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Automation of Collection of Primary Data for Development of a Passenger Origin-Destination Trip Correspondence Matrix Based on Computer Vision and Neural Network Technologies

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ABSTRACT

The origin-destination trip matrix is a fundamental characteristic of a transport network, and development of a reliable correspondence matrix is the most important task in organising passenger traffic. It is the basis on which the public transport route network of a city (region) is built and optimised.

Currently, collection of initial information for construction of a travel correspondence matrix is carried out through field surveys comprising questionnaire surveys of the population; accounting for movement of passengers according to the coupons issued to them; checkers, tellers manually counting passengers in vehicle compartments; simple surveys of passengers. Besides, mathematical modelling is used based on statistical data on the number of residents in various districts of the city, employees in enterprises and students in educational institutions, as well as on available data on the characteristics of passenger traffic along certain routes. All these surveys are very expensive and are carried out once over few years; they give a large error, which is why decisions made on the basis of these data are far from being optimal.

There are a lot of solutions in the software and hardware market that provide automated collection of data on passenger flows. They are based on the use of infrared sensors or of video recording. However, none of these systems provide information about the points of entry and exit of each passenger.

The objective of this study was to develop methods for automating the collection of reliable information about passenger trips, that will be the base for building up-to-date and reliable passenger trip correspondence matrices. This task can be solved by constant monitoring of passengers' trips with fixing places of entry and exit of each passenger.

The study describes the possibility of creating software based on computer vision and artificial intelligence which will provide automation of collection of primary information about travel of each passenger from the place of boarding into the vehicle to exit from it, that is, automation of data generation to build a passenger trip correspondence matrix.

Keywords: passenger transport, passenger flows, trip correspondence matrix, artificial intelligence, neural networks, machine learning, computer vision.

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INTRODUCTION

Trip origin-destination correspondence matrix is a basic table describing how people travel around a city. It shows how many residents move from one district of the city to another and is the base for building the route network, identifying the required number of vehicles, developing the traffic timetable [1; 2].

In modern cities and megalopolises, a lot of residential and industrial infrastructure is being built, enterprises are being relocated, residential and employment locations are changing, resulting in a dynamic change in the volume and directions of trips. Under these conditions, the construction of true trip correspondence matrices requires absolutely reliable information about real passenger trips.

There are a lot of solutions in the software and hardware market that provide automated collection of passenger traffic data. In most cases, they are based on infrared sensors [3] and video recording by cameras located in the entry and exit door openings of vehicles [4]. However, none of the existing automation systems for collecting data on passenger traffic provides information about the points of entry and exit of each passenger, while these data are basic for developing passenger origin-destination trip correspondence matrices. Due to the lack of such data, the trip correspondence matrices are still developed based on sample surveys, population surveys, statistical data on the number of residents in certain districts of the city and the number of employees at enterprises. These data do not reflect the real picture of daily migration of the urban population. Accordingly, decisions made based on this information are far from being optimal. All existing methods of automating the accounting of passenger flows do not allow obtaining data for constructing a trip origin-destination correspondence matrix.

Based on the foregoing, the *objective* of this study was to develop methods for automating data acquisition to develop a complete and reliable correspondence matrix of population trips with public land passenger transport.

This task can be solved by constant monitoring of passengers' trips with fixing the place of entry and exit of each passenger. To fix the place of entry and exit of each passenger, it is proposed to use the *methods* of computer vision and artificial intelligence.

RESULTS

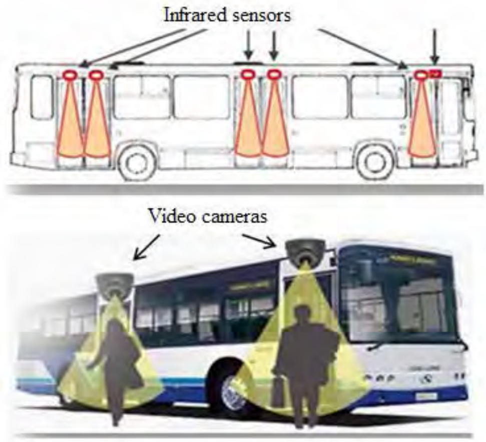
Shortages of Existing Technology to Solve Pertinent Problems

When solving the problem of optimising the route network of public transport, two concepts should be clearly distinguished: passenger traffic and the passenger trip correspondence matrix. Passenger flow largely characterises the general statistics of passenger movement (the number of passengers at different times of the day, days of the week, during different seasons, etc.) with reference to a stop, route, transport company, city, etc. The passenger trip origin-destination correspondence matrix (Pic. 1) is a quantitative characteristic that determines the volume of passenger flow between each pair of «points» [1; 2]. Here «points» refer either to specific stops of public transport, or conditional zones that were obtained by combining stopping points to some areas (for example, city districts).

