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Automating Road Traffic Monitoring Using Computer Vision

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ABSTRACT

The objective of the article is to describe application of computer vision and artificial intelligence technologies for solving the problems of road infrastructure design.

The article evaluates the traditional methods of quantitative and qualitative analysis of traffic flows in terms of labour intensity and accuracy using the method of comparative analysis, the advantages and disadvantages of the considered methods are indicated. A new method of traffic flow analysis using unmanned aerial vehicles and computer vision technology based on convolutional neural networks is proposed. The considered method makes it possible to fully automate collection and analysis of data on traffic flows. The article describes the first application of the proposed method when performing transport and economic surveys within the framework of the design of «Northern bypass of the city of Perm». The advantages of the applied method in relation to the traditional ones are described. To implement this project, software was developed for analysing traffic flows using video materials.

Further, traffic monitoring is considered, its goals and objectives are described, the necessary functionality of the road traffic monitoring automation system is indicated, the traffic parameters that it should determine are listed. The methodology for implementation of an automated traffic monitoring system based on video materials on a section of the road is considered.

A presented project of a traffic monitoring system makes it possible to extend the previously considered approach to the entire road network. Technologies are described that make it possible to implement this system based on video analytics of materials from CCTV cameras. A method for vehicle re-identification is proposed, and the implementation of this method is demonstrated. The method allows building a correspondence matrix of vehicles recorded by CCTV cameras located on different segments of the road network, as well as determining all traffic parameters for the entire street and road network.

The conclusions outline the prospects for development of the developed software in terms of application in intelligent transport systems.

Keywords: *road traffic, monitoring, traffic data, traffic modelling, transport and economic research, computer vision, artificial intelligence, video analytics, traffic parameters, intelligent transport systems.*

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The *objective* of the article is to consider the opportunities that computer vision and artificial intelligence technologies can provide for the transport industry. For the first time in Russia, transport and economic surveys were carried out using artificial intelligence, as part of the design of «Northern Bypass of the city of Perm», carried out by JSC Giprostroymost Institute. Traffic intensity was recorded through video filming from an unmanned aerial vehicle and subsequent analysis of video materials using TrafficData software package according to the *methodology* of transport research.

Modern methods of recording of traffic intensity

Professor of MADI [Moscow automobile and road construction state technical university] M. R. Yakimov analysed in detail the «modern» methods of accounting for traffic intensity in his monograph [1]. At the example of research carried out in Perm, professor Yakimov considered three main methods used in practice:

1. Manual method: direct data collection is performed by the accountants. «These are specially trained people who stand at intersections during the day and measure traffic from different directions».

2. Semi-automatic method: data collection is carried out using video equipment, which allows video filming at the entire surveyed intersection, and the collected information is processed manually.

3. Automatic method: with the help of transport accounting detectors. The method is relevant for the sections of the road network where the equipment is installed.

The methods were evaluated according to the following indicators:

• One-time costs.

• Current costs.

• Time costs for collection/processing of information.

• Assessment of quality of data collected.

The method of comparative analysis has shown that the third method is the costliest from a financial point of view, since it requires installation of sensors for each lane. Accordingly, the first method is the least expensive. An hour was spent on processing the collected materials according to the first method, three hours were spent according to the second method, and 15 minutes were spent according to the third method. The second method is the most accurate, because it allows to count and re-count cars from video recording several times, which eliminates the factor of human error. Therefore, the semi-automatic method was taken as a reference. When compared with the standard, the first method showed relative deviations from 3 to 33,5 %, the third – from 7 to 57 %. Such errors of the third method are caused by inaccuracies in reading information and imperfection of the devices available to researchers.

Hence, comparative analysis has shown that to obtain initial information for single intersections, it is necessary to use a semi-automatic method of collecting information. If the use of a semi-automatic method of collecting information is impossible at the intersection under study, then it is advisable to use a natural method of collecting data. Data collection with the use of transport metering sensors showed unreliability of data received, the errors are more than 20 %.

Experience of application of computer vision technology and artificial intelligence

With the advent of quadcopters in our life, the method of video recording has become even more relevant, since now we are not tied to the places where cameras for monitoring traffic conditions are installed and can cover the entire intersection, which allows us to simultaneously record movement of cars in all directions. However, statistical analysis of the costs of similar tasks has shown that processing of such video materials presents a certain complexity. For example, it turned out to be rather difficult to determine the traffic intensity in each of the nine directions at the roundabout in the gate of General Butkov Street (Kaliningrad) shown in Pic. 1.

