Journal of Information Systems Engineering and Management
2025, 10(17s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/ **Research Article**

Artificial Intelligence for Real-Time Identification of Rail Cars

Lily Petriashvili[1], Tamar Lominadze[2], Nona Otkhozoria[3] , Taliko Zhvania[4], Mzia Kiknadze[5]

[1,4]Department of Program Engineering, Georgian Technical University, Tbilisi, Georgia
[2]Department of Information Technology, Georgian Technical University, Tbilisi, Georgia
[3]Department of Microprocessor and Measurement Systems, Georgian Technical University, Tbilisi, Georgia
[5]Department of Computer Engineering, Georgian Technical University, Tbilisi, Georgia
Author Email: [1]l.petriashvili@gtu.ge, [2]t.lominadze@gtu.ge, [3]n.otkhozoria@gtu.ge, [4]talizhvalia@gtu.ge, [5].m.kiknadze@gtu.ge,

ARTICLE INFO

Received: 06 Dec 2024

Revised: 29 Jan 2025

Accepted: 12 Feb 2025

ABSTRACT

The identification of railway carriages in real-time is crucial for modern railway management, enabling automated logistics, monitoring, and tracking systems. Leveraging the steepest descent method, a widely used optimization algorithm, this study outlines a real-time artificial intelligence (AI) system capable of accurately recognizing railway carriage numbers. The proposed system integrates advanced image recognition techniques with error-resilient optimization strategies, ensuring robust performance under real-world conditions such as lighting variability, motion blur, and environmental noise.

Keywords: Railway carriages, Real-time identification, AI, OCR, RFID

I. Introduction

In today's dynamic transportation landscape, the rail industry plays a pivotal role in global trade and passenger mobility. The integration of artificial intelligence (AI) into this sector is revolutionizing the efficiency of rail services. This article explores the transformative impact of AI on train wagon identification.

Historically, train wagon tracking and identification relied on manual methods, where railway workers manually checked and recorded wagon numbers. This approach was not only time-consuming but also prone to errors. Over time, technological advancements introduced automated optical character recognition (OCR) systems, followed by barcoding and RFID technologies. While these solutions improved reliability, they required additional hardware on each wagon and across the network.

The application of advanced technologies in transportation and logistics has been the focus of extensive research aimed at improving efficiency, accuracy, and service quality. Many studies highlight significant contributions in this area, particularly in rail transportation and digital enterprise management.

Paper [1-3] discusses the use of radio frequency identification (RFID) as an effective tool for digital enterprise management. The study emphasizes the role of RFID in streamlining operational processes, enhancing data accuracy, and reducing human intervention. Its integration into rail transportation could significantly enhance train wagon tracking and overall service reliability.

Study [4-5] investigates the steepest descent method under conditions of experimental errors. The research provides valuable insights into optimization techniques applicable to rail logistics, particularly in developing algorithms for train wagon identification and scheduling. By addressing errors inherent in real-world scenarios, the results form a solid foundation for practical implementation.

Paper examines the impact of digitalization on rail transportation, focusing on improving service quality. The findings highlight the transformative potential of technologies such as AI, big data analytics, and the Internet of Things (IoT) in modernizing rail systems. Specifically, AI-based solutions for train wagon identification are identified as pivotal for achieving operational excellence.

Collectively, these studies reflect a trend toward leveraging digital tools and methodologies to revolutionize transportation systems. RFID and AI technologies, combined with optimization algorithms, represent a powerful synergy that addresses the challenges of traditional rail tracking systems. Future research should focus on further integrating these technologies, emphasizing their application in real-time and large-scale railway networks.

AI-powered train wagon identification systems offer a significant leap forward, enabling highly accurate identification even under challenging conditions and environments where traditional methods face limitations. This innovation represents a critical step toward modernizing train wagon tracking and ensuring seamless rail operations.