The trip origin-destination correspondence matrix is a fundamental characteristic of the

Destination areas	Origin areas				
	1	2	3	n	Σ
1		P_{12}	P_{13}	P_{1n}	P_1
2	P_{21}		P_{23}	P_{2n}	P_2
3	P_{31}	P_{32}		P_{3n}	P_3
⋮					
n	P_{n1}	P_{n2}	P_{n3}		P_n
	1	2	3	n	

Pic. 1. Trip origin-destination correspondence matrix [1; 2].



Pic. 2. Automated passenger traffic accounting systems [4].

transport network, and development of a true trip origin-destination correspondence matrix is the most important task in organising passenger transportation. The trip origin-destination correspondence matrix is the basis on which the public transport route network is built and optimised. In turn, a well-built route network allows you to determine the required number of vehicles on routes, optimise the timetable, reduce material costs for organising transportation, and, ultimately, meet the people's need for transport services with minimal costs.

Automation of passenger traffic accounting is currently quite deeply developed and implemented in the form of many different technical solutions: contact sensors on the steps of a vehicle, infrared sensors [3] or video cameras [4] in the area of the front door (Pic. 2).

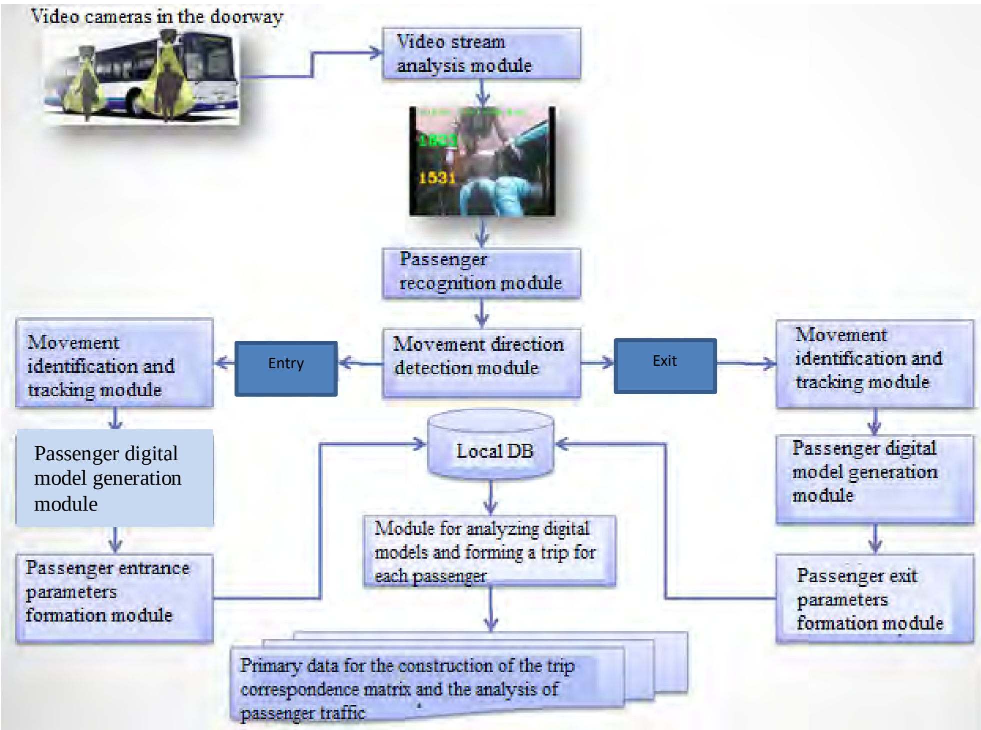
However, statistical data on passenger traffic on routes does not make it possible to construct a passenger trip origin-destination correspondence matrix. These data provide just a summary of incoming and outgoing passengers.

