*International Journal of Engineering & Technology*, 7 (2.28) (2018) 230-233

International Journal of Engineering & Technology

*Website: www.sciencepubco.com/index.php/IJET*

***Research paper***

# Technologies for restoring the OD matrix elements based on the results of processing video materials obtained from the quadcopters

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**Abstract**

The article shows the technology of obtaining the initial data for modeling the movement of traffic and pedestrian flows on separate elements of the street-road network. The algorithm of automated calculation of traffic and pedestrian intensity based on the analysis of video data is given. The example of the city of Perm in Russia shows the technology of restoring the OD matrix elements based on the results of processing video materials obtained from the quadcopters.

***Keywords***: *Traffic Intensity; Modeling; Aerial Video; Intersection; OD matrix.*

## 1. Introduction

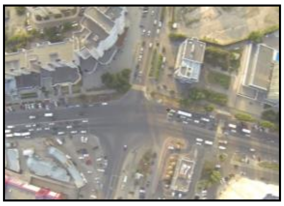
Transport models based on statistical data on the structure of transport demand in urban areas are the basis for transport planning, modeling and forecasting the traffic intensity. Such models are called macroscopic models. Such models are built for the whole municipal district, city, region or the whole country. However, for studying the work of individual elements of the road network and elements of the urban transport infrastructure, micromodeling is used. The initial information for micromodeling is the vehicular and pedestrian traffic [1].

The initial information on the vehicular and pedestrian traffic under a crossroads or a group of crossroads is preferably presented in the form of a OD matrix showing the number of vehicles or pedestrians moving in each of the possible directions of traffic through a crossroads or a group of crossroads [2, 3]. In this connection, the task of constructing algorithms for restoring OD matrix elements based on the use of modern technologies, including the analysis of video images obtained from the quadcopters, seems topical.

## 2. Problem formulation

At present, the problem of collecting information on traffic intensity on the city's road network for the development of traffic control schemes, modeling traffic situations and forecasting traffic conditions is very significant [4, 5].
To collect information about vehicular and pedestrian traffic, it is possible to do manual counting. In order to collect information on vehicular and pedestrian traffic at one crossroads, it is possible to attract only one operator, who can be located near the intersection and count the number of vehicles and pedestrians carrying out maneuvers of traffic through the intersection, and after that will build the OD matrix (4x4 sizes). An example of the intersection and the resulting OD matrix is shown in Figure 1.

a.



b.

| | Entry directions | | | |
|---|---|---|---|---|
| 1 | | 0 | 78 | 5 |
| 2 | 8 | | 1 | 60 |
| 3 | 80 | 6 | | 1 |
| 4 | 0 | 59 | 10 | |

**Fig. 1:** Investigation of a single X-shaped intersection in the city. a. Image of the investigated intersection; b. The result of the study of the traffic intensity through the intersection in the form of OD matrix

However, when we talk about a group of crossroads, it is impossible to do manual counting. Moreover, it is impossible to do manual counting with the involvement of only one operator, and it is also impossible to accomplish with simultaneous involvement of four operators. The collection of data and the construction of a OD matrix in this case is possible only in view of the identification of each vehicle entering the area under investigation and subsequent tracking of the route of this car from entering the study area and before leaving the study area.
At the moment, there are many companies on the market that offer digitization of videos obtained from the quadcopters for the purpose of counting the number of cars, for example, obtaining the values of traffic intensity [6, 7]. The market for the provision of such services has been formed, in particular such services are offered by Indian, Pakistani companies, as well as some European companies. However, relevant commercial algorithms for restoring the OD matrix elements have not yet been developed and, accordingly, there is no commercial software based on the imple-

mentation of such algorithms [8, 9]. To date, in the automatic mode, analysis of such video fragments with the subsequent restoration of traffic intensity and construction of the OD matrix is not possible (e.g. Figure 2).

a. b.

| | Entry directions | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Entry directions | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 1 | 0 | 0 | 0 | 0 | 1 | 83 | 6 | 6 |
| 2 | 5 | 0 | 0 | 0 | 76 | 0 | 2 | 10 |
| 3 | 3 | 7 | 0 | 0 | 0 | 0 | 1 | 60 |
| 4 | 8 | 5 | 3 | 0 | 0 | 0 | 67 | 0 |
| 5 | 0 | 80 | 5 | 6 | 0 | 0 | 0 | 0 |
| 6 | 63 | 0 | 6 | 2 | 6 | 0 | 0 | 0 |
| 7 | 1 | 0 | 0 | 59 | 4 | 10 | 0 | 0 |
| 8 | 0 | 0 | 64 | 0 | 0 | 6 | 2 | 0 |

**Fig. 2:** Investigation of a group of X-shaped intersections in the city. a. Image of the group of intersections; b. The result of the study of the traffic intensity through the group of intersections in the form of OD matrix

For these purposes, when obtaining data on the vehicular and pedestrian traffic, it is quite effective to use the quadcopters, which at the present time allow a long time (up to 30 minutes) to receive video fragments of the intersection from a height of 120-170 meters. From this foreshortening (Fig. 1a, Fig. 2a), the intensity of the vehicular and pedestrian traffic, and the density of its individual sections, as well as the speed of traffic flows, delays, and places of conflict of the vehicular and pedestrian traffic are quite clearly visible.

