MACHINE BUILDING
МАШИНОСТРОЕНИЕ

Check for updates

UDC 621.86/.87: 004.032.26
https://doi.org/10.23947/2541-9129-2024-8-2-57-67

Research Article

Use of Artificial Intelligence to Monitor the Reliability of Removable Load-Handling Devices

EDN: WVVMDV

Vladislav V. Egelsky, Nikolay N. Nikolaev, Elena V. Egelskaya ✉, Anatoly A. Korotkiy
Don State Technical University, Rostov-on-Don, Russian Federation
✉ egelskaya72@mail.ru

Abstract
Introduction. The malfunction of removable load-handling devices (RLHD) poses significant production risks. That is why research in this field is relevant. The problem has often become a topic of scientific investigation. The authors propose using artificial intelligence more extensively to monitor the state of RLHD. This paper presents a study on how to improve the machine vision model to better identify the absence of locks on RLHD hooks. A probable occurrence of such an issue in production is noted. A storage and monitoring system for RLHD condition is proposed. The aim of this study is to demonstrate the potential for further training of neural networks to significantly enhance the efficiency of RLHD monitoring, ensuring their safe use.
Materials and Methods. The work is based on the results of a survey conducted at the LLC "KZ Rostselmash" plant from 2022 to 2023, involving 144 RLHD. Mathematical statistics methods were used to process the data. A neural network model previously trained using the YOLO computer vision algorithm was studied. It was retrained taking into account the norms of the rejection of RLHD, specified in federal rules and standards. Images of RLHD with defects and missing parts were collected from these sources and used to create a training database. The database was expanded by augmentation. The Roboflow platform was used for work.
Results. The array of images used for further training of the neural network was divided into three samples: training (88%), validation (8%) and test (4%). These samples were used to train and validate its results. The training was completed after 260 epochs, with a steady increase in accuracy. The neural network model of computer vision obtained in this way automatically detected a common defect in the RLHD hook — the absence of a lock. Its performance was assessed using three indicators: average accuracy (94%), prediction accuracy (88.8%) and response (89.2%). The neural network could receive images from a video camera in real-time and recognize hook defects. During the RLHD inspection at the Rostselmash plant, a grab for lifting engines was found to have all three hooks defective — without locks. To avoid such situations, at the end of work, it was recommended to place the RLHD on a special stand equipped with a microcontroller device that could monitor for a number of potential issues using radio frequency identification.
Discussion and Conclusion. The main goal of this proposed solution is to detect and address signs of non-compliance with the established standards. This task can be implemented in facilities that use lifting equipment. In this case, the timely noticed RLHD defects will allow preventing production incidents. As a result, material damage can be reduced and injury statistics improved.

Keywords: monitoring the condition of removable load-handling devices, rejection of load-handling devices, defects of hooks for cargo work

Acknowledgements. The authors would like to express their gratitude to the colleagues — specialists from the Operation of Transport Systems and Logistics Department at Don State Technical University — for their assistance in preparing the research materials.

For Citation. Egelsky VV, Nikolaev NN, Egelskaya EV, Korotkiy AA. Use of Artificial Intelligence to Monitor the Reliability of Removable Load-Handling Devices. *Safety of Technogenic and Natural Systems.* 2024;8(2):57–67. https://doi.org/10.23947/2541-9129-2024-8-2-57-67

Научная статья

Использование искусственного интеллекта для контроля надежности съемных грузозахватных приспособлений

В.В. Егельский, Н.Н. Николаев, Е.В. Егельская ✉, А.А. Короткий

Донской государственный технический университет, Российская Федерация

✉ egelskaya72@mail.ru

Аннотация

Введение. Неисправность съемных грузозахватных приспособлений (СГП) создает значимые производственные риски. Этим обусловлена актуальность исследований в данном направлении. Проблема часто становится темой научных изысканий. Авторы предлагают шире использовать искусственный интеллект для мониторинга состояния СГП. В представленной работе показано, как усовершенствовать модель машинного зрения для лучшего выявления отсутствия замков на крюках СГП. Отмечена вероятность широкого распространения проблемы в производственной практике. Предложена схема стенда хранения и контроля состояния СГП. Цель исследования — продемонстрировать возможности дообучения нейросети для существенного повышения эффективности контроля СГП, обеспечивающего безопасность их применения.

Материалы и методы. Работа базируется на актах обследования 144 СГП на заводе ООО «КЗ «Ростсельмаш»» в 2022–2023 гг. Материалы обрабатывались методами математической статистики. Исследовалась нейросетевая модель, предварительно обученная по алгоритму компьютерного зрения YOLO. Ее дообучили с учетом норм браковки СГП, зафиксированных в федеральных правилах и стандартах. Из этих источников взяли изображения СГП с дефектами и отсутствующими элементами и сформировали базу для дообучения сети. Базу расширили методом аугментации. Для работы использовали платформу Roboflow.

Результаты исследования. Массив изображений для дообучения нейросети разделили на три выборки: обучающую (88 %), проверочную (8 %) и тестовую (4 %). По ним проводили обучение и верифицировали его результаты. Обучение завершилось за 260 эпох при стабильном увеличении точности работы. Полученная таким образом нейросетевая модель компьютерного зрения автоматически обнаруживает часто встречающийся дефект крюка СГП — отсутствие замка. Качество ее работы оценили по трем показателям: средняя точность (94 %), точность предсказания (88,8 %) и отклик (89,2 %). Нейросеть может в режиме реального времени получать изображение с видеокамеры и распознавать дефект крюка. При обследовании СГП на заводе «Ростсельмаш» обнаружили эксплуатируемый захват для подъема двигателей, у которого все три крюка оказались дефектными — без замков. Для исключения таких ситуаций по окончании работы целесообразно размещать СГП на специальном стенде с микроконтроллерным устройством, которое отследит наличие ряда проблем с помощью радиочастотной идентификации.