Currently, automation of data collection for development of a passenger trip origin-destination correspondence matrix has not actually been implemented. This problem is solved with a fairly large error and with great expense on the basis of specially organised field surveys. It should be noted that full-scale survey methods are often associated with significant organisational, financial, and legal problems, so their application sometimes becomes impossible, especially in large cities where passenger flows are large. For some modes of transport (rail, air, water), the problem of developing a trip correspondence matrix can be solved based on the analysis of purchased tickets that indicate the points of departure and arrival.

The classical method of obtaining data for constructing a trip origin-destination correspondence matrix is associated with field surveys (special travel coupons, questionnaires of the population, polling of passengers by pollsters in vehicles, etc.), as well as with mathematical modelling methods [5]. The disadvantages of field surveys are explained through significant laboriousness of collecting and processing data, low reliability of data due to the human factor, high cost of the survey, lack of repeatability statistics (it is impossible to distinguish weather conditions, season, and other features of the current day). The high cost and labour intensity of the survey are the reasons why such surveys are carried out every 15–20 years only, which does not make it possible to promptly update and optimise management decisions.

There are approaches to automating development of an approximate trip origin-destination correspondence matrix in the metro using mobile phones of passengers [6]. Cellular operators can track the entries and exits of passengers from the metro, determining the moments when their mobile subscriber switches to a base station located in the metro (enters the metro) or to a base station in the city (exits the metro). Such anonymous data can serve as the basis for development of a trip correspondence matrix for each pair of metro stations. However, this approach is unacceptable for land passenger transport. Difficulties in solving this problem are also associated with the large dimension of primary information, and with the lack of a single methodology for obtaining a trip correspondence matrix for a given city, which should include not only job and education-related trips, but also travelling with cultural and household purposes, as well as travelling of retirees.

The city's working population and students travel daily by public transport to job and study locations. Such trips account for the largest share as they are regular. However, there are trips of unemployed retirees, as well as other travelling of residents which is of a cultural and household nature. These trips, one way or another, affect the congestion of city routes. The general trip origin-destination correspondence matrix, which includes labour, cultural and household trips, will fully describe the nature of all trips in the city.



Pic. 3. The basic structure of a system for automating the collection of primary data on passenger trips with public transport based on neural network technologies (compiled by the author).

Such detailing seems to be especially important for the purposes of optimising the route network.

Description of Suggested Technology

Is it possible to automate the process of recording trips with a clear fixation of the entry and exit point for each passenger? It is almost impossible to solve such a problem based on infrared sensors, since they do not allow identifying an object. But it is quite possible based on video recording. In recent years, with development of convolutional neural networks (CNN, R-CNN, Mask R-CNN), there has been an explosive development of neural network technologies and computer vision systems. Accordingly, it became possible to develop fundamentally new automated systems for accounting and analysis of passenger flows based on these technologies with the possibility of forming a reliable and complete passenger trip origin-destination correspondence matrix for urban land passenger transport. The development of such a system, which is absent in the software and hardware market, is the novelty of this work.

The basic structure of the system for automating the collection of primary data on passenger trips in public transport, which is based on neural network technologies and developed within the framework of this study, is shown in Pic. 3.

The software and hardware complex shown in Pic. 3, consists of the following elements:

• Video camera located in the upper part of the vehicle entrance door opening.

• Onboard minicomputer.

This complex works as follows. The video stream in real time comes from the video camera to the onboard computer and is processed by specialised software. This software solves the following tasks:

• Recognises passengers entering and exiting the vehicle (passenger detector – top view).

