Easy to install* *Serves several lanes at the same time*	*Operation deteriorates with strong temperature fluctuations and turbulence in the airflow* *Measurement of lane occupancy on paths at high speeds can be degraded*
Passive acoustic	*Passive detection* *Serves several lanes at the same time*	*Decreased accuracy of readings when operating at low temperatures*

Technology	*Advantages*	*Disadvantages*
	Insensitive to precipitation	*Some models of this technology are not recommended for use in "stop-start" driving conditions* *Deteriorates performance in the presence of extraneous sound interference*
Video	*Serves several zones and several lanes at the same time* *Easy to install and reconfigure the detecting zones* *The ability to collect large amounts of data* *Wide detection area*	*Exposure to harsh climatic conditions, shadows, sudden movement of vehicles from one lane to another, icing, day and night change can affect the operation of cameras* *Some camera models are susceptible to strong winds* *Large objects of observation can obstruct small*

Video surveillance systems are increasingly attracting the interest of researchers and developers. Such systems are being introduced into everyday life, including transport, and video cameras are becoming more affordable.

4. PROBLEMS OF OBTAINING DATA ON THE COMPOSITION OF A TRAFFIC STREAM AND CALCULATING ITS CHARACTERISTICS

At the moment, various types of sensors are actively used in the ATCS to collect information. However, their use can be very expensive and ineffective due to rapid wear, narrow viewing angle, and low noise immunity [12 - 14]. In addition, sensors and software for them are closely connected/integrated with the entire ATCS, increasing the complexity of their installation and maintenance. Therefore, in recent years, it is video surveillance systems that have increasingly attracted the interest of researchers and developers [1, 2, 15, 16]. In addition, based on video surveillance systems, it is possible to develop independent automated systems for estimating the density of the traffic flow and its composition. They can be used separately from any ATCM, which is important for relatively small but rapidly growing cities.

It is also necessary to consider in more detail the problem of continuous monitoring/control of moving objects on various road sections, regardless of weather conditions and time of day. Analysis of video image processing systems and object recognition on it showed that the process of video image processing and analysis is identical for all such systems [10, 11, 17]. It consists of several stages: foreground selection, selection and classification of moving objects, recognition, and description of the found objects motion.

At each stage, you can use different algorithms with their advantages and disadvantages. For example, at the stage of foreground selection, you can use the methods of the time difference, optical flow, background subtraction, etc. [10, 11, 17]. Background subtraction methods are quite effective, but resource-intensive and somewhat latent in updating the background model, optical flow algorithms are sensitive to noise, etc. At the last stage, when it is required to recognize which vehicle has entered the surveillance area (and whether it is a vehicle at all), it may be necessary to use artificial neural networks (hereinafter neural networks) of different topologies, depending on which algorithms were used in the previous stages and what class the vehicle is recognized. The problem is that under different environmental conditions (for example, changing illumination), it is necessary to use different algorithms for digital video processing.

In this case, the main load is assigned to the first stage methods, the foreground selection stage. The quality of the methods work of subsequent stages, and hence the entire system as a whole, largely depends on how accurately the chosen method allows to separate the points of the image belonging to the moving objects from the points of the static background [10, 11, 17]. It is the methods of the first stage that are greatly influenced by the external environment, and they are, as a rule, the most resource-intensive in the entire chain of video processing methods and moving objects detection [10, 11, 17].

The problem can be solved by increasing the stability of video processing algorithms through the joint use of their various types, but this does not completely solve it, since the resource intensity of these algorithms increases the video processing time.

Another problem is related to the stage of recognition of moving objects. At this stage, neural networks are usually used. For example, what kind of moving object is detected - a vehicle or a person - if a vehicle is detected, then what class it is (car, truck, bus, etc.), etc. This increases the resource intensity of the system and slows down its performance.

Given the significant progress in the field of multicore and multiprocessor systems, it is possible to propose new ways to solve these problems, based on parallel, distributed, and cloud computing.

Thus, it is possible to single out the following urgent and closely interrelated problems facing the developers of an automated system for estimating the traffic density and vehicles classifiying.