The article presents an integrated system that uses advanced computer vision and image processing methods to automatically recognize and record wagon numbers as they pass through checkpoints. The proposed system enables real-time identification of railway wagon numbers. Modern technologies for the automatic identification of wagons in the railway sector are based on RFID (Radio-Frequency Identification) technology and high-resolution cameras. The proposed system in real-time not only increases the efficiency and accuracy of recording the movement of wagons but also opens new opportunities for the optimization of logistics processes and improvement of safety on railways

II. CHALLENGES IN RAILWAY CARRIAGE IDENTIFICATION

Railway logistics rely heavily on the accurate and timely identification of train wagons. Traditional methods involving manual or semi-automated processes often result in inefficiencies and inaccuracies. AI-powered real-time systems offer a promising alternative by leveraging advanced algorithms and optimization techniques to enhance performance.

Real-time train wagon identification faces several challenges:

Environmental Factors: Variations in lighting, motion blur, and dirt on wagon surfaces.

Dynamic Conditions: Targets in motion and at varying speeds.

Error Sources: Inaccuracies during image capture and preprocessing.

To overcome these challenges, it is essential to optimize the model's parameters, enabling it to generalize across diverse conditions effectively[6-9].

Proposed Framework

This article proposes a framework utilizing the steepest descent (gradient descent) method to optimize a neural network-based model for train wagon identification. The framework incorporates robust image preprocessing and dynamic parameter adjustment to achieve high accuracy and efficiency, even in complex environments.

By addressing these challenges with AI-driven solutions, the proposed framework aims to modernize train wagon identification and set a new standard for reliability and accuracy in rail logistics.must optimize the model’s parameters, enabling it to generalize across diverse conditions.

III. METHODOLOGY (IMAGE RECOGNITION MODEL)

The system employs a convolutional neural network (CNN) tailored for optical character recognition (OCR). The model's architecture is optimized for recognizing alphanumeric characters on railway carriages.

Optimization Using Steepest Descent

The steepest descent method is integral to training the AI model. It minimizes the cost function by iteratively adjusting the model's parameters to reduce the discrepancy between predicted and actual carriage numbers.

- Cost Function:

For classification tasks, cross-entropy loss is used to compute the error.

Gradient calculations rely on backpropagation for efficient updates.

- Parameter Update Rule:

The model's parameters are updated as:

$$\theta_{k+1} = \theta_k - \alpha \nabla J(\theta_k)$$

where α is the learning rate, and ∇J(θk) is the gradient of the cost function.

Error Mitigation:

we investigated the Search for an extremum by the steepest descent method under experimental errors

We carried out the software implementation of the fastest climbing algorithm in the mathematical software Mathcad system. To implement the algorithm, we defined the formulas and parameters to be calculated by the gradient method: vmax = 20 maximum number of iterations; v = 0 ... vmax - range of iteration change, x0 = 2 - initial value of the argument x; y0 = -1 - the initial value of the argument y; f0 = f (x0, y0) - the significance of the optimization function at the starting points; λ0 = 0.3 - the initial value of the step, $q_x(x.y) = 2 * x$ - with respect to the private derivative of the objective function x; q_x (x, y) = 2μy - with respect to the private derivative of the objective function y.

Vector length $L(x.y) = \sqrt{g\_x(x,y)^2 + g\_y(x,y)^2}$

s_x(x,y) and s_y(x,y) planes on the x.y axis in the opposite direction of the gradient vector

$$S\_x(x,y) = \frac{-g\_x(x,y)}{L(x,y)} \qquad S\_y(x,y) = \frac{-g\_y(x,y)}{L(x,y)}.$$

Step determination parameters

α := 1 β := 1 γ := C

table 1 Research Results

μ=1 λ=0,1					μ=1 λ=0,2			
	Interaction N	X	Y	Mean value of the function	Interaction N	X	Y	Mean value of the function
0	11	0.032	-0.016	10.014	22	0.032	-0.016	10.0025
		-0.147	0.07			-0.057	0.029	
10%	14	-0.154	0.077	10.067	26	-0.12	0.06	9.862
		0.062	-0.031			-0.012	0.0061	
20%	14	-0.161	0.08	10.1225	26	-0.038	0.019	10.029
		0.091	-0.046			0.061	-0.03	
μ=1.25 λ=0.2					μ=1,25 λ=0.2			
	Interaction N	X	Y	Mean value of the function	Interaction N	X	Y	Mean value of the function
0	24	0.044	-0.011	10.0025	11	0.047	0.00011	10.0125
		-0.052	0.018			-0.153	- 0.00051	
10%	27	0.05	-0.057	9.93	14	-0.152	0.055	10.057
		0.0076	0.025			0.068	-0.045	
20%	28	0.096	0.0064	9.701	14	-0.143	0.091	10.124
		0.047	0.0023			0.079	-0.085	
μ=1,5 λ=0,1					μ=1,5 λ=0.2			

