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Control of the Safety of Bulk Cargo by Determining the Unfilled Volume of the Gondola Car with Stereophotogrammetry

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ABSTRACT

The process of developing integrated transport systems involves not only a radical change in the scale of the tasks being solved, but also the use of effective methods and tools.

The object of the study is the process of controlling safety of cargo transported in a gondola car. The subject of the study is the relief of the upper surface of the cargo and the unfilled space of the gondola car. The relevance of the study is due to the growing volumes of transportation and significant losses of bulk cargo during transportation, the development of information technology and the possibility of creating an affordable tool for monitoring the safety of transported goods.

The objective of the study is to describe an intelligent tool for monitoring the safety of goods transported by rail in gondola cars, and the process of its application in real time. The proposed control method requires for the transfer of operator functions to a digital assistant and the minimisation of the equipment necessary for monitoring. It is proposed to control the safety of bulk cargo by processing the image of a gondola car with cargo obtained from photo-video cameras with a convolutional neural network, and to calculate the volume of space unfilled with cargo using photogrammetry methods.

Keywords: *railways, cargo safety control, unfilled volume of a gondola car, relief of the cargo surface, convolutional neural network, photogrammetry, stereophotogrammetry, digitalisation of railway transport, intelligent transport systems.*

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INTRODUCTION

Railway transport ensures the uninterrupted operation of all sectors of the economy, transporting extracted minerals, equipment and products of industrial and manufacturing production.

For transportation of machinery and equipment, bulk and piecemeal, long and bulky, large-sized and other cargo that does not require protection from precipitation, universal gondola cars or specialised open wagons are used.

According to Rosstat [Federal State Statistics Service], the main types of cargo transported by rail in 2021 were coal (371 668,57 thousand tons or 29 % of the total volume of loading of main types of cargo), construction cargo (126 674,9 thousand tons or 10 % of the total volume), iron and manganese ore (119 983,0 thousand tons or 9 % of the total volume), as well as coke, non-ferrous metal ores, ferrous metal scrap and timber cargo [1].

Sand, crushed stone, alumina and other types of bulk cargo containing small fractions can be transported in gondola cars. During such transportation, due to the influence of external factors, cargo losses are inevitable.

It is bulk industrial cargo transported in open and closed cars that have the largest share of cargo weight losses during transportation [1].

The reasons for the loss of bulk cargo during transportation may be loose internal gaps and other defects in the car body that appear as a result of pressure from the mass of the cargo after loading, vibration during movement, or wear and deformation of the car during operation. Loss of cargo is caused by violation of transportation and storage conditions, blowing out of cargo particles by air flow (dust entrainment), shedding of the top of the cargo pile beyond the side of the body and the actions of intruders. The reason for the loss of cargo may also be a violation of production technology, for example, shipment before the completion of the change in physical and chemical properties. Due to external conditions and the inherent properties of the cargo, its natural loss may occur. As a result, the amount of cargo in the car at the delivery point will differ from the amount of cargo at dispatch.

Even partial loss of cargo leads to financial costs and adverse consequences for all persons interested in quality transportation. Consignees are faced with a shortage of the required volume of necessary goods. Shippers, carriers and persons responsible for transportation may receive claims from consignees. Detection of loss by the consignee upon receipt or already during processing of cargo can lead to disruptions in its business processes [2]. The difficulty of determining the location of cargo loss and the responsible organisations leads to lengthy disputes, loss of trust in shippers and a decrease in the competitiveness of cargo carriers in the market.

Reliability of transportation is one of the main requirements for transport companies. To reduce the likelihood of cargo loss, timely detection of loss and identification of bottlenecks in the supply chain, railway transport enterprises need a modern tool for monitoring the safety of cargo transported in open cars. Monitoring the condition of cargo during transportation in real time is an effective process for ensuring reliable transportation.

Modern scientific research in the field of transportation management and transport operation witnesses a steady trend to improve transportation processes using digital tools and to improve business processes using computer vision systems and artificial intelligence [2; 3].

The *objective* of the study is to describe the intelligent structure of monitoring the safety of goods transported by rail in open cars, and the process of its application in real time. As a result of the use of software, the operator's functions for visual control of cargo in railway transport should be transferred to a digital tool with the addition of new capabilities, increasing the volume and improving the quality of control.

Since technologies are affordable, do not require a complex process of implementation at the enterprise and additional personnel skills, have a higher degree of diffusion and speed of spread, the research process should solve the problems of minimal use of various types of equipment and ease of operation of the tools of control over cargo safety.

[1] Transport of Russia. Information and statistical bulletin. Ministry of Transport of the Russian Federation. Moscow, 2022.