The development of computer vision and machine learning technologies has made it possible to automate this task. The developed software, built based on the latest convolutional network architectures, made it possible to bring the semi-automatic method described by M. R. Yakimov to a fully automated one. Once again, artificial intelligence has made it possible to save a person from routine tedious work.

With its help, labour costs for collecting data on traffic flows at an intersection or on

Pic. 1. Surveying a circular intersection from a quadcopter (provided by JSC Giprostroymost Institute).

a road section are significantly reduced. As a result, within the framework of ordinary transport and economic surveys, using the method of simple mathematical analysis, it was possible to deduce real distribution of traffic intensity throughout the day. Now there is no need to use the coefficients of unevenness to determine the average daily intensity given in [2]. It is known that these coefficients are determined based on measurements made on Moscow Ring Road using sensors [3]. Essentially, this data constitute a particular case and cannot be used universally.

In this way, data collection at an intersection or road section is automated by *analysing video images using computer vision*, for example, in order to optimise traffic flows using the method of *mathematical modelling*.

In Russia as part of implementation of the state program «Safe and High-Quality Highways», the Ministry of Transport of the Russian Federation approved orders on the need to monitor road traffic [4; 5]. To implement these activities in the country, it is necessary to automate macro-research.

Similar systems have recently appeared abroad, especially in Europe and North America, where traffic monitoring is regularly carried out along the main transport arteries of agglomerations, as well as in cities. The products of such companies as DataFromSky (Czech Republic), GoodVision (Great Britain), Miovision (Canada), etc. are excellent examples there-of.

Road traffic monitoring

To begin with, let us formulate the goals of traffic monitoring. In Russia in conformity with the analysis of the documents [4; 5] they are as follow:

• To assess the current quality of traffic management.

• To determine priority measures to improve quality of traffic management of the road network.

• To evaluate the effectiveness of measures taken to improve quality of traffic management.

To achieve these goals, it is necessary that the road traffic monitoring system (RTMS) could solve the following tasks:

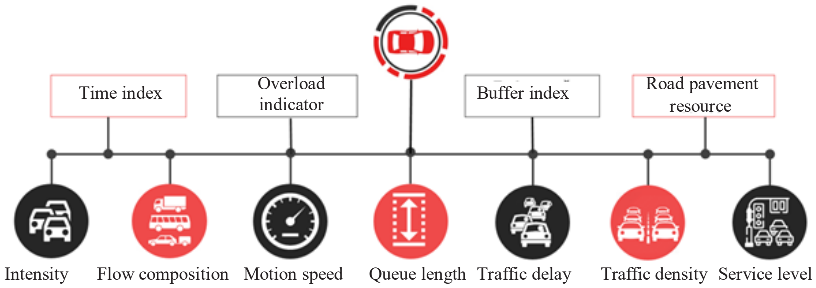
• To identify the parameters of road traffic.

• To accumulate data on traffic parameters.

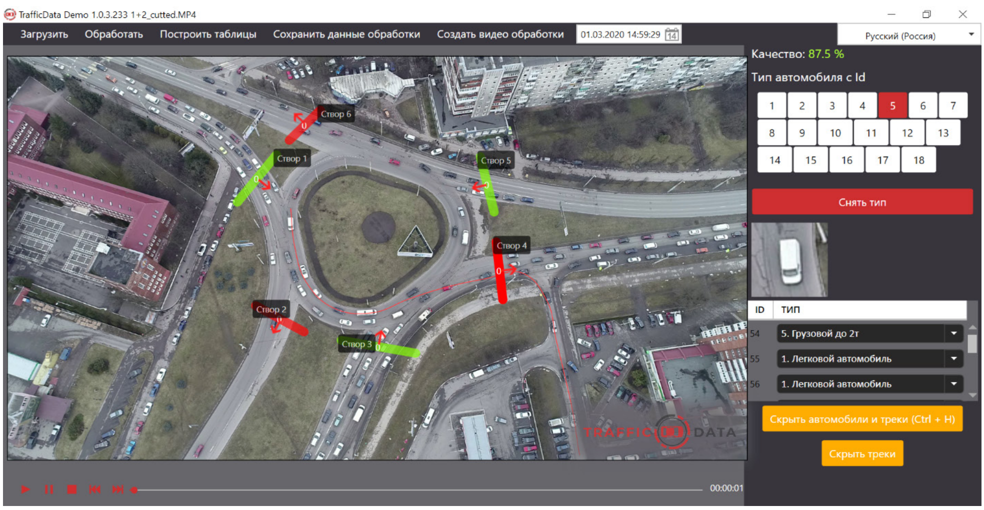
• To generate reports on changes in traffic parameters in a visualised form.

So, we are talking about the parameters of the road traffic specified in [2; 5] and shown in Pic. 2.

