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Development of an Algorithm for Analysing the Condition of the Road Surface Using Artificial Intelligence

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ABSTRACT

Motorways are a strategically important part of a country's infrastructure. High requirements for their condition stipulate regular monitoring of quality of the road surface. The large length of motorways in Russia and the impact of weather and climate conditions (seasonal temperature fluctuations, precipitation) emphasise the relevance of searching for non-destructive testing methods for road diagnostics that ensure short terms of diagnostic work and the use of minimal resources.

The considered existing solutions for detecting road surface damage include the use of ground penetrating radar, laser method, method of analysing vibration effects of road surface irregularities, detection of damage based on lidar data and mobile mapping systems.

The objective of the study was to develop an algorithm for analysing the condition of the road surface that allows detecting road surface distresses based on images obtained during the diagnostics of motorways by the KP-514-RDT airfield and road measuring mobile laboratory completed by the IndorRoad and RDT-Line software packages.

The development of an algorithm for detecting road surface defects was carried out using machine learning methods. The detected defects have precise georeferencing according to stationing of the measured road segment. As a result of development, a trained model was obtained that allows automatic marking of defects of different classes on the image. The developed algorithm is integrated into the software for managing the monitoring of the condition of regional and municipal roads.

Keywords: motorways, road diagnostics, non-destructive testing, artificial intelligence, machine learning, detection of road surface defects.

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INTRODUCTION

The condition of the road surface directly affects the level of road traffic safety [1; 2]. According to statistics from the Scientific Centre for Road Traffic Safety of the Ministry of Internal Affairs of the Russian Federation, as of the end of 2022, unsatisfactory road conditions, implying the inadequate condition and arrangement of roads and railway crossings, were the cause of 30,5 % of road traffic accidents. The number of people killed in such accidents was 4089, while 48241 were injured [3]. In this regard, an important state task is to ensure measures to maintain roads in conformity with conditions stipulated by standards and regulations.

According to Federal State Statistics Service, the current length of the public road network in Russia is 1575,5 thousand km, of which 64,7 thousand km are federal highways, 503 thousand km are regional or intermunicipal motorways, 1008 thousand km are local motorways. Hard surfaces are absent on 29,2 % of motorways, and less than half of them have improved road pavement that ensures high transit capacity regardless of natural and climatic conditions[1]. At the same time, 15,3 % of federal highways[2], 49,4 % of regional motorways and 46,3 % of local motorways do not meet regulatory requirements [1], which can cause road traffic accidents. Consequently, timely detection and diagnostics of road surface damage are of crucial importance for ensuring road traffic safety [4; 5].

According to the requirements of the legislation[3], annual diagnostics, inspection and assessment of the technical condition of highways to determine whether the transportation and operational characteristics comply with the requirements of technical regulations are the responsibility of the owner of the motorways. High-quality road monitoring allows us to analyse and predict the service life of a road facility, competently plan future work to bring facilities into compliance with regulatory requirements, distribute financial resources and monitor the work of the general contractor, which will have a positive effect on improving road traffic safety and reducing mortality from road traffic accidents due to unsatisfactory road conditions.

The extent of motorways in Russia implies a large volume of diagnostic work, which affects the timing and cost of its implementation, which is especially important to consider due to the limited resources of local and regional budgets [6]. Here, the development of more effective and efficient methods for assessing the quality of the road surface becomes relevant.

The implementation of traditional methods for assessing the quality of roads [7] takes a long time, requires a large amount of equipment and numerous specialists, which does not allow us to talk about their efficiency and effectiveness. In this regard, mobile methods of non-destructive testing are of particular importance when conducting diagnostics of road structures, in this case, when performing the study, the object does not lose its original properties, and the work can be completed in a short time, without using a large number of resources.

RESULTS

To formulate requirements for development of an algorithm for analysing the condition of a road surface, an overview of existing solutions for mobile non-destructive testing in the diagnostics of highways has been made.