RESEARCH METHODS

Based on the results and successful testing of a previously completed study on identifying damaged cargo and packaging during transportation and warehousing using a convolutional neural network, it was decided to develop the technology in priority areas [2].

Based on the results of the description of the problem of loss of bulk cargo during transportation in gondola cars, conclusions were drawn about the relevance and research goals were set.

As a result of the analysis and systematisation of existing and promising methods for monitoring the safety of cargo in gondola cars, it became clear that at the moment there are no tools that meet the goals.

In the process of searching for tools and methods for calculating uneven surfaces and small fractions of a certain object, an analysis of open sources of information was carried out, including in Russian and foreign abstract databases of previously completed studies, thematic publications, data on the websites of technology companies, government bodies, etc. As a result of the search and analysis, it was concluded that the objectives of the study can be achieved through the transfer of photogrammetry methods.

An extrapolation of stereophotogrammetry is proposed for shaping and calculating the relief parameters of the upper part of the cargo in a gondola car.

A descriptive and visual representation of image processing by an intelligent computer-software information system was carried out in the process of determining the unfilled volume of a gondola car using the photogrammetry method.

Based on objective scientific forecast data, conclusions were drawn about the possibility of using the proposed method to control the safety of bulk cargo during transportation.

LITERATURE REVIEW

The principles of ensuring the safety of bulk cargo transported in gondola cars are reflected in the relevant regulatory documents, which require, to prevent spillage and blowing, to clean the cars from the remnants of previously transported cargo and to use serviceable cars and unloading hatches [4]. An example of regulatory regulation to be quoted is the Order of the Ministry of Transport of Russia dated January 14, 2020, No. 9 «On approval of the rules for transportation of goods by rail in open rolling stock» [2]. Compliance with the norms and rules for the transportation of goods in gondola cars makes it possible to exclude their excessive loss during transportation as compared to established standards.

To ensure the safety of goods transported in gondola cars, sealing materials are used to seal body defects, including the lining of cars [5]. Special tools and compaction equipment are used to level and statically compact cargo during loading. The loads are covered with protective materials and bound with special pastes and impregnations. If necessary, it is possible to choose big bags, containers for transportation, use car liners and other devices that protect against the loss of bulk cargo.

Control of the safety of cargo can be carried out by weighing the loaded rolling stock at the departure station and destination station [6]. During weight control, the difference between the masses of sent and received cargo, exceeding the limit of permissible discrepancy considering natural loss, indicates the loss of cargo.

Automatic commercial control systems have been developed and used in railway transport, allowing to inspect frames, sides, roofs, hatches and control the cleaning of cars, visually identify, video record, recognize inventory numbers, control the filling level of tanks, the dimensions of cars, the filling of liquid and bulk cargo, identify heterogeneity of cargo (for example, water in petroleum products), carry out dynamic and static under-wheel weighing of cars and record the passage of the train.

Automatic systems include a steel supporting structure located on the tracks for installation of control equipment, television and thermal imaging systems, electronic gates with infrared and optical oversize sensors, a car counting unit and wheel counting sensors, a strain gauge rail, light and sound alarms, lighting systems for monitoring in the dark time of day, communication lines and devices for transmitting signals without interference in conditions of electromagnetic radiation. Such automatic systems require the presence

[2] Order of the Ministry of Transport of the Russian Federation dated January 14, 2020, № 9 «On approval of the rules for transportation of goods by rail in open rolling stock».

of an equipped operator-observer workplace.

Infrared beam sensors form a clearance zone, the intersection of which (beam overlap) indicates that the permissible loading volume of the rolling stock has been exceeded [7].

Control of uniformity and level of loading of cars with liquid and bulk cargo is ensured by direct visual observation by the operator of the loading or by the video stream received from video cameras installed on the frame of the electronic clearance gates.

Thermal imaging systems are used for remote and non-contact monitoring of the filling level of tanks and the filling of cars with liquid and bulk cargo [8]. On the thermographic image, the operator recognizes the border of the loading or embankment of cargo formed in different colours and draws conclusions about the actual filling of the car.

Calculation of cargo mass based on information about the actual level received from a thermal imaging camera is carried out manually or automatically based on the calibration parameters of the body in accordance with its inventory number, as well as the density and temperature of the cargo.

A tool using non-contact laser (3D) scanning can be used to scan the perimeter, geometry and upper part of the body of each car, performed before departure and upon arrival at the destination, making it possible to determine the difference in the volume of cargo in the car and identify the fact of loss [9].

The operation of most 3D laser scanners is based on the principle of triangulation, placing a beam on the surface of an object and measuring the distance to it, or measuring the response time of the beam from the surface of the object. Based on a cloud of points of geometric samples that have coordinates in space, a 3D model is built.