Обсуждение и заключение. Основное предназначение описанного решения — выявление и фиксация признаков несоответствия СГП требуемым нормативам. Задача может быть реализована на объектах, эксплуатирующих подъемные сооружения. В этом случае своевременно замеченные изъяны СГП позволят предупреждать производственные инциденты. В итоге можно рассчитывать на снижение материального ущерба и улучшение статистики по травматизму.

Ключевые слова: контроль состояния съемных грузозахватных приспособлений, браковка грузозахватных приспособлений, дефекты крюков для грузовых работ

Благодарности. Авторы выражают признательность коллегам — специалистам кафедры «Эксплуатация транспортных систем и логистика» ДГТУ за помощь при подготовке материалов исследования.

Для цитирования. Егельский В.В., Николаев Н.Н., Егельская Е.В., Короткий А.А. Использование искусственного интеллекта для контроля надежности съемных грузозахватных приспособлений. *Безопасность техногенных и природных систем.* 2024;8(2):57–67. https://doi.org/10.23947/2541-9129-2024-8-2-57-67

Introduction. The sites where lifting cranes and other types of cranes are used are considered hazardous production facilities (HPF)[1] and must comply with strict safety regulations. This includes safe operation of the equipment complex and its elements, such as removable load-handling devices (RLHD). The health of this system depends to some extent on human factors [1], and the risks associated with these operations can be reduced by introducing automation and digital solutions.

HPF activities are under the supervision of the Federal Service for Environmental, Technological and Nuclear Supervision (Rostechnadzor). At the same time, lifting structures and their associated equipment are exempt from regular inspections[2], and the condition of the equipment is monitored by relevant services within the operating enterprises [2].

Rostechnadzor publishes annual statistics on accidents and incidents, as well as conclusions based on the results of its investigations[3]. These materials help us identify the main causes of accidents, particularly those related to the monitoring of the condition of lifting devices. Some of the main causes include:

– absence of designated specialists responsible for the safe operation of lifting devices;

– admittance to work of personnel without appropriate qualifications;

– absence of job descriptions and production instructions at the facility;

– untimely scheduled inspections, repairs and technical inspections of lifting devices and equipment working in conjunction with them.

Slingers use removable devices to hang loads from the hooks of lifting cranes or crane manipulators. The trouble-free operation of the facility depends on the accuracy of these procedures.

Lifting structures should only be used in work projects or with technological maps, which include a mandatory element — a cargo slinging scheme[4]. Before starting work, slingers, crane operators, and specialists responsible for safe work production get familiar with the technological maps with provision of signature upon familiarization. The slinging systems are posted at the work site.

The second important safety factor is the condition of the RLHD equipment. RLHD malfunctioning can lead to falling of goods, lifting devices, or their components. Additionally, the stability of the lifting structure can be compromised, which can result in material losses and injury to personnel.

Regulatory legal acts and job descriptions specify the requirements for continuous monitoring of the RLHD condition. According to these documents:

– the slinger is responsible for daily monitoring of the RLHD condition, for which they are given time prior to starting work[5];

– at least once every 10 days, the specialist responsible for the safe operation of lifting structures monitors the condition of slings. At least once a month, they also monitor grabs and traverses.

The results of the inspections are recorded in the logbook of periodic inspections of removable lifting devices and containers.

The fulfillment of these requirements should exclude the possibility of using faulty, defective RLHD.

It is known from statistics and literature [2] that the accident rate at HPF depends on the qualifications of managers and responsible specialists. Personnel with insufficient competencies [3] may neglect control, skip some stages, and violate the rules of RLHD inspections and documentation of their results.

The correct use of artificial intelligence greatly enhances the effectiveness of RLHD control.

This article explores the potential of further training neural networks [4] in order to improve the accuracy of monitoring the RLHD operational state. We propose introducing neural network-based computer vision technologies [5] for monitoring the operability of hooks on removable load-handling devices.

This approach is in line with the National Strategy for the Development of Artificial Intelligence for the period up to 2030[6].

The aim of this study is to explore the potential for further training of a neural network in order to enhance the capabilities of machine vision for determining the RLHD suitability. The practical application of this proposed solution has the potential to improve the efficiency of monitoring the RLHD status and, consequently, enhance the safety of their usage.

---

[1] *On Industrial Safety of Hazardous Production Facilities.* Federal Law No. 116-FZ dated 21.08.1997. Consultant Plus. URL: http://www.consultant.ru/document/cons_doc_LAW_15234/ (accessed: 18.03.2024). (In Russ.).

[2] Id.

[3] Rostechnadzor. *Report on the Activities of the Federal Service for Environmental, Technological and Nuclear Supervision in 2022*. URL: https://www.gosnadzor.ru/public/annual_reports (accessed: 10.03.2024). (In Russ.).

[4] *On the Approval of Federal Norms and Rules in the Field of Industrial Safety "Safety Rules for Hazardous Production Facilities where Lifting Structures are Used"*. Rostechnadzor Order No. 461 dated 26.11.2020. Garant. URL: https://base.garant.ru/400165076/ (accessed: 10.03.2024). (In Russ.).

[5] *Standard Instruction for Slingers on the Safe Production of Work by Lifting Machines (RD 10-107-96).* Garant. URL: https://base.garant.ru/3924623/ (accessed: 10.03.2024). (In Russ.).

[6] *National Strategy for the Development of Artificial Intelligence for the Period up to 2030.* Consultant Plus. URL: https://www.consultant.ru/document/cons_doc_LAW_335184/ (accessed: 10.03.2024). (In Russ.).

Materials and Methods. Slings are designed to hook, strap and hold cargo on the hook of a lifting device [6]. Different methods of sling rejection are used, depending on the design of the sling and the material it is made from. The standards for sling rejection are defined in relevant documents. The test methods are described in the state standards[7].