The article [8] describes in detail one of the methods of non-destructive testing, i. e. diagnostics of highways using ground-penetrating radar (GPR). The ground-penetrating radar method is advisable to use to identify various signs of road surface deformation that are not determined by the method of road surface drilling. The ground-penetrating radar survey is based on the study of the field of high-frequency waves, as well as the difference in rock permittivity. In the case described in paper above, the OKO-2 ground-penetrating radar with an AB-1000R air shielded antenna was attached with a bracket to continuously moving vehicle. The survey was conducted on the example of an operating facility; the results of the analysis of the set of reflected signals in special software helped to identify cracks, distresses, and potholes in the upper layer of the road surface, requiring replacement of the asphalt concrete pavement. This method is effective in solving problems of detecting and identifying roadway defects, but at the same time, interpreting the results of the GPR survey is a complex and labour-intensive process, accessible only to specialists with professional skills in the field of geological research. Besides, the method

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[1] Transport. Official statistics: Federal State Statistics Service. [Electronic resource]: https://rosstat.gov.ru/statistics/transport. Last accessed 10.09.2023.

[2] The length of federal highways. [Electronic resource]: https://rosavtodor.gov.ru/. Last accessed 10.09.2023.

[3] Federal Law of 08.11.2007 No. 257-FZ «On Highways and Road Activities in the Russian Federation and on Amendments to Certain Legislative Acts of the Russian Federation». [Electronic resource]: http://www.kremlin.ru/acts/bank/26452. Last accessed 10.09.2023.

has its constraints: the quality of the obtained survey results may decrease in bad weather conditions (rain, air temperature below –40 and above +40 degrees)[4].

To obtain accurate road geometry and visual description of road defects, it is advisable to use highly detailed spatial data. A technique to obtain such data is to conduct laser scanning of the road. Laser scanning is performed using cameras, laser equipment (lidar[5] [Light Detection and Ranging]) and navigation devices installed on a vehicle [9]. The laser scanning results in a point cloud representing a digital three-dimensional model of the road. Using a three-dimensional model, it is possible to identify road surface defects and carry out the necessary measurements. Due to the high cost of laser equipment, this method cannot be widely used for diagnostics of regional and local motorways; furthermore, the operation of the lidar is limited in some weather conditions.

In [10], the input data for detecting road defects include point clouds and orthomosaic collected using mobile mapping technology, which involves the use of a Trimble MX9 scanning system installed on the roof of a vehicle. The method included several stages: data collection using mobile mapping, processing of the obtained results, classification of spatial objects for further identification of the location of a specific defect (roadway, bike path, pedestrian zone), visual inspection by the operator of orthomosaic and panoramic images and extraction of the road damage area from them in the form of polygons, lines or points. Each selected image was assigned a unique identifier and attributes, including the defect surface, defect location, location lane number, depth, type, severity level, size and other geometric parameters. Based on the results of the work, a database of road damage was obtained, consisting of shape files with point, linear and polygonal defects.

The mobile mapping method in road diagnostics has many advantages: high scanning speed, allowing not to stop traffic at the surveyed site, reduction of time and financial costs for field work, a large volume of attribute data for each damage, precise determination of the location of the defect found, the ability to sort the database of found defects. At the same time, the use of this method assumes the work of a trained operator who is able to not only search for, but also classify roadway defects using an image. Automation of damage search in this case requires the use of specialised software.

The task of detecting road surface defects based on laser scanning data without the need for data marking with the participation of an operator is investigated by the author of the article[6]. The goal of the project was to develop an algorithm for automatic detection of road surface defects based on data obtained from a lidar device. The complexity of this approach lies in the large volume of preparatory processes, including preparation of a high-quality point cloud and the selection of a defect search area. Thus, at the first stage, the *db* data format with an embedded binary code was converted to a convenient *csv* format. Then, using the RANSAC algorithm, the data was corrected. To create a high-quality dataset, the obtained point clouds were aligned using the RANSAC algorithm. To minimise potential errors and distortions using the ICP algorithm, two point clouds were combined into one. This made it possible to transform the point cloud into high-quality material for further searching for road surface damage. Defect detection, in particular of deep potholes, was carried out in the selected area with the highest point density. The developed algorithm for finding potholes consisted of determining statistical outliers in distribution of point heights using the DBSCAN clustering method, which allows grouping points defined as «potholes» into separate clusters. Based on the results of all the operations performed, the coordinates of the centre of each cluster were determined, representing the exact location of the road defect. Thus, the work managed to achieve the result in detecting one of the types of damage, i.e. a pothole.