To solve the problems described above, the cited orders of the Ministry of transport of Russian Federation were systemised and adapted to automated implementation, and a methodology for automating traffic monitoring was developed. Also, based on this methodology, a project for the organization of RTMS was developed, which allows determining all traffic parameters to assess quality of traffic not only on each section of the road (intersection, between intersections), but also on the entire highway, or road network in 24/7 mode.



Pic. 2. Road traffic parameters (author's drawing).



Pic. 3. Arrangement of gates on video using the interface (provided by the author).

To solve the assigned tasks, RTMS must have the following functionality:

• Video filming of the road network around the clock.

• Processing video materials in streaming mode at a speed higher than the incoming video.

• Reading of license plates of vehicles.

• Identifying of traffic parameters.

• Development of a data base of traffic parameters for all road sections and for the entire observation period.

• Ensuring work with database (averaging, filtering, development of reports).

Let us see how this functionality is implemented in the developed software system.

Flow intensity

Traffic intensity is determined according to directions. The directions are set by the gates indicated by the user in the video (Pic. 3). There are three types of gates: entrance, exit and through ones.

Flow composition

The qualitative analysis of traffic flow, supported in the developed software considers the requirements of both the order of the Ministry of Transport of the Russian Federation [5] and the standards for suburban roads [6] and for urban roads [7]. Thus, our software complex recognizes 21 types of vehicles and pedestrians.

Motion speed

By video image it is possible to determine:

• Instantaneous speed at each point of the trajectory.

• Average speed in the section between gates.

• Speed detection capacity ensured with 85 %, 95 % rate.

A heat map is available for visual display of distribution of motion speeds at the intersection.

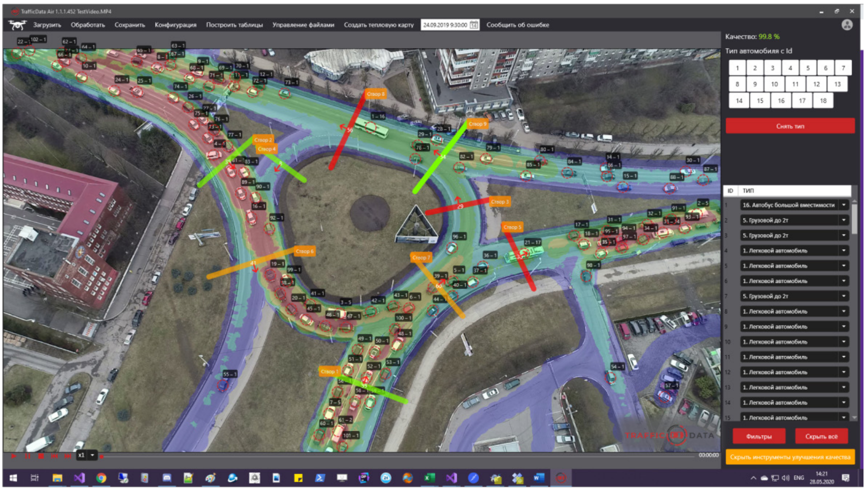
Traffic density

Traffic density for a road section is determined according to the formulae:

Table 1

Description of detected road users (from the video processing report generated by the software complex)

Abbreviation	Explanation
1. Passenger car	1. Passenger car
2. Minibus	2. Minibus
3. Motorcycle and moped	3. Motorcycle and moped
4. Bicycle	4. Bicycle
5. Small truck (van)	5. Small truck (van)
6. 2-a truck 2–6 t	6. Two-axle truck of 2–6 t
7. 2-a truck 6–8 t	7. Two-axle truck of 6–8 t
8. 3-a truck 8–14 t	8. Three-axle truck of 8–14 t
9. 3-a truck > 14 t	9. Three-axle truck over 14 t
10. 4-a truck	10. Four-axle truck
11. 4-a r-train (2-a truck + t)	11. Four-axle road train (two-axle truck with a trailer)
12. 5-a r-train (3-a truck + t)	12. Five-axle road train (three-axle truck with a trailer)
13. 3-a sem. r-train (2-a sem. t + st)	13. Three-axle semitrailer road train (two-axle semitrailer tractor)
14. 4-a sem. r-train (2-a sem.t + st)	14. Four-axle semitrailer road train (two-axle semitrailer tractor)
15. 5-a sem. r-train (3-a sem.t + st)	15. Five-axle semitrailer road train (three-axle semitrailer tractor)
16. 5-a sem. r-train (2-a sem. t + st)	16. Five-axle semitrailer road train (two-axle semitrailer tractor)
17. 6-a sem. r-train	17. Six-axle semitrailer road train, extra large bus
18. Car with >= 7 axles	18. Car with seven or more axles
19. Bus of small capacity	19. Bus of small capacity
20. Bus of average capacity	20. Bus of average capacity
21. Bus of large capacity	21. Bus of large capacity
22. Trolleybus	22. Trolleybus
23. Articulated bus/trolleybus	23. Articulated bus and articulated trolleybus
24. Pedestrians	24. Pedestrians