1. The number of vehicles is increasing, which leads to a rise in traffic intensity and more frequent congestions on the roads of large cities. It is necessary to create automated traffic control systems to effectively manage it.

2. Existing traffic control systems do not always use effective facilities for collecting information on traffic density and its composition, which arouses interest in the use of other more effective means - video signal processing. In addition, it is not always necessary to deploy the entire ATCM. It is enough to do with the use of an automated system for estimating the traffic density and its composition based on a video surveillance system.

3. When developing an automated system for estimating the traffic density and its composition based on video surveillance systems, it is required not only to focus on existing systems abroad but also to look for some ways to develop an effective solution of software import substitution (as the majority of ATCM are bought abroad and very expensive) or improve/modify them to ensure continuous monitoring/control of moving objects regardless of the time of day and weather conditions.

5. AUTOMATED SYSTEM FOR ESTIMATING THE TRAFFIC DENSITY AND ITS COMPOSITION BASED ON NEURAL NETWORKS

The system for estimating the traffic density and its composition consists of three modules (Fig. 1): a detector of moving objects, a vehicle identifier, and a traffic density calculator. The moving objects detector covers the next tasks: foreground selection, moving objects detection, and their classification. In the vehicle identifier, moving objects are recognized based on neural networks. They have already been successfully used in various ATCMs for traffic control (for example, adaptive traffic lights) and recognition of license plates of traffic offenders' vehicles. The Traffic Density Calculator computes the density using information about the vehicles successfully recognized by the Vehicle identifier.

Further, only the first two modules, which are of greatest interest, will be considered, and the general scheme of the system operation will mean the general scheme of operation of these two modules. The general scheme of the system operation is shown in Fig. 2.

A surveillance video camera transmits data about the traffic situation, which successively go through all stages of processing, then the identified moving objects are recognized.

6. WAYS TO IMPROVE THE AUTOMATED SUBSYSTEM FOR ESTIMATING THE TRAFFIC DENSITY AND ITS COMPOSITION

To increase the speed of the system and the degree of its independence from changing environmental factors, we can use modern means of parallelizing processes based on multi-core processors or/and video cards [13, 14, 18], since the development of multi-threaded and multiprocessor programming tools allows us to quickly and cheaply organize high-performance and at the same time universal computing power, replacing, for example, specialized video processors with modern universal video cards, which have a fairly high potential in the field of parallel computing. In addition, cloud technologies allow the addition of more powerful dedicated servers and distributed computing technology.

It is possible to increase the degree of independence of the subsystem from the external environment by increasing the stability of foreground highlighting algorithms through the joint use of their various types. However, this will not increase the system's performance but will decrease it. Work at this stage can be accelerated by dividing video frames into fragments, for example, according to the number of bands being monitored (Fig. 3). Each fragment will be processed by a separate process/thread on the local computer or sent to a specialized cloud and distributed computing server (which requires additional financial costs and maintenance services).