Each sling must have a marking tag indicating the manufacturer, serial number, load capacity and test date. The absence of a tag is unacceptable and is an indication of a defect. An important element of the RLHD and slings is a hook with a mandatory locking device (hook lock) [7].

In preparing this article, we used mathematical statistics to analyze the results of a mass RLHD survey conducted at the LLC "KZ "Rostselmash" plant in Novocherkassk in 2022 and 2023. The survey was conducted by specialists from the engineering consulting center "Mysl"", which was affiliated with Novocherkassk State Technical University. The results of the survey were compiled in the form acts — mandatory appendices to the passports of each RLHD. These documents were the source materials of the presented scientific work (Fig. 1, 2).

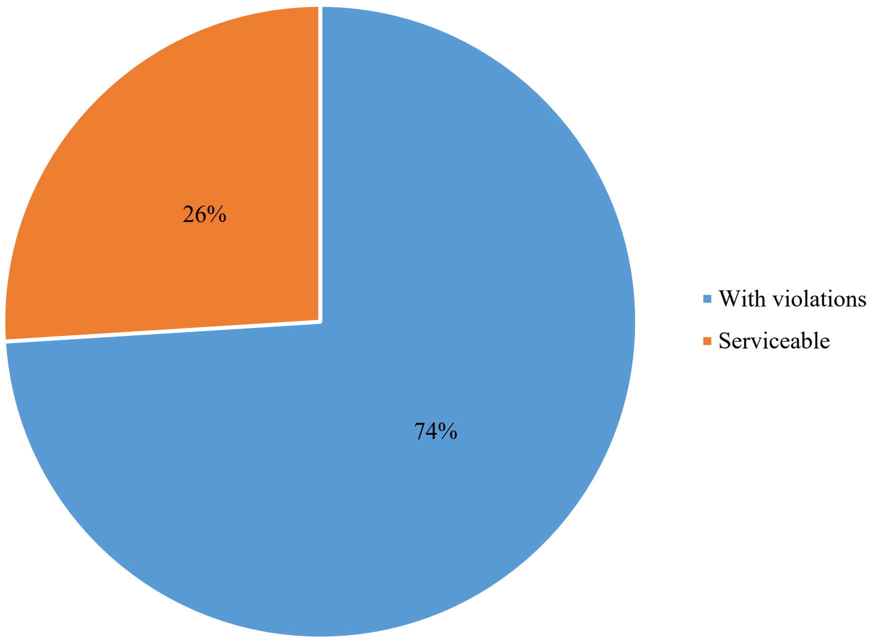

Fig. 1. Ratio of serviceable and non-serviceable RLHD

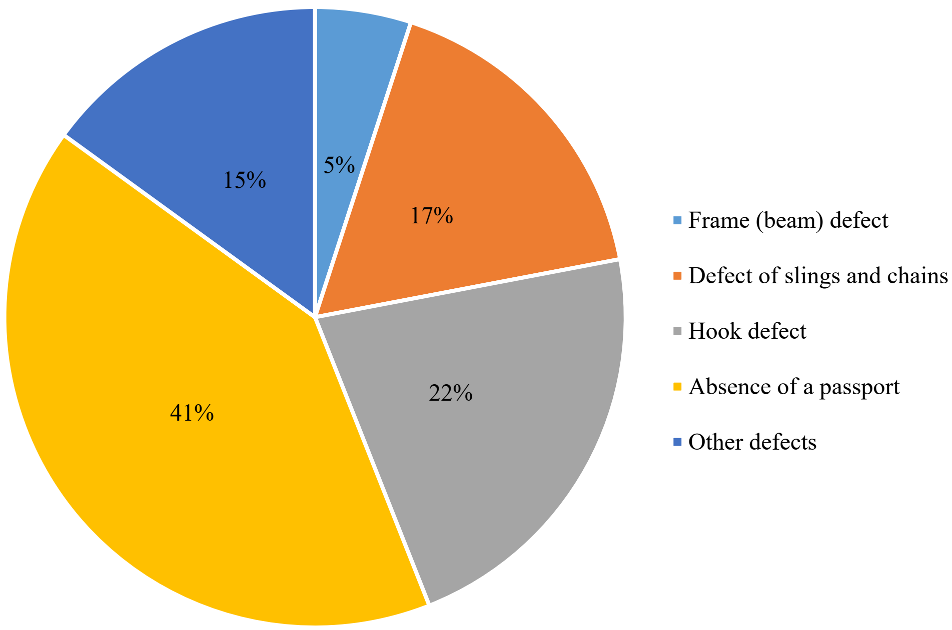

Fig. 2. Proportion of RLHD with inconsistencies and defects

[7] GOST 33715-2015. *Cranes. Non-Fixed Load-Lifting Attachments and Tare. Exploitation.* Garant. URL: https://base.garant.ru/71684432/ (accessed: 10.03.2024). (In Russ.).

According to the survey of 144 RLHD, three quarters of the devices did not meet the requirements of regulatory documentation[6] (Fig. 1).

The analysis of the distribution of defects and inconsistencies in regulatory documentation showed that the absence of an RLHD passport was most common (more than 40% of cases). The most common technical flaw was a hook defect (22% of cases). Defects in chains and slings accounted for 17% of recorded cases, and other defects accounted for 15%. Structural defects amounted to 5%. These were flaws in special grips, pins, clamps, frames, beams, and traverses.

It is advisable to start the study with questions of monitoring the condition of hooks. In almost 100% of cases, their defects were the absence or breakdown of the sling retainer (lock).

In [8], the possibilities of integrated risk assessment in the diagnosis of steel ropes using computer vision are explored. This approach has become the basic one in the development of methods for quickly identifying nonconformities and malfunctions of the RLHD. Devices that do not meet the required standards should not be permitted to operate. To this end, technical control must be strengthened through a digital monitoring system equipped with computer vision that can automatically detect visually identifiable malfunctions.