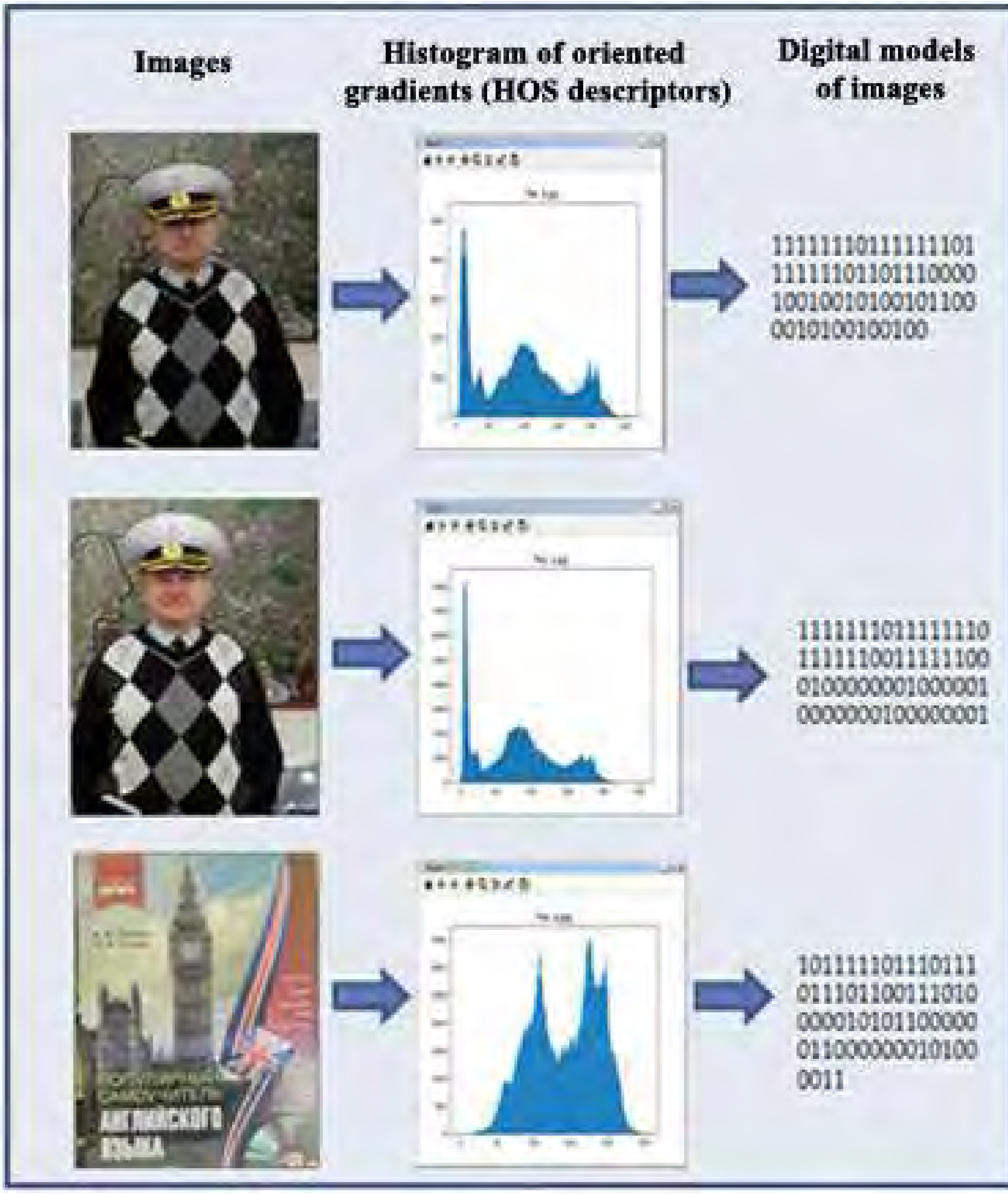
• Converts the image of each entering passenger into a unique digital model and saves it.

• Fixes the entry parameters of each passenger (date, time, entry stop).

• Converts the image of each exiting passenger into a unique digital model and saves it.

• Fixes the exit parameters of each passenger (date, time, exit stop).

• Compares the digital model of the image of exiting passengers with digital models of the passengers who have entered the vehicle and generates a unique pair of entry-exit values for each passenger.