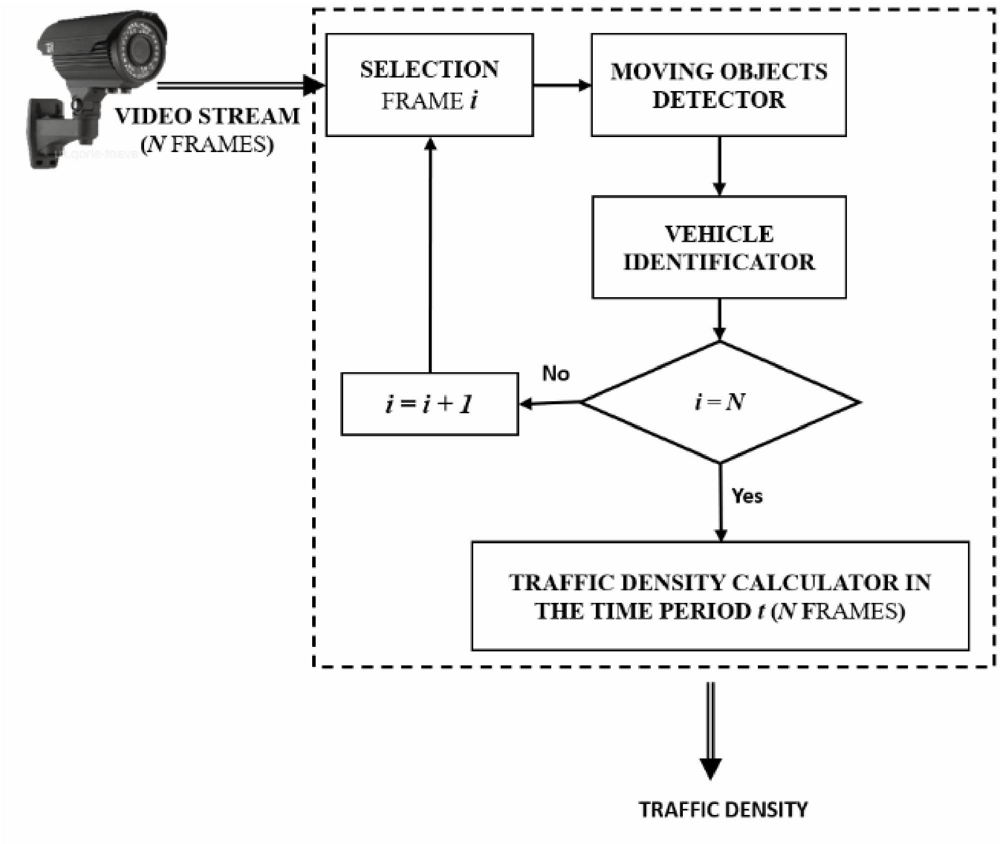

Fig. 1. Functional model of the developed intelligent subsystem

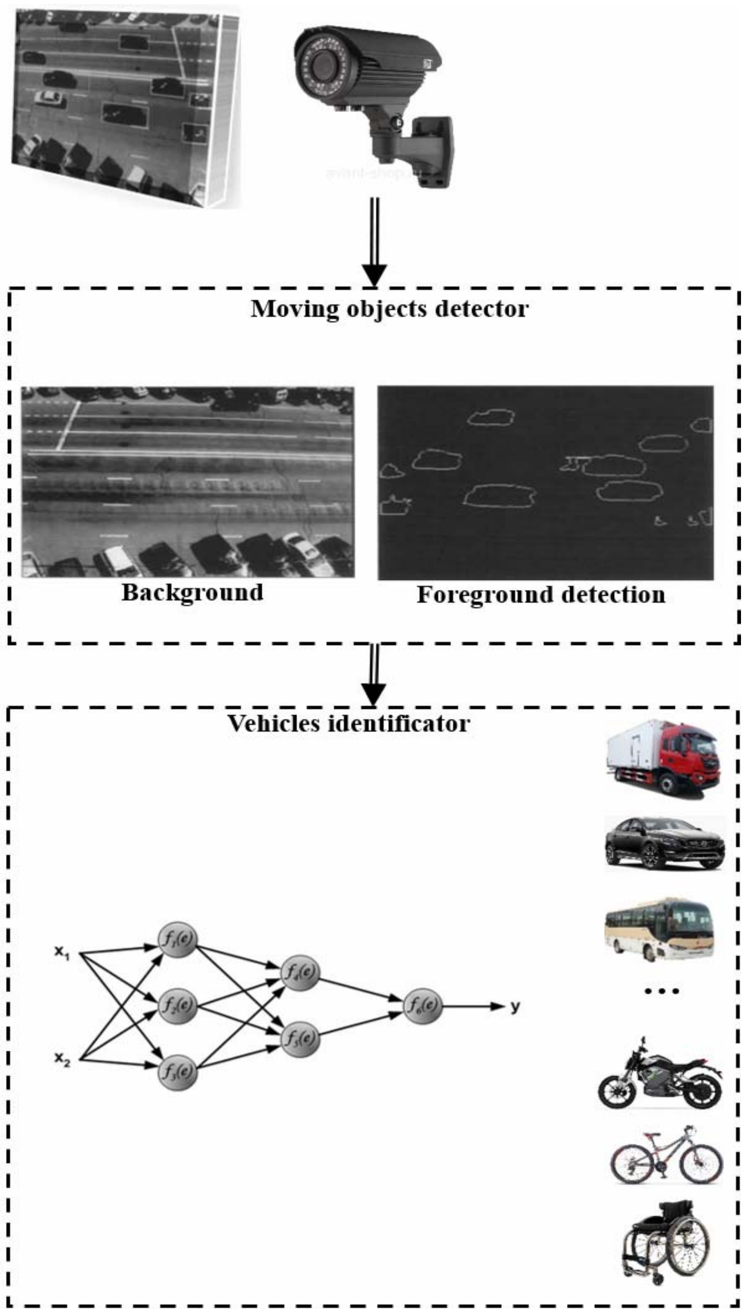

Fig. 2. General scheme of the subsystem operation

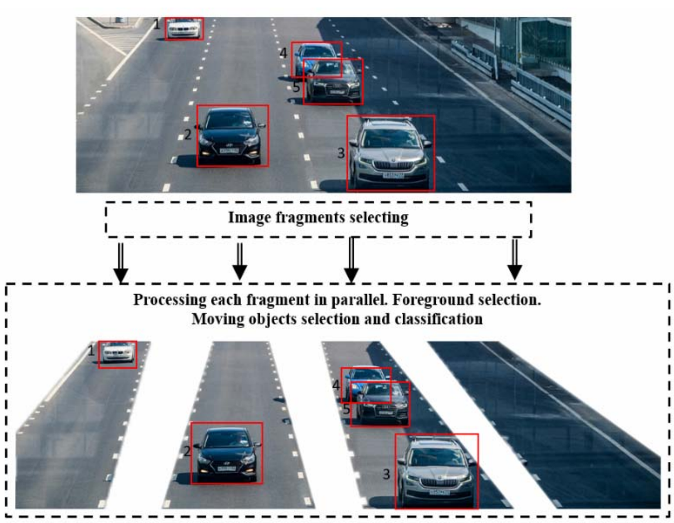

Fig. 3. Splitting the frame into fragments for their subsequent parallel processing at the first and second stage

An unresolved problem remains that arises at the last stage of the system's operation - the stage of recognizing moving objects. In the case when the number of vehicles falling into the observation area in a short period of time is large, the neural network has to quickly recognize a huge number of moving objects, this will lead to a decrease in system performance and increasing consumption of resources. There is also a problem with training such a network. It can take quite a long time for a local server. If the subsystem functions in real-time, then in this case, it is necessary to send a high-quality video stream to a specialized cloud server over an ultra-high-speed network (4G / 5G or fiber). This also leads to additional financial costs and the lack of the possibility of independent autonomous functioning.