Based on the results of the comparative analysis, one of the computer vision algorithms was chosen — the pre-trained YOLOv8 open access neural network[8]. This was the latest version of a well-known model for real-time object detection and image segmentation. It was based on the latest advances in deep learning and computer vision and had high performance in terms of speed and accuracy. Due to its design features, it was suitable for various applications and adapted easily to different hardware platforms. YOLOv8 identified many real-world objects: people, cars, computers, pieces of furniture, etc. However, YOLOv8 needed additional training to detect RLHD [9]. It was performed using the open online service Roboflow[9], which provided the user with tools to create a database of annotated images necessary for training the YOLOv8 model. The service allowed you to upload and annotate images by specified classes, assign them to train, validation and test samples [10].

Results. To retrain the network, unannotated images of hooks of different types, sizes and shapes with and without a lock (Fig. 3) were used. These images were collected from various sources, including during the RLHD examination.

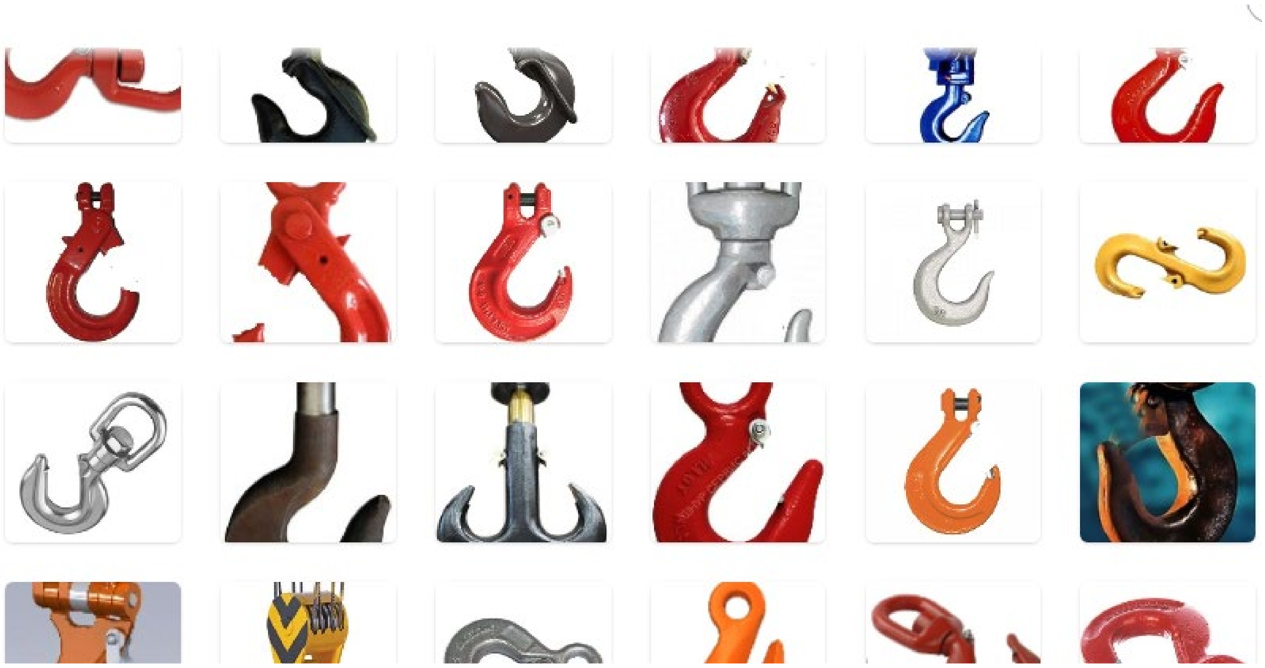

Fig. 3. Images of hooks without locks uploaded to the Roboflow service

The variety of hook images improved the quality of learning and subsequent recognition, significantly reduced the number of errors of the pre-trained model [11].

At the next stage, the contours of the recognition objects were selected using the smart polygon tool and annotated according to the hookWithLock (for hooks with a lock) and noLock (for hooks without a lock) classes (Fig. 4).

[8] *Introducing Ultralytics YOLOv8.* Ultralytics. URL: https://docs.ultralytics.com/ (accessed: 10.03.2024).
[9] *Everything You Need to Build and Deploy Computer Vision Models.* Roboflow. URL: https://roboflow.com/ (accessed: 10.03.2024).