Using industrial 3D scanning, a three-dimensional model of the body with a load is formed in the metric coordinate system. The resulting 3D scan profile is mathematically divided into elementary volumetric cubes, the volumes of which are determined based on the parameters of the body in accordance with its inventory number [10].

After calculating the volumes of the simplest bodies, all calculated volumes are summed up. As a result, a three-dimensional 3D model of the car is formed based on the actual dimensions. The difference between the digital twins of the body at the points of departure and destination, already expressed in units of volume, if the permissible loss norms are exceeded, will indicate the loss of cargo.

The listed modern and promising tools for monitoring the safety of cargo require the installation of additional equipment necessary to perform only these tasks and the involvement of personnel.

The use of additional equipment and materials complicates and increases the cost of the transport process, while not excluding the loss of goods, for example, due to the malicious intent of third parties. Cargo safety monitoring using automatic commercial control systems also requires the installation of expensive equipment directly at the control point and the involvement of an operator to carry out continuous monitoring at each control point.

RESULTS

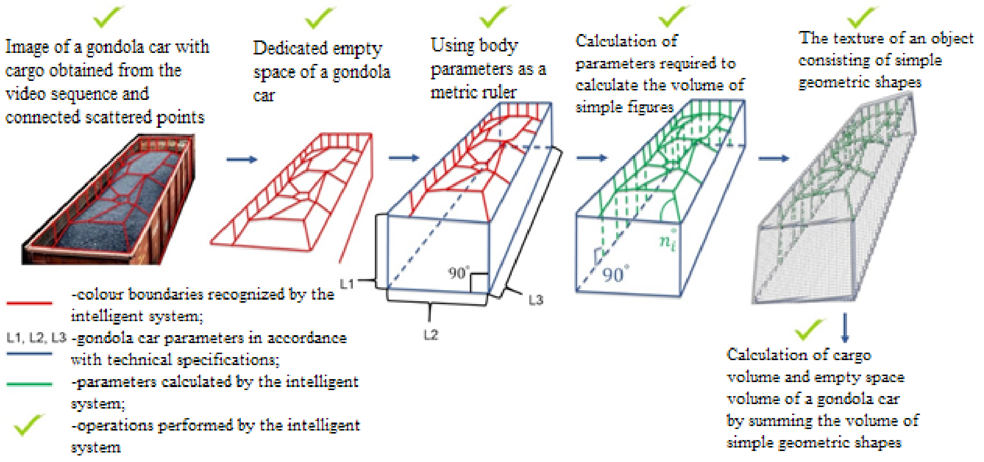
Scanning systems that require the least expensive equipment include systems that use passive scanners that do not have their own radiation, but detect visible light reflected from the surrounding space.

The method of automatic digital models based on photogrammetric tools can be compared with fairly accurate 3D laser scanning [11].

Stereoscopic passive scanning systems using photometric technology involve the use of one or two 2D cameras located in different places and oriented in the same direction [12].

Creating a three-dimensional model and determining the size, shape, position and other characteristics of objects is carried out based on photographs taken from different angles and is done using photogrammetry or stereophotogrammetry. Image processing is carried out using special software.

To obtain video images in places where cargo safety is monitored, it is necessary to install video cameras. A visual 2D image of the real world (a gondola car with cargo) obtained from the video sequence is loaded into the neural network. The image resolution is determined by the camera resolution. To detail the controlled object, the image resolution must be sufficient to recognize the boundaries of the car body, contamination of the car and the contours of the topography of



Pic. 1. Image processing by an intelligent computer-software information system in the process of determining the unfilled volume of a gondola car using the photogrammetry method [developed by the author].

the cargo. The higher is the detail of the image, the higher is the accuracy of calculating the unfilled volume of the gondola car due to the correct recognition of the contour details of the cargo surface.

As a result of photogrammetric analysis of colour digital images of an open car with cargo inside obtained and loaded into a computer program, it is possible to obtain metric data on the shape, size, distances between elements and other parameters of the selected object (Pic. 1).

In this study, the object chosen to obtain metric data is the unfilled space in the upper part of the gondola car.

Video recordings received from cameras and pixelated images are loaded into the neural network. To unify the input data, before loading into the neural network, images can be converted into a 1D array of a fixed size.

Using a semantic segmentation algorithm, a gondola car with cargo and empty space is detected and isolated from the image based on unique features.

To create a three-dimensional model of the selected object, it is necessary to upload photographs taken from different angles. For images to be combined, each subsequent frame must intersect with the previous one by 30 % [13].

On the resulting model, a cloud of points is scattered along the colour boundaries (changes in pixel brightness). The number of points affects the measurement accuracy. Maximum accuracy is achieved with the maximum number of points. Based on the cloud of points, the surface texture of the load is constructed, consisting of simple geometric shapes.