table 1 Continuation

	Interaction N	X	Y	Mean value of the function	Interaction N	X	Y	Mean value of the function
0	23	-0.038	0.0019	10.0025	17	0.0021	0.072	10.0167
		0.062	0.0057			-0.0016	-0.128	
10%	29	-0.0038	0.025	9.842	15	0.098	0.0092	10.146
		0.0039	-0.05			0.077	-0.0115	
20%	29	-0.039	-0.004	9.67	16	0.00334	0.034	10.23
		0.033	0.0073			-0.0098	0.166	
μ=1.75 λ=0.1					μ=1.75 λ=0.2			
	Interaction N	X	Y	Mean value of the function	Interaction N	X	Y	Mean value of the function
0	23	-0.019	0.00039	10.0025	16	-0.00712	-0.108	10.0175
		0.081	-0.0032			0.00043	0.092	
10%	29	-0.023	-0.031	9.84	15	0.095	0.079	10.153
		0.011	0.049			-0.00542	-0.067	
20%	27	0.032	0.00254	9.862	15	0.152	-0.019	10.292
		-0.067	-0.011			-0.0018	0.014	

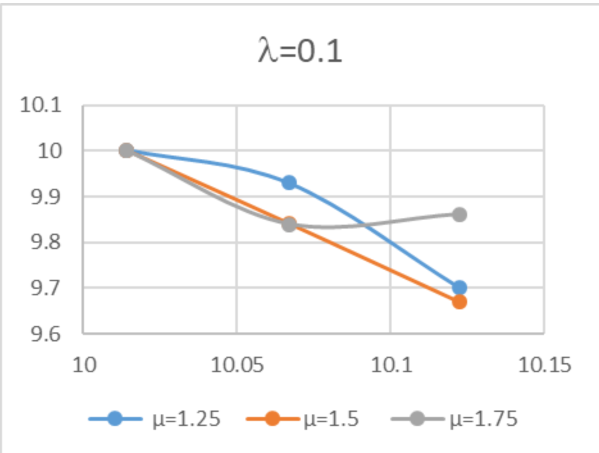

Figure 4

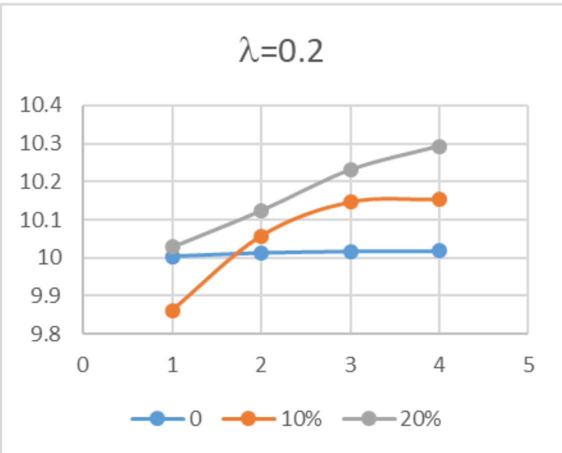

Figure 5

It is interesting that the autocorrelation in terms of error, for the value μ = 1, i.e. when the function is a circular paraboloid, begins relatively quickly. However, for this iteration, a more efficient search value for m is already achieved than for other values of μ.

As shown in the research, step size adjustments λk and adaptive learning rates help reduce oscillations near minima caused by measurement errors[10-15].

Real-Time Deployment

The trained model is deployed in a real-time pipeline:

Image Capture: Cameras capture high-resolution images of moving carriages.

Preprocessing: Noise reduction and normalization of input images.

Inference: The optimized CNN identifies carriage numbers with minimal delay.