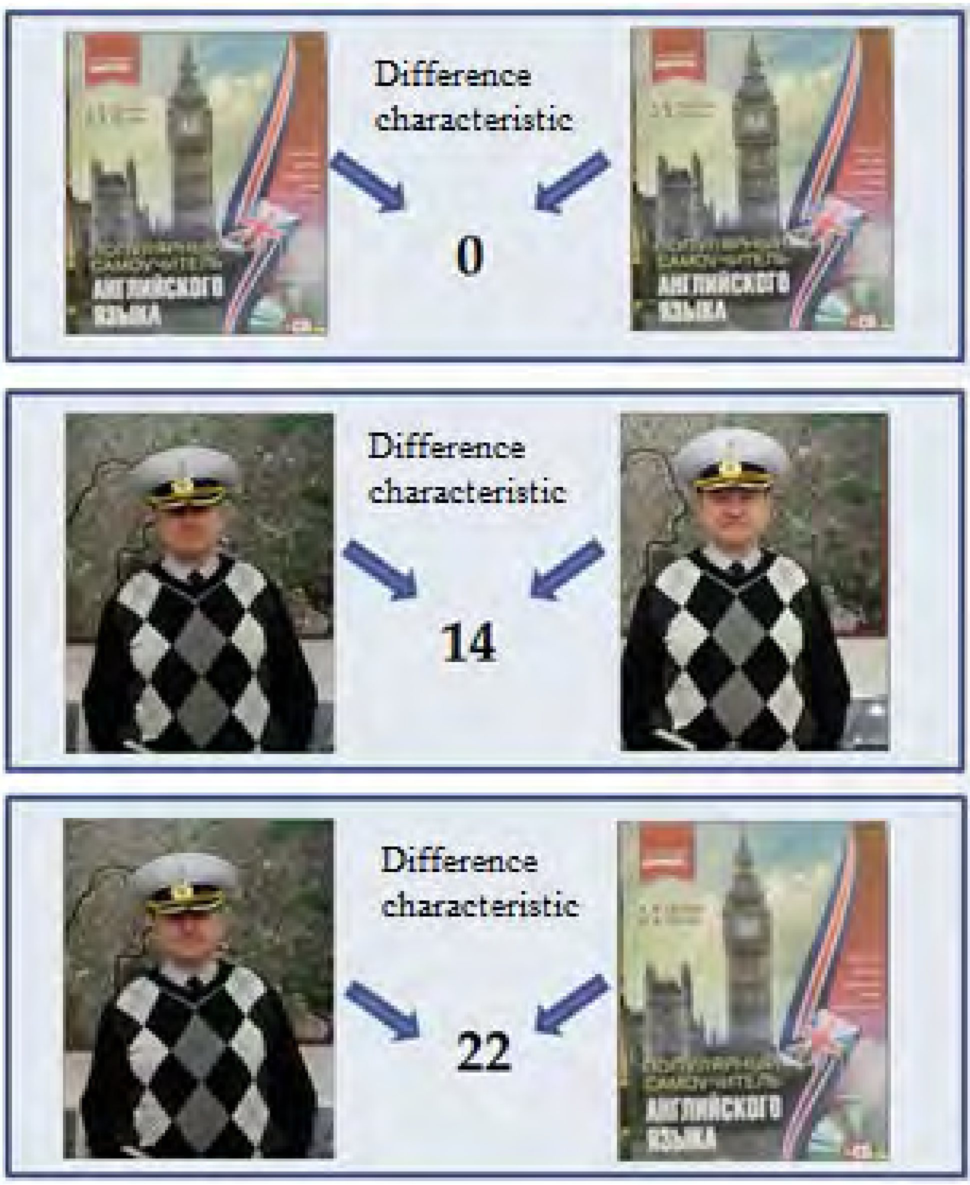


Pic. 4. Digital models of images based on the histogram of oriented gradients (developed by the author).

• Counts the number of passengers: who entered the cabin, exited the cabin, who are in the cabin of the vehicle at each stopping point.

The parameters of the trip of each passenger obtained in this way are transferred to the server platform upon completion of operation of the vehicle on the route, where, based on the server software, the passenger trip origin-destination correspondence matrix and statistics on passenger traffic will be formed.

At first glance, it is possible, without using digital models, to simply compare the snapshot of the passenger at the entrance with the snapshot of the passenger at the exit. However, for such a comparison, it is imperative to perform the image normalisation procedure. But even after normalising the images, you may not get the desired result, since the passenger can enter directly and exit sideways, at some angle or even backward. Multiple cyclic image rotation and comparison will be required, which will require additional processing time and may not lead to the expected result. In addition, the complete image takes up a fairly large amount of RAM, which will also require large time resources for processing. It is more correct in this case to use a digital identification model of the image. Such models are based on selection of a set of key