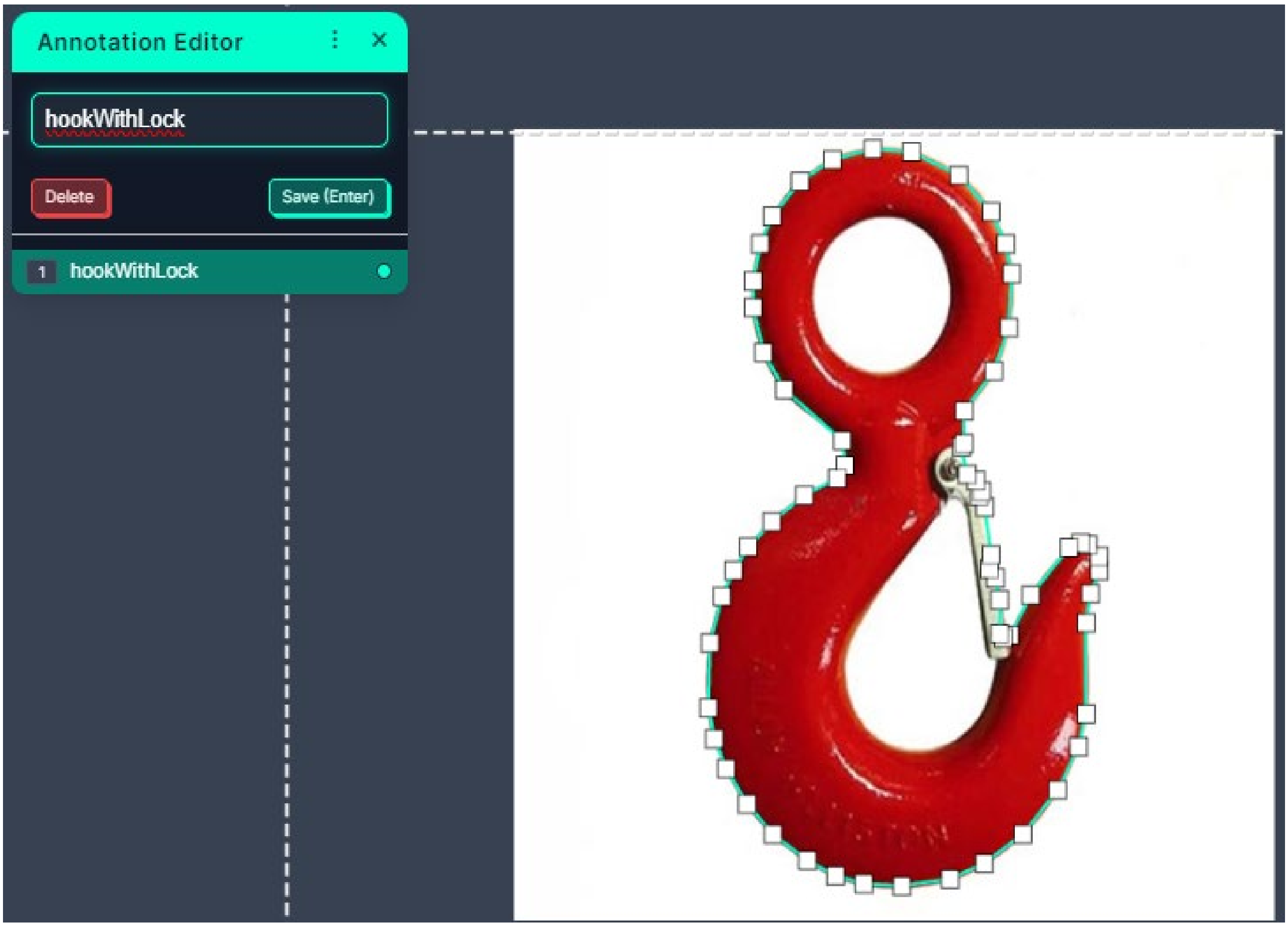

Fig. 4. Annotating the image

The next stage in the additional training process for the neural network in Roboflow was augmentation, i.e. increasing the sample size by converting images. Perspective, noises, turns, etc. were used for this purpose. As a result, 401 annotated images were obtained (Fig. 5)

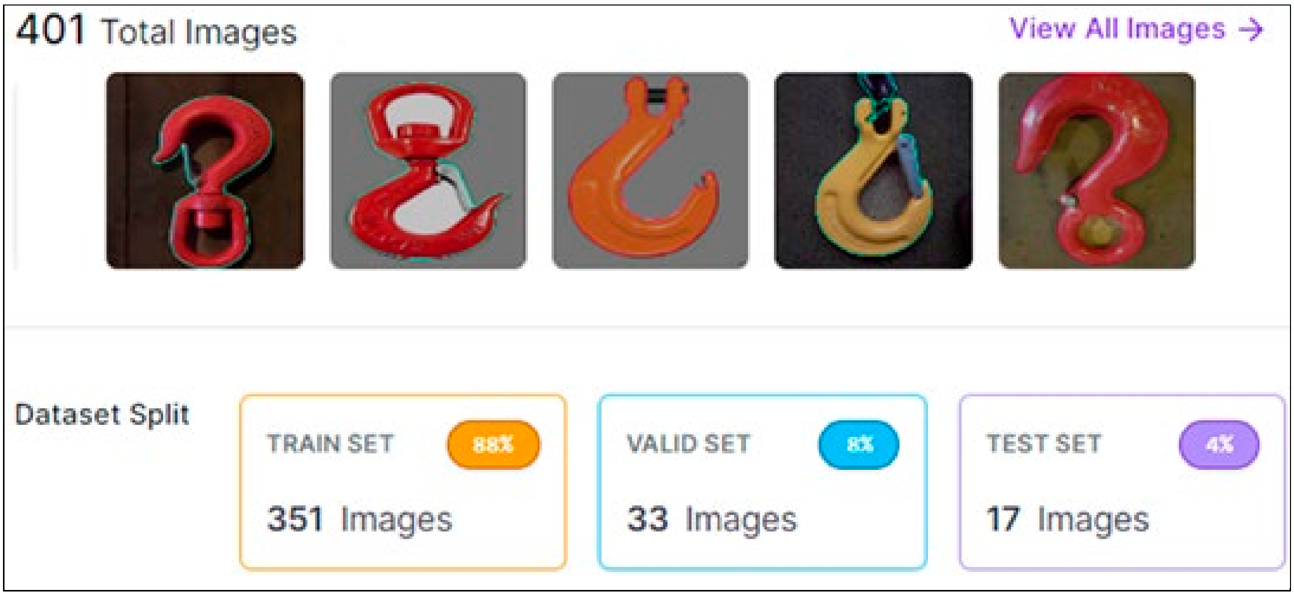

Fig. 5. The result of annotation and augmentation

The resulting array of images was divided into train set, valid set and test set in the ratio of 88%, 8% and 4%, respectively. Samples were used for network training and verification of learning outcomes [12].

The network trained and compared the results with a valid sample. At the same time, the accuracy of its work steadily increased, and the training was completed in 260 epochs (Fig. 6).