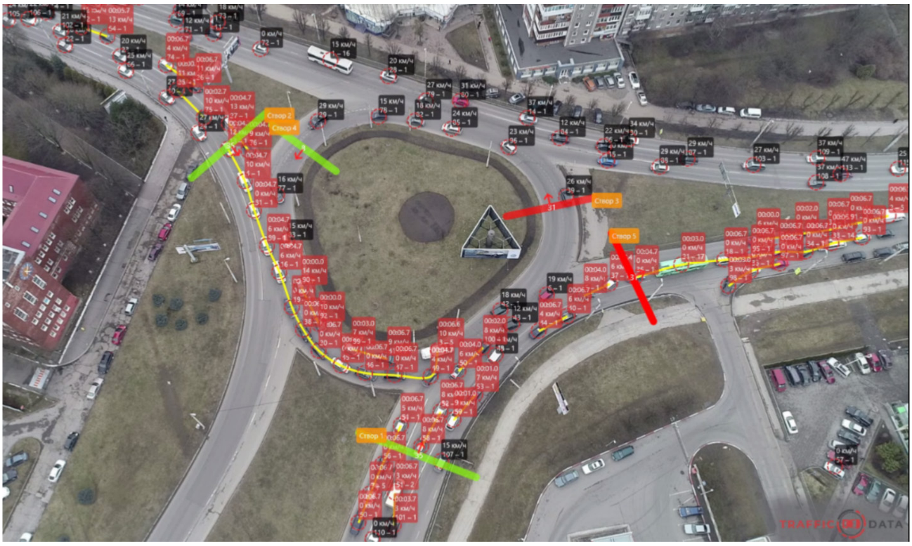
Pic. 4. Heat map of distribution of motion speeds on the road section (provided by the author).

$\rho = \frac{1}{\bar{I} \cdot \bar{V}}$, cars, normalized to passenger cars, per kilometre,

where $\bar{I}$ is average time interval between normalized cars, and $\bar{V}$ is average motion speed of vehicles at the road section.

Queue length

The developed software complex allows determining the length of the queue and time spent by a car in the queue in the considered direction, as well as the parking time using the video image. The criterion for getting a car into



Pic. 5. Screenshot of visualization of queuing at the intersection (cars in the queue are united by yellow (lighter) lines, the labels change colour from black to red, time spent in the queue is displayed).

Pic. 6. License plate detection (left) and analysis of car traffic by video image (right). (License plate is partially retouched for publication).

the queue is the distance between cars which in the light is no more than 5 m.

Traffic delay

To determine traffic delay time, first it is necessary to determine time to overcome the road section while there is a free movement. The free movement criterion is set by the user as the minimum interval between cars at a speed of more than a threshold value. If there are no data on free movement, then they are determined through the maximum permitted speed on the road section.

Then, based on data collected from the video, the calculated traffic parameters are determined:

- Service level.
- Overload indicator.
- Time index.
- Buffer index.

Upon request analysis results are displayed in MS Excel.

Project of road traffic monitoring system

The project of RTMS for a highway of 1500 km, divided into 300 sections, was developed. The entrance and exit of each section is equipped with cameras. The system monitors traffic 24/7, fully automatically, responding to all requirements [4; 5].

To implement this project, two technologies were combined: license plate recognition and vehicle detection with video.

This allowed: first, to build a correspondence matrix, observing the car from different cameras, i.e. across the entire road network equipped with RTMS; second, to receive all the necessary data about the car from the video images without connecting to the traffic police database, which resolved the issue with personal data.

At the same time, after deep optimisation of computer vision algorithms, it became possible to reduce system requirements to such extent that it made it feasible to manage a network of 100 cameras with just a single server in streaming mode. The total cost of the system was only 100 thousand roubles/km.

Brief conclusions. The need for traffic data has matured so much that readiness was manifested to set up a person per each 300 m of road every year to collect those data [4], while quality of such data leaves much to be desired [1]. With the help of RTMS, with which the authors of the system propose to equip the network of surveyed roads, this data can be obtained every five minutes with an accuracy of 95 %.

To manage any process, it is necessary to have data about it. Only by regularly collecting complete and reliable traffic data we can move on to the creation of ITS. The described software system was created to solve that problem of data collection.

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