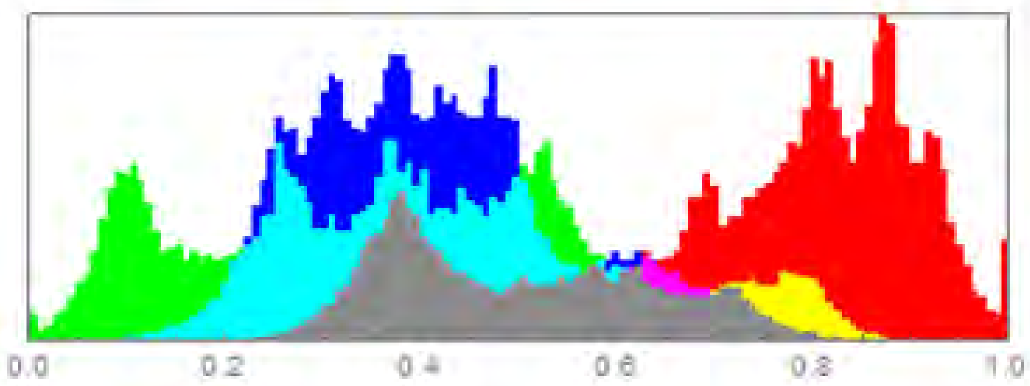
Pic. 5. Examples of image comparison based on their digital models (developed by the author).

points on images. The Delaunay triangulation or Voronoi diagrams, which are used in face matching and morphing systems, can be used as a basis for such models. Histograms of oriented gradients (HOG singular point descriptors) can be used, which are applied in computer vision for object recognition [7].

Currently, the implementation of technology and software modules to automate collection of data on passenger trips based on neural network technologies and computer vision with participation of the author has started. The Pic. 4 shows examples of generation of digital image models, which are built on the basis of a histogram of oriented gradients. Here the images were reduced to one colour which is grayscale.

Naturally, the digital model takes up much less space in the computer's memory and, in addition, it makes it possible to compare images and evaluate their similarity. Pic. 5 shows examples of image comparison based on their digital models.

As can be seen from Pic. 5, for absolutely identical images, the difference coefficient calculated based on the digital model is zero. With the growth of the difference between the fragments of images, the characteristic of the



Pic. 6. An example of a histogram of image colours (developed by the author).

differences increases. So, in the second row the same person changed the position of the head, and this change was recorded in the histogram. However, the characteristic of difference (14) did not exceed the threshold value (19), and the objects depicted on them can be classified as identical. But in the third row, the characteristic of difference (22) exceeded the threshold value, which suggests that the images picture different objects (the threshold value is determined empirically). Using a digital model and a correctly selected threshold value, it is possible to assess similarity or differences of objects in the images, that is, for the problem under consideration, to find a correspondence between the passenger who entered and exited. With even greater accuracy, it is possible to compare objects in images using a histogram of not a single colour, but a histogram of a group of colours (Pic. 6).

Homography methods are of particular interest for searching for similarity in images. When using them, the angles of rotation and tilt of compared images are not of fundamental importance [8]. This is especially important for solving the problem under consideration, since the position of the passenger moving in the area of the camera above the entrance door cannot be strictly fixed. Pic. 7 shows an example of visual comparison of images using the homography method. To ensure sufficient accuracy of passenger recognition at the entrance and exit, it will be necessary to use a combination of the above methods of forming and comparing digital models.

Pic. 7. Visual comparison of images by the method of homography (compiled by the author).

To fix the location of entry-exit of a passenger based on his image in the video stream, it is necessary to perform the following steps, particularly, to:

• Recognise the silhouette of a passenger when he enters the vehicle.

• Segment the silhouette, transform it into a digital model and fix the parameters of the entrance.

• Recognise the silhouette of a passenger when he exits the vehicle.

• Segment the silhouette, transform it into a digital model and fix the parameters of the entrance or exit.

• For the passenger who exited the vehicle, based on the comparison of digital models, find the parameters of the entrance, and form the trip (stop at the entrance – stop at the exit).

The location (stop) of the passenger's entrance and exit can be determined using the onboard satellite navigation system of the vehicle. Synchronisation of primary data on the places of entry and exit of passengers with stopping points can be carried out either at the vehicle level (by integrating the onboard software of two subsystems), or on the server side of the navigation data processing system (by comparing the time of entry and exit of passengers from the passenger travel accounting system with the exact time of vehicle's presence at stopping points obtained from the navigation system).

As a result of video processing, the software generates anonymised data on passenger trips with the following parameters:

• Stopping point, date, and time of boarding the vehicle.