It is possible to speed up the system by using parallelization using multiprocessor systems. You can do the following: distribute the task across multiple neural networks. To do this, each neural network needs to be trained to distinguish a limited set of moving objects. Relatively speaking, each neural network will become an "expert" on its group of objects (cars, trucks, buses, etc.). Each such network will operate within a separate process or thread.

This approach has already been used successfully for static images. In particular, to speed up the process of hieroglyph recognition [19] (Fig. 4).

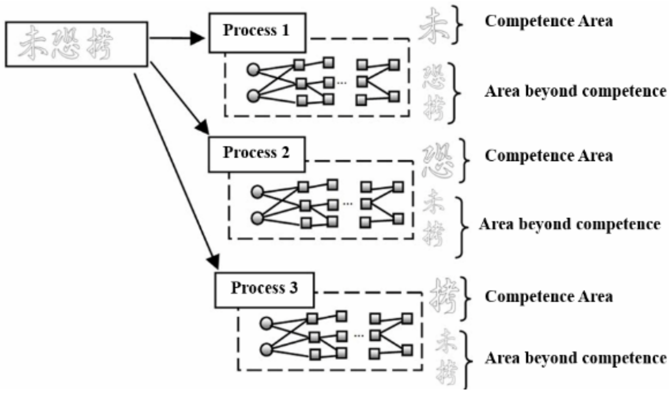

Fig. 4. Images distribution over neural networks by parallelization on the example of the recognition of 3 hieroglyphs problem

The distribution of data among processes is handled by a special dedicated process, which can be conditionally called the main one. After distributing the data, each process performs work on its data block and then sends the result to the main process, which summarizes all received data and makes a decision on the recognition result. As a result of recognition, the main process must select the result of the neural network that is most confident in its answer. In this scheme, each neural network will have a much simpler structure than one universal multilayer neural network, it will be able to train faster, it will give a high-precision result faster.