## 3. A solution to problem

The restoration of the OD matrix elements for the observed intersection is based on algorithms for recognizing the movement of traffic and pedestrian flows through the intersection. The basis of such an analysis is the video material obtained with video from the air using the quadcopters. Usually, shooting is made from a height of 170 meters in 4K resolution and with a bitrate of 30 or 60 frames per second. In this case, to create an algorithm for restoring the OD matrix elements, two consecutive tasks must be solved:

1. Recognition of moving objects and recognition of these objects by types, including various types of cars: a car, truck, bus, trolleybus or tram, as well as pedestrians.
2. Tracking the object from the place of its recognition and before leaving the intersection.

The first task was solved on the basis of computer vision and computer training using neural networks. For learning the algorithm, a database of images of various moving objects (cars, trucks, public transport) was obtained from a vertical survey of an object (intersection or a group of intersections) from a height of 170 meters [10].

The second task was solved on the basis of comparison of successive frames and estimation of the parameters of object acceleration with the invariability of the location of the frame in the field of investigation. Based on two algorithms for recognition and tracking, a library of software modules was created, which allows to solve the problem of restoring the OD matrix elements through one or several intersections.

At the first stage of the algorithm, the first frames of the video material are processed. At this stage, in the interactive mode, the operator marks the field of the first frame, on which typical objects are selected, for which the grid is subsequently formed and bound. Besides, special lines and zones of the place of entry and exit to the analyzed area are allocated. In the places of departure and entry, there is a recognition of moving objects (cars and pedestrians).

For transport and pedestrian flows following from all possible entry directions and in the direction of all possible directions, we will adopt the following notations:

$Q_i$– the intensity of vehicles following from the i-th direction of entry, vehicles/hour;

$Q_i^{direct}$ - intensity of vehicles coming from the i-th direction of entry direct, vehicles/hour;

$Q_i^{right}$– intensity of vehicles coming from the i-th direction of entry to the right, vehicles/hour;

$Q_i^{left}$– intensity of vehicles coming from the i-th direction of entry to the left, vehicles/hour;

$q_{ij}^{direct}$ - the intensity of the vehicles following direct from the j-th lane of the i-th direction of movement, vehicles/hour;

$q_{ij}^{right}$– the intensity of the vehicles following to the right from the j-th lane of the i-th direction of movement, vehicles/hour;

$q_{ij}^{left}$– intensity of the vehicles following to the left from the j-th lane of the i-th direction of movement, vehicles/hour;

$qp_i$ - the number of pedestrians crossing the i-th direction of entry, pedestrians/hour.

Visually, the variables are shown in Figure 3.

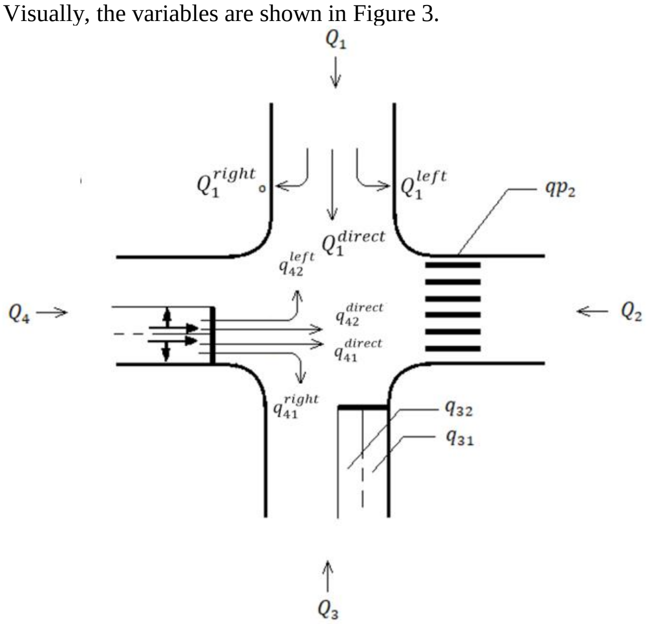



**Fig. 3:** Notations of the movement of traffic and pedestrian flows through the intersection

The problem reduces to counting $Q_i^{direct}$, $Q_i^{right}$, $Q_i^{left}$, $q_{ij}^{direct}$, $q_{ij}^{right}$, $q_{ij}^{left}$ and to note them in the OD matrix. Each element of the OD matrix - $Q_{ij}$ will be found as the sum of the intensity of motion across all lanes, as in (1).

$$Q_{42} = \sum_{i=1}^{n} q_{4i}^{direct}. \tag{1}$$

where n - the number of lanes at the entrance to the intersection from direction 4.