• Stopping point, date, and time of exiting the vehicle.

This information is recorded in the logbook as a text file. Such a file, containing, for example, information about 1000 passenger trips, will occupy no more than 50 kB in computer memory. After the vehicle completes its operation on the route, this data array must be transferred to a stationary computer (or to a server platform), where a passenger trip origin-destination correspondence matrix will be formed using the data. In addition, using the same data array, it will be possible to obtain traditional reporting on passenger traffic.

The solution to this problem is based on the use of neural networks, machine learning and various methods of image processing. In this regard, the following tools were used for software development:

• Programming language Python.

• Specialised libraries for building neural networks and machine learning (Keras [9], PyBrain, Scikit-learn, TensorFlow, PyTorch with torchvision, etc.).

• Libraries for image and matrices processing (OpenCV [10], ImageAI [11], NumPy).

To simplify creation of similar applications and reduce the program code, we have developed our own Postoperative Library for Image Transformation – PostoLIT.

To date, using this toolkit, some basic modules of the computer vision system have been implemented to solve the problem, in particular:

• R-CNN neural networks for object recognition.

• Image segmentation and clustering modules based on Haar cascades.

• Modules for recognition and segmentation of object instances based on Mask R-CNN networks.

• Modules for recognising key points of the image (based on technologies for finding facial landmarks and face elements).

• Modules for constructing digital models of images based on a histogram of oriented gradients.

• Modules for matching images based on homography and HOG detectors.

Who might be interested in systems of automated data collection on trips with fixing the place of entry and exit of each passenger? First, these are passenger motor (bus) transport enterprises. According to the analytical agency Avtostat, as of January 1, 2020, there are about 409,9 thousand buses in Russia[1], more than 8 thousand trams[2] and 4 thousand trolleybuses[3]. This sufficiently large fleet of vehicles can use this system. Such systems are of interest to city and regional authorities, which provide and organise transport services for the residents. Today in the Russian Federation there are 85 constituent entities and 1117 cities, of which 173 cities have a population of over 100 thousand inhabitants[4]. There are 43

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[1] Russian bus fleet: key indicators at the beginning of 2020 [*Rossiiskiy park avtobusov: osnovnie pokazateli na nachalo 2020 goda*]. [Electronic resource]: https://www.autostat.ru/infographics/43090/. Last accessed 25.02.2021.

[2] The state of the tram system in Russia [*Sostoyanie tramvainoi sistemy v Rossii*]. [Electronic resource]: http://www.ipem.ru/news/publications/914.html. Last accessed 25.02.2021.

[3] Trolleybus cities in Russia [*Trolleibusnie goroda Rossii*]. [Electronic resource]: http://trollcity.narod.ru/stat.htm. Last accessed 25.02.2021.

[4] Federal structure of Russia [*Federalnoe ustroistvo Rossii*]. [Electronic resource]: https://mnogofactov.ru/goroda-i-strany/skolko-sub-ektov-v-rf-na-2019-god.html. Last accessed 25.02.2021.

largest domestic suppliers of information systems for transport companies, which, among other software products, develop and implement systems for accounting for passenger traffic[5]. They will be able to use the developed software modules to integrate them into their existing passenger traffic accounting systems and automated fare collection systems, thereby expanding their functionality, as well as to create new products based on the proposed software and technological solutions.

Besides, the proposed technological approach and software may be in demand not only in the transport industry, but also in other sectors of production activity, where it is required to fix movement of objects with external individual characteristics, where it is necessary to estimate time of customer service, as well as to assess the effectiveness of service personnel, e.g., in systems for determining the time spent by customers in retail outlets, assessing the time of customer service in the municipal centres providing services to residents, in clinics, in banks and other organisations. All this favours the prospects for the development and the demand for computer vision systems.

CONCLUSIONS

Computer vision and artificial intelligence are, perhaps, the most demanded areas of information technology development.

Existing automation systems for collecting data on passenger trips do not allow fixing the place of entry and exit of each passenger; accordingly, it is not possible to build a trip origin-destination correspondence matrix using these data.

The level of achievements in the field of artificial intelligence and computer vision makes it possible to automate the collection of data on passengers' trips with public transport while fixing the place of entry and exit of each passenger. Considering the fact that currently there are no such solutions in the software market, they have significant competitive advantages and a good prospect for implementation.

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