The general scheme of the system operation, in which the process of digital processing of video images and object recognition is parallelized, is shown in Fig. 5. A frame coming from a video camera is divided by the main process/stream, for example, into two fragments. These fragments are transferred to two constantly running processes (threads), which simultaneously process the video image (the first and second stages). At the output of each of these processes (streams), there will be many objects with a certain set of characteristics. For each object, a new process (thread) will be spawned to recognize it. It, in turn, will parallelize the object recognition problem on a set of neural network experts, which will lead to the generation of new parallel processes or threads. Each neural network, having analyzed the characteristics of the selected object, will return the process (thread) that allocated the task, the value of the probability that it belongs to a vehicle of a certain class. This process (thread) will decide what class the identified vehicle is, and will transfer this data to the process (thread) that generated it, i.e. process (stream) of video image processing. The latter, in turn, will accumulate these data until a certain moment, for example, before the expiration of the time period t, after which it will transfer them to the traffic density calculator.

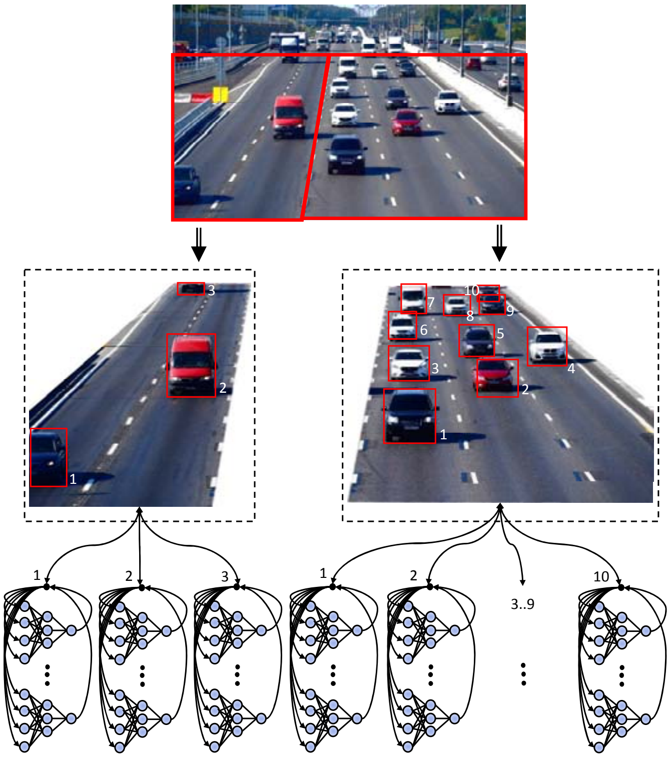

Fig. 5. Improved scheme of the developed system

7. CONCLUSION

This paper describes the use of artificial neural networks in conjunction with algorithms for digital video processing to create an automated subsystem for estimating the traffic density and its composition. A new approach for improving this system by using parallel computations is proposed.

The proposed scheme of the intelligent transport subsystem allows achieving high performance while maintaining resistance to constantly changing environmental factors. However, this scheme implies a large load on the hardware, especially with a sharp increase in the number of moving objects in the observation area. For more efficient operation of the system, it is recommended to use universal video cards, which parallelize and speed up the process of solving complex mathematical problems, instead of specialized hardware.

The developed intelligent subsystem is focused on further integration with conventional video surveillance systems used for violations video recording and makes it possible to increase the efficiency of traffic management in cities, reducing the labor intensity of installation and maintenance. It is also possible to use this system as a module within the ATCS, IoT, IIoT, and IoV.

The developed approach and automated subsystem are successfully used in the educational process of School of Information Engineering (Xian Eurasia University (Xian, China)).

Future work directions may include extending the proposed algorithm and ITS for global traffic management, including the optimization of all trends described in chapter 2.

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