The patent for the invention «Method for diagnosing the smoothness of a road surface» [11] presents a method for assessing the quality of a road surface by analysing the vibration effects of road irregularities during vehicle's movement. This method involves the use of a mobile vibration

[4] Guidelines for the use of ground-penetrating radars in surveying road structures. [Electronic resource]: https://pandia.ru/text/77/122/621.php. Last accessed 23.09.2023.

[5] Since there are at least seven different casings of this short form for light detection and ranging (see, e.g.: Deering, C. A., Stoker, J. M. Let's Agree on the Casing of Lidar. *LiDAR News Magazine*, 2014, Vol. 4, No. 6. [Electronic resource]: https://lidarmag.com/wp-content/uploads/PDF/LiDARNewsMagazine_DeeringStoker-CasingOfLiDAR_Vol4No6.pdf), a «lidar» is used in the English translation of the article. – *Ed. note.*

[6] Detecting Road Defects Without Labelled Data: Hackathon, Lidar, Ransac, ICP and 44 Sleepless Hours. [Electronic resource]: https://habr.com/ru/articles/765230/. Last accessed 25.02.2024.

measuring complex consisting of vibration sensors installed on the unsprung part of the vehicle, a computing complex, an operator's workstation, power supplies, and a satellite positioning system. In this case, the quality of the road surface is assessed by comparing the amplitudes of the vibration effects of the obtained reference base of road smoothness [evenness] parameters at the certification stage when putting the road into operation and the data of control measurements during operation of the road at the same points on the route. Based on the results of the analysis of changes in the vibration effects parameters, it is possible to identify areas of pavement destruction, formulate recommendations for adjusting the speed limit on the studied segments of the road, and, according to the authors, predict the service life of the road surface. The need for a reference base of road smoothness parameters makes it difficult to use this method for large volumes of work, as it requires increased inventory costs.

The considered non-destructive testing solutions are effective in diagnosing the condition of roads, but do not fully ensure automation of the search for road surface damage, convenient for use by decision makers. Today, tools for automation and increasing the efficiency of obtaining data on the condition of the road surface, developed using artificial intelligence, are gaining popularity and have proven effectiveness.

Diagnostics of roads using artificial intelligence has been widely studied abroad in the last decade [12–17]. In Russia, this topic is represented by the works of S. S. Kravtsov, I. A. Kanaeva, B. V. Sobol, P. V. Vasiliev and other researchers [18–23]. The solutions are based on the method of automatic processing of images obtained using a smartphone, a video recorder installed in a vehicle, or a UAV. This paper demonstrates the process of developing an algorithm for analysing the condition of the road surface, which allows detecting defects in the road surface based on images from an airfield and road laboratory.

Based on the results of the review of existing solutions for mobile non-destructive testing in road diagnostics, the distinctive characteristics of the road surface condition analysis algorithm developed within the framework of this research work have been formed:

– Data collection for assessing the road surface condition when driving at speed (without costly blocking traffic on roads and without the risks associated with work carried out along busy highways with dense traffic).

– The use of machine vision to detect damage to the road surface.

– No need to conduct an initial (reference) survey of the road surface condition.

– Accurate georeferencing of the detected defect according to the stationing of the measured road segment.

Development of the algorithm was based on the data obtained within the framework of road certification work using the KP-514-RDT airfield and road laboratory measuring complex in combination with the IndorRoad and RDT-Line software. The frames obtained during the relevant survey were converted with the help of software into a separate flow of photographs of small segments of the roadway of the same dimensions, conditionally connected into a single frame of the entire diagnosed motorway. At the second stage, the optimal architecture of the neural network was determined for solving the problem of finding and segmenting road surface defects; at the third stage, its own training dataset was prepared: 35225 defects were manually identified on 2500 images. The following types of objects were used for marking: cracks, block cracking, potholes, corrugation, depressions, upheaval, shoving, patching, etc.