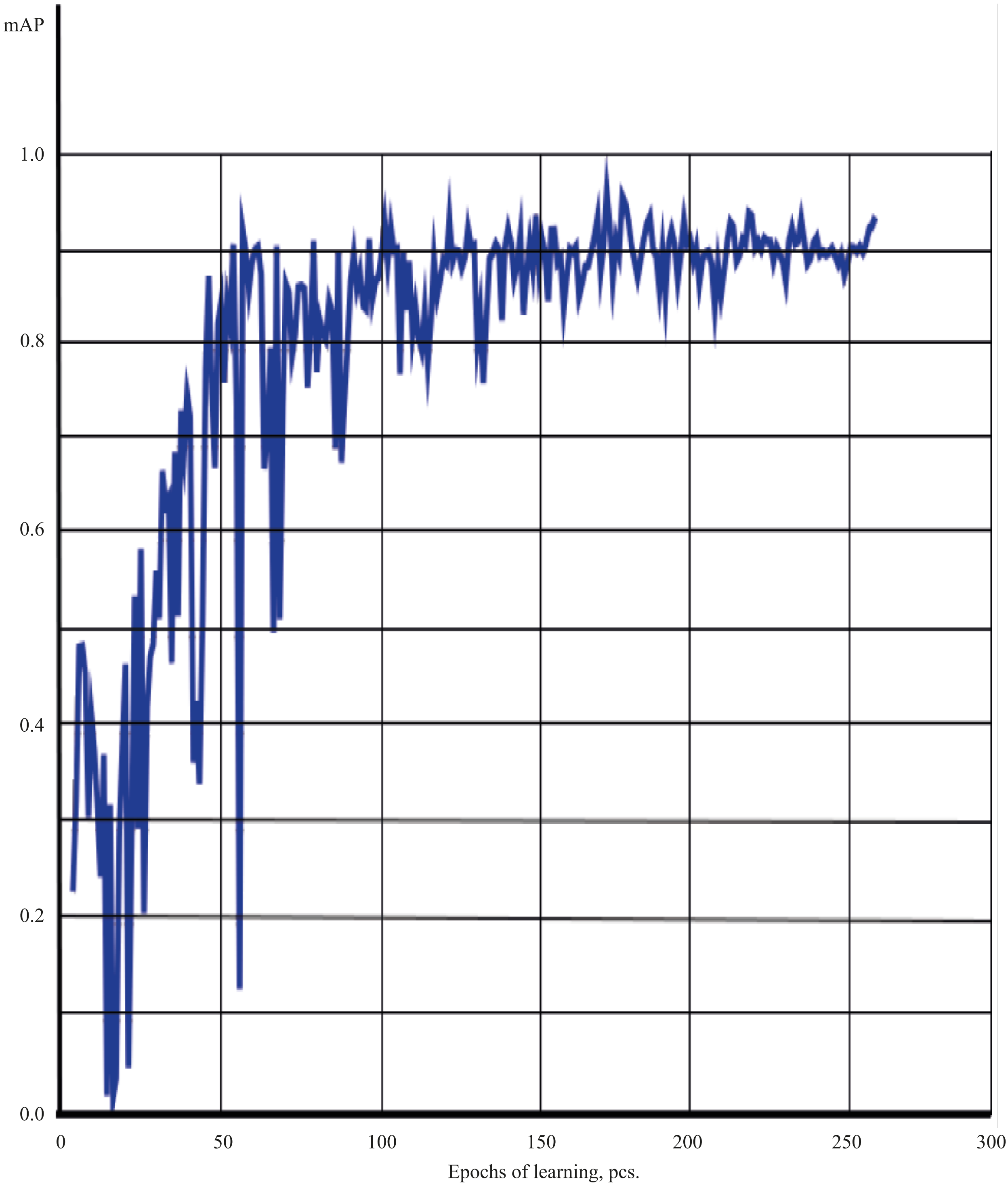

Fig. 6. Changes in the accuracy of computer vision neural network in the learning process

As a result, we obtained a neural network model of computer vision, which automatically detected a common defect of the RLHD hook — the absence of a lock. The quality of its work was assessed by three indicators described below (Fig. 7)

Fig. 7. Indicators of the quality of training of the resulting neural network

1. Average precision value (mAP), equal to the average value of the average accuracy index for all classes in the model. In this case, it was 94%.

2. Precision of prediction — showed how often the model's predictions turned out to be correct. The fixed level was 88.8%.

3. Recall — the percentage of successfully identified tags. It was 89.2%.

Such a neural network could receive a real-time image from any video camera and recognize a hook defect (Fig. 8)

a) *b)*

Fig. 8. Work of a pre-trained neural network to detect hooks: *a* — with a lock; *b* — without a lock

This neural network was easily embedded in the program code in any programming language. This made it possible to create a software product for automated assessment of the presence of RLHD defects and implement it into a production digital system for monitoring the RLHD condition [13].

During the RLHD inspection at the LLC “KZ “Rostselmash”” plant, a PM-001501 grab was found. The device was manufactured by the production company “Pod’em-master” and was designed for lifting engines of the Yaroslavl Motor Plant. It could serve as an example of the operation of a faulty RLHD (Fig. 9).

Fig. 9. PM-001501 grab without locks on hooks

As you can see, there were no mandatory locks on all three hooks. Nevertheless, the device was operated, which posed risks to the life and health of personnel, as well as endangered the integrity of technical facilities. It was logical to assume that such elements were in operation at many enterprises in Russia. To avoid such situations, the authors of this article proposed to place the RLHD on a special stand at the end of the work (Fig. 10).