In some cases, at the first stage of recognition of objects, a semi-automatic mode is applied, where the operator independently selects on the video material a rectangular area in which the mobile object is located and in the subsequent just behind this rectangular area and tracking occurs when the object moves through the intersection [11].

Furthermore, the algorithm was extended to video materials obtained from ground-based surveillance cameras, including survey cameras located at intersections and cameras operating as part of an automated traffic management system, which are directed at an angle to the horizon (e.g. Figure 4).

**Fig. 4:** Fragment of processed video material obtained from ground-based surveillance cameras

Figure 5 shows a fragment of the algorithm at the stage of tracking traffic through the intersection.

**Fig. 5:** Fragment of the algorithm at the stage of tracking traffic through the intersection

As a result of the algorithm, a library of programs was compiled that allows to digitize the movement of each car in local coordinates in the form of a material point with an interval of one second. Every second the algorithm allows you to obtain data on the location of the point, its speed and acceleration (e.g. Figure 6).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0,400.00
297,0,1,"Car3",[115578.552217,1512784.485143,0.000000],-1.124380,0.000000,[209,209,209],[209,209,209],[209,209,209],[209,209,209],0,4.610003,1.984914,0,0,0
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373,0,1,"Car6",[115495.560428,1512886.304918,0.000000],1.771626,0.000000,[95,95,95],[95,95,95],[95,95,95],[95,95,95],0,4.339998,1.799511,0,0,0
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```


**Fig. 6:** Log file with the characteristics of the traffic of vehicles through the intersection

## 4. Experimental

Based on the algorithms described above, AirVideoTrafficAnalyser software was developed to automatically calculate the traffic intensities using video materials. The main task of the AirVideoTrafficAnalyser software is to restore the elements of the OD matrix based on the results of processing video materials obtained from the quadcopters to create micro and macro-level traffic models through the intersection.

The software allows you to set one or more counting areas on a video clip. Moreover, the counting areas take into account the number of vehicles passing through them in all possible directions with an accuracy of at least 95%. The output of the traffic intensities by the counting zones occurs in the online mode. There is a possibility of video correction under adverse shooting conditions (night time, fog, etc.). The software supports most video formats (* .avi, mp4, * .mpg, * .mov, etc.). It is possible to work with both high-resolution video clips (4K) and low-resolution video clips (480p). Export of counting results is possible in several formats (tabular format - OD matrix, text format).

Let's consider an example of the organization of effective traffic with the use of software development of automated calculation traffic intensities using video materials in the city of Perm in Russia: Khlebozavodskaya street - Heroev Hasana street (e.g. Figure 7).

**Fig. 7:** An example of a micromodel of the crossroads Hlebozavodskaya street - Heroev Hasana street in the city of Perm in Russia with the use of the software AirVideoTrafficAnalyser

Based on the received and automatically processed initial data on the vehicular and pedestrian traffic, a micromodel of motion was constructed and the main characteristics of the motion of this movement were determined, such as: total travel time, total delay time, delay time before insertion, total stop time, number of vehicles not entered, number of stops, number of vehicles in the network, total path length, average idle time of the vehicle, average number of vehicle stops, average speed, average vehicle delay time, etc.

## 5. Conclusion

The presented algorithm for recognition and tracking of mobile objects showed its efficiency in the analysis of video data obtained from both quadcopters and ground-based cameras operating at an angle to the horizon. The obtained data from the program modules are successfully exported to all known micromodeling programs, including PTV Vision VISSIM, TSS Aimsun, Quad-stone Paramics, Saturn. In the future, the development of these technologies involves a package for the processing of groups of video materials at intersections shot at different times with different resolutions.

The technologies have been successfully used in the cities of Russia: Perm, Saratov, Tomsk, Makhachkala, Ufa, Krasnodar, Novosibirsk, Vladimir, Veliky Novgorod, Lipetsk, Omsk, Tyumen, Penza and others when working on the development of complex transport schemes and road traffic schemes in order to improve the efficiency of the urban road network. The results of the projects can be found on the specially created channel www.youtube.com/user/permnextradar, which displays the results of the analysis of all the individual intersections.

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