As a result of machine learning of the used Mask R-CNN neural network architecture, a model was obtained that allows automatic marking of defects of different classes in a photo. The quality of the model was assessed using a dataset that included 1000 photos with defects of two classes: «Cracks» and «Potholes».

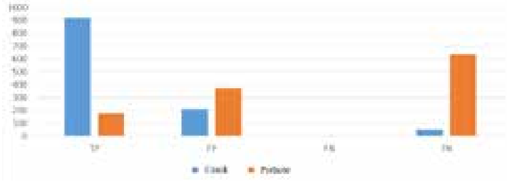
To assess the performance of the model, the «Error Matrix» metric is provided (Pic. 1). The metric is a table with four different combinations:

1) TP – True Positive: the model found a defect in the photo where it is present.

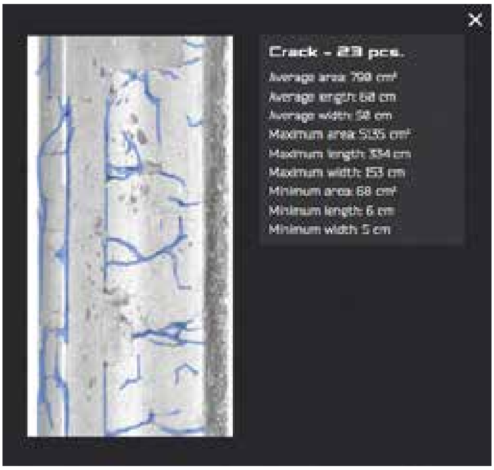
2) TN – True Negative: the model did not find defects in the photo where there are really no defects.

3) FP – False Positive: the model found a defect in the photo where there are no defects.

4) FN – False Negative: the model did not find a defect, but it is present in the image.



Pic. 1. «Error Matrix» Metric [developed by the authors].



Pic. 2. The result of the algorithm's operation regarding the «Crack» class [developed by the authors].

Pic. 3. The result of the algorithm's operation regarding the «Pothole» class [developed by the authors].

From Pic. 1 it is evident that in most cases the model makes a correct classification for the «Crack» class, while for the «Pothole» class the model most often makes a true negative decision.

Table 1 also shows the metrics used to evaluate the performance of the algorithm, prepared based on the calculation of the error matrix indicators.

Pics 2, 3 show the results of the algorithm's operation regarding «Crack» and «Pothole» calsses. For each image, the parameters of the area, length and width of the detected damages are determined.

The developed algorithm is integrated into the web application «System for monitoring the condition of housing and communal services' facilities (heating mains, landscaping (lawns, parks, urban forests), buildings (roofing, facades))», in terms of the module for monitoring the condition of regional and municipal roads.

CONCLUSIONS

The development of more efficient and effective methods of non-destructive testing of the quality of roads in the context of limited resources of local and regional budgets is an urgent task. In this context, mobile non-destructive testing methods for road quality are promising, since they allow not to subject the road surface to additional impacts and do not require stopping the traffic flow at the surveyed site.

Table 1

Metrics used to evaluate the performance of the algorithm

№	Name of the metric	Value
1	Accuracy	0.73
2	Positive predictive value	0.64
3	Sensitivity	1.00
4	Specificity	0.49

The reviewed methods of non-destructive testing of the condition of roads do not fully ensure the automation of the search and determination of the parameters of damage to the road surface. Besides, constraints inherent in the considered methods, such as the complexity of interpreting the results, the need for participation of a trained specialist in the interpretation, the requirement for availability of a reference database of road parameters, hinder the possibility of their widespread use, including for making management decisions by responsible persons.

As part of the described research, an algorithm for analysing the condition of the road surface was developed, allowing for automatic detection of road defects based on images obtained during the certification of roads using the KP-514-RDT airfield and road laboratory measuring complex in combination with the IndorRoad and RDT-Line software. No operator work is required when classifying defects and determining their parameters. Damage detection is performed using a trained neural network. The developed algorithm allows for prompt assessing of the current condition of the road without visiting the sites, identifying areas requiring repair, measuring pavement distress parameters and estimating the cost of possible works on current or major repairs.

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