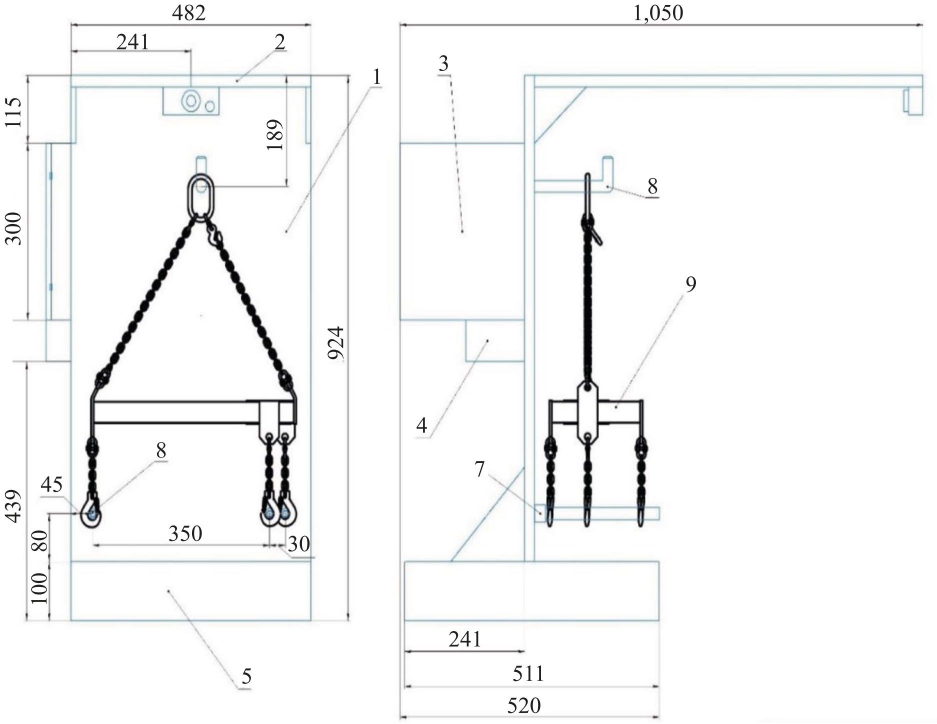

Fig. 10. Stand for storage and monitoring of the RLHD condition: 1 — stand; 2 — bracket with camera; 3 — box for RLHD passport; 4 — electronic unit; 5 — base; 6 — hook pin; 7 — insulator; 8 — hanger; 9 — removable load-handling device

The stand was equipped with a microcontroller device that monitored the availability of the RLHD passport using an RFID tag (radio frequency identification). In addition, it was used to determine the correct placement of hooks on the stand. The tactile pins of the ESP32 controller were used for this purpose. When the hooks were positioned correctly, their condition was recorded by a camera [14] mounted on the stand bracket. The resulting image was interpreted by a trained neural network model of computer vision and a preliminary conclusion was drawn on the presence or absence of a defect [15].

Discussion and Conclusion. The proposed software and hardware solution is designed for automated assessment of the condition of RLHD elements of operated lifting cranes. Using the potential of artificial intelligence improves the quality and efficiency of monitoring. In particular, it allows timely identification of the lack of necessary elements and defective indicators of the RLHD. This opens up the possibility of a significant reduction in accidents. Adequate implementation of the proposed approach in production practice will also ensure informed decision-making regarding extending the service life, admission to further operation or rejection of the RLHD.

References

1. Egelskaya EV, Romanenko MYu. Aspects of Application of a Risk-Based Approach to Hazardous Production Facilities. *Safety of Technogenic and Natural Systems.* 2020;(4):45–49. https://doi.org/10.23947/2541-9129-2020-4-45-49

2. Egelsky VV, Nikolaev NN, Egelskaya EV, Korotkiy AA. Influence of the Competencies of Lifting Crane Specialists on the Probability of Emergencies. *Safety of Technogenic and Natural Systems.* 2023;(2):70–79. https://doi.org/10.23947/2541-9129-2023-7-2-70-79

3. Sanaz Sadeghi, Nazi Soltanmohammadlou, Payam Rahnamayiezekavat. A Systematic Review of Scholarly Works Addressing Crane Safety Requirements. *Safety Science*. 2021;133:105002. https://doi.org/10.1016/j.ssci.2020.105002

4. Chislov ON, Lyabakh NN, Kolesnikov MV, Bakalov MV, Zadorozhny VM. Neural Network Investigation of Transport Systems. *Transport: science, equipment, management (Scientific information collection)*. 2021;(10):9–13. https://doi.org/10.36535/0236-1914-2021-10-2 (In Russ.).

5. Turluyev RR. Neural Networks in Corporate Governance Systems. In: *Proceedings of the II All-Russian Scientific and Practical Conference "Digitalization: Russia and the CIS in the context of global transformation"*. Petrozavodsk: Novaya Nauka; 2021. P. 7–16. https://doi.org/10.46916/12042021-2-978-5-00174-191-6 (In Russ.).

6. Shuai Kang, Hongbing Wang. Crane Hook Detection Based on Mask R-CNN in Steel-making Plant. *Journal of Physics: Conference Series*. 2020;1575:012151. https://doi.org/10.1088/1742-6596/1575/1/012151

7. Weiguang Jiang, Lieyun Ding. Unsafe Hoisting Behavior Recognition for Tower Crane Based on Transfer Learning. *Automation in Construction*. 2024;160:105299. https://doi.org/10.1016/j.autcon.2024.105299

8. Panfilov AV, Nikolaev NN, Yusupov AR, Korotkiy AA. Integral Risk Assessment in Steel Ropes Diagnostics Using Computer Vision. *Safety of Technogenic and Natural Systems.* 2023;(1):56–69. https://doi.org/10.23947/2541-9129-2023-1-56-69