To calculate the volumes of simple figures, it is necessary to orient the program in the metric system, designating point markers. To do this, it is necessary to compare the points with a metric ruler, on the scale of which all distances will be calculated.

The volume of unfilled space in a gondola car is determined regardless of the topography of the cargo surface.

The sides of the car body, the parameters of which are known from the technical characteristics of each car model, can be used as a metric ruler. Technical characteristics of car models include body volume in cubic meters and internal dimensions in millimetres, including height from the floor to the end of the walls, length and width along the floor.

The car model is encrypted in a unique eight-digit inventory number printed on the side wall and on the centre beam of the frame. To identify the car model, the intelligent expert system for monitoring the safety of cargo must be supplemented with a unit with cameras for video recording of car numbers and a compatible tool for automatic recognition and decoding of side numbers in motion.

Technical vision systems make it possible to recognize the inventory number of a car in motion [14].

An alternative to using body sides as a metric ruler is to install measuring rulers at control points as additional equipment.

DISCUSSION

Regardless of the reason for the loss, the volume and weight of the cargo in the car decreases. When the volume of bulk cargo in a car decreases, in most cases the cargo sags and its level in relation to the upper sides of the body decreases. The space between the surface of the load and the plane along the top of the sides of the car (free space) increases. Thus, an increase in free space may indicate the loss of cargo, and a comparison of the volume of free space at the beginning of transportation and the volume of free space at the control point at the selected stage of transportation will allow us to record the fact of loss and determine the volume of lost cargo.

The use of images obtained from photo and video cameras makes it possible to recognize certain objects [3].

Photogrammetry methods make it possible to construct a measurable model of a loaded gondola car [15].

At night, in unfavourable weather and climatic conditions, and in other conditions when it is difficult to obtain a clear image, as well as when the cargo surface is hidden during transportation, for example, by snow cover, the quality of cargo safety control may deteriorate significantly or may not be possible at all.

It is possible to minimise the influence of natural phenomena and other external factors on the process of obtaining a sufficiently clear image and the result of its processing with the help of additional devices, structures, and technologies that provide the most uniform illumination without hard shadows and glare, performing higher-resolution shooting, and protecting the controlled area from precipitation and using computer programs that use a super-resolution image recognition algorithm and convolutional neural networks.

The advantage of using the image processing method using a convolutional neural network and stereophotogrammetry is the minimum required amount of necessary equipment on the railway track, mainly video cameras, and the absence of the need to involve a person to process information during monitoring the safety of cargo.

The proposed method makes it possible to increase the probability of detecting the loss of cargo in a gondola car before delivery to the consignee and to automate routine operations by transferring the functions of identifying the fact of loss from a specialist to an intelligent software-computer assistant based on loss recognition using a convolutional neural network and stereophotogrammetry.

The use of the proposed method solves the problem of timely identification, photographic recording and registration of the fact of loss of bulk cargo. The problems of involving employees in the process of proceedings, finding a person responsible, administration, loss of time and additional costs, reducing the level of customer satisfaction and cumulative negative economic effect are being solved. This method can be useful for medium and large enterprises transporting and processing cargo flows by rail.

Transport management is increasingly moving from heuristic to automated and intelligent one [16]. An intelligent railway is a complex technical and technological system interconnected with the digital economy [17].

In modern economic conditions, focused on technological superiority, and considering the characteristics of the transport industry, which needs rapid development, an important factor is the possibility of dissemination and maintenance of introduced technologies [18].

The possibility of implementing the proposed method without installing additional equipment meets the requirements for innovative technologies in railway transport.

Further development of technology for monitoring the safety of cargo in gondola cars using stereophotogrammetry is to create a viable product and implement it in real conditions.

CONCLUSION

Intellectualisation of cargo safety control and information processes meets the requirements and is the most important direction in the development of railway transport[3] [19].

As a result of this study, a description of the intelligent computer-software structure for monitoring the safety of bulk cargo transported by rail in gondola cars is suggested. Cargo safety is monitored in real time using

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[3] Transport strategy of the Russian Federation until 2030 with a forecast for the period until 2035 (as amended by Order of the Government of the Russian Federation dated November 27, 2021 No. 3363-r).Moscow, Government of the Russian Federation, 2021.

stereophotogrammetry methods. Visual control functions are transferred to a convolutional neural network.

Based on the results of the description of existing control methods, we can conclude that the proposed tool is the most affordable for transport companies, does not involve a complex implementation process and does not require additional skills from personnel. The proposed method has a higher degree of diffusion and speed of dissemination in transport production.

The research has allowed to solve the problems of minimal use of various types of equipment and ease of operation of the cargo safety monitoring tool.

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