9. Piskoty G, Affolter Ch, Sauder M, Nambiar M, Weisse B. Failure Analysis of a Ropeway Accident Focussing on the Wire Rope's Fracture Load under Lateral Pressure. *Engineering Failure Analysis*. 2017;82:648–656. https://doi.org/10.1016/j.engfailanal.2017.05.003

10. Aimin Zhu, Zhiqian Zhang, Wei Pan. Technologies, Levels and Directions of Crane-Lift Automation in Construction. *Automation in Construction*. 2023;153:104960. https://doi.org/10.1016/j.autcon.2023.104960

11. Zhe Sun, Zhufu Zhu, Ruoxin Xiong, Pingbo Tang, Zhansheng Liu. Dynamic Human Systems Risk Prognosis and Control of Lifting Operations during Prefabricated Building Construction. *Developments in the Built Environment*. 2023;14:100143. https://doi.org/10.1016/j.dibe.2023.100143

12. Vahid Kargar, Mehdi Jahangiri, Moslem Alimohammadlu, Mojtaba Kamalinia, Marziyeh Mirazahossieninejad. Risk Assessment of Mobile Crane Overturning in Asymmetric Tandem Lifting (ATL) Operation Based on Fuzzy Fault Tree Analysis (FFTA). *Results in Engineering*. 2022;16:100755. https://doi.org/10.1016/j.rineng.2022.100755

13. Szpytko J, Duarte YS. Exploitation Efficiency System of Crane Based on Risk Managemen. In: *Proceedings of the International Conference on Innovative Intelligent Industrial Production and Logistics — IN4PL.* SciTePress; 2020. P. 24–31. https://doi.org/10.5220/0010123200240031

14. Stroganov YuN, Belov VV, Belova NN, Maksimov AN, Ognev OG. Analysis of Model for Assessing the Road Train Movement Stability. *Journal of Physics: Conference Series.* 2021;1889:042051 https://iopscience.iop.org/article/10.1088/1742-6596/1889/4/042051

15. Haoran Ding, Mingxing Li, Ray Y. Zhong, George Q. Huang, Multistage Self-Adaptive Decision-Making Mechanism for Prefabricated Building Modules with IoT-Enabled Graduation Manufacturing System. *Automation in Construction*. 2023;148:104755. https://doi.org/10.1016/j.autcon.2023.104755

About the Authors:

Vladislav V. Egelsky, Postgraduate Student of the Transport Systems Operation and Logistics Department, Don State Technical University (1, Gagarin Sq., Rostov-on-Don, 344003, RF), ORCID, sp_5sp_6pb_97n14@mail.ru

Nikolay N. Nikolaev, Cand.Sci. (Eng.), Associate Professor, Associate Professor of the Transport Systems Operation and Logistics Department, Don State Technical University (1, Gagarin Sq., Rostov-on-Don, 344003, RF), SPIN-code: 8640-3508, ORCID, ResearcherID, ScopusID, nnneks@yandex.ru

Elena V. Egelskaya, Cand.Sci. (Eng.), Associate Professor of the Transport Systems Operation and Logistics Department, Don State Technical University (1, Gagarin Sq., Rostov-on-Don, 344003, RF), SPIN-code: 4663-9101, ORCID, egelskaya72@mail.ru

Anatoly A. Korotkiy, Dr.Sci. (Eng.), Professor, Head of the Transport Systems Operation and Logistics Department, Don State Technical University (1, Gagarin Sq., Rostov-on-Don, 344003, RF), SPIN-code: 1948-3628, ORCID, ScopusID, korot@novoch.ru

Claimed Contributorship:

VV Egelsky: data preparation for neural network training.

NN Nikolaev: development of research methodology, neural network training.

EV Egelskaya: assessment of the state of the issue and the relevance of the research, participation in the formulation of the initial concept, design of the research results.

AA Korotkiy: generalization of the research results, formulation of the conclusions.

Conflict of Interest Statement: the authors declare no conflict of interest.

All authors read and approved the final version of the manuscript.

Received 22.03.2024
Revised 05.04.2024
Accepted 10.04.2024

Об авторах:

Владислав Витальевич Егельский, аспирант кафедры эксплуатации транспортных систем и логистики Донского государственного технического университета (344003, РФ, г. Ростов-на-Дону, пл. Гагарина, 1), ORCID, sp_5sp_6pb_97n14@mail.ru

Николай Николаевич Николаев, кандидат технических наук, доцент, доцент кафедры эксплуатации транспортных систем и логистики Донского государственного технического университета (344003, РФ, г. Ростов-на-Дону, пл. Гагарина, 1), SPIN-код: 8640-3508, ORCID, ResearcherID, ScopusID, nnneks@yandex.ru

Елена Владимировна Егельская, кандидат технических наук, доцент кафедры эксплуатации транспортных систем и логистики Донского государственного технического университета (344003, РФ, г. Ростов-на-Дону, пл. Гагарина, 1), SPIN-код: 4663-9101, ORCID, egelskaya72@mail.ru

Анатолий Аркадьевич Короткий, доктор технических наук, профессор, заведующий кафедрой эксплуатации транспортных систем и логистики Донского государственного технического университета (344003, РФ, г. Ростов-на-Дону, пл. Гагарина, 1), SPIN-код: 1948-3628, ORCID, ScopusID, korot@novoch.ru

Заявленный вклад авторов:

В.В. Егельский — подготовка данных для обучения нейронной сети.

Н.Н. Николаев — разработка методики исследования, обучение нейронной сети.

Е.В. Егельская — оценка состояния вопроса и актуальности исследования, участие в формировании исходной концепции, оформление результатов исследования.

А.А. Короткий — обобщение результатов исследования, формулирование выводов.

Конфликт интересов: авторы заявляют об отсутствии конфликта интересов.

Все авторы прочитали и одобрили окончательный вариант рукописи.

Поступила в редакцию 22.03.2024
Поступила после рецензирования 05.04.2024
Принята к публикации 10.04.2024