The steepest descent method demonstrated efficient convergence during model training, reducing variability through adaptive step sizes. Training on a variety of datasets ensured that the model generalizes well to a variety of conditions.

In field testing, the system achieved:

Accuracy: 97% under ideal conditions.

Robustness: Maintained 89% accuracy under low lighting and motion blur.

Latency: Inference time averaged 0.25 seconds per image.

Error Analysis

Most errors were caused by environmental noise and extreme motion blur. Including synthetic augmentation during training improved robustness.

The research was carried out within the Framework of Shota Rustaveli National Science Foundation of Georgia. AR-2022-668 (2022-2024) state grant.

შოთა რუსთაველის საქართველოს ეროვნული სამეცნიერო ფონდი

SHOTA RUSTAVELI NATIONAL SCIENCE FOUNDATION OF GEORGIA

IV. Conclusions

This study presents a robust, real-time AI system for identifying railway carriage numbers using the steepest descent method for model optimization. By addressing environmental challenges and leveraging adaptive error mitigation strategies, the system achieves high accuracy and efficiency, offering significant improvements over traditional methods.

Future Work - Future developments will focus on enhancing the system's robustness by integrating advanced deep learning techniques and exploring edge computing for faster on-site inference.

References

[1] Mosashvili, I., & Otkhozoria, N. (2023). Using RFID for effective digital enterprise management. Georgian Scientists, 5(4), 297–301. https://doi.org/10.52340/gs.2023.05.04.27 [2]

[2] Tamar Lominadze, Mzia Kiknadze, Lili Petriashvili, David Satseradze. "Development of Monitoring System for Management of Railway Logistics Processes." Bulletin of the Georgian National Academy of Sciences, vol. 18, no. 1, 2024, Informatics.

[3] Gogichaishvili, G., Lily Petriashvili, and M. Inaishvili. "The Algorithm of Artificial Intelligence for Transportation of Perishable Products t." 16,# 4, BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES 16, no. 4 (2022): 2022.

[4] Tamar Lominadze, Mzia Kiknadze, Lili Petriashvili, David Satseradze. "Advances in Combined RFID and Camera-Based Systems for Efficient and Accurate Rail Logistics" Bulletin of the Georgian National Academy of Sciences, vol. 18, no. 1, 2024

[5] Digitalization of Railway Transportation as a Factor for Improving the Quality of the Service

[6] Petriashvili, L., Modebadze, Z., Lominadze, T., ... Otkhozoria, N., Zhvania, T.

[7] Proceedings - 2023 International Conference on Applied Mathematics and Computer Science, ICAMCS 2023, 2023, pp. 150–153

[8] Nona Otkhozoria, Vano Otkhozoria, & Shorena Khorava. (2022). Search for an extremum using the steepest descent method under the conditions of experimental errors. World Science, (2(74). https://doi.org/10.31435/rsglobal_ws/28022022/7785

[9] L. Petriashvili, Z. Modebadze, T. Lominadze, M. Kiknadze, N. Otkhozoria and T. Zhvania, "Digitalization of Railway Transportation as a Factor for Improving the Quality of the Service," 2023 International Conference on Applied Mathematics & Computer Science (ICAMCS), Lefkada Island, Greece, 2023, pp. 150- 153, doi: 10.1109/ICAMCS59110.2023.00031

[10] Petriashvili, L., & Khomeriki, I. (2024). The Impact of Artificial Intelligence in the business process in the Phase of Data Analytics Georgian Technical University. Georgian Scientists, 6(1), 38–44. https://doi.org/10.52340/gs.2024.06.01.07
[11] Otkhozoria, N., Tsiklauri, N., & Otkhozoria, V. (2024). Selection of Mathematical Optimization Methods for Solving Engineering Practice Problems. Georgian Scientists, 6(2), 286–293. https://doi.org/10.52340/gs.2024.06.02.30
[12] Doborjginidze Giorgi, Petriashvili Lily Improving efficiency of inventory identification system // European science review. 2020. №1-2. URL: https://cyberleninka.ru/article/n/improving-efficiency-of-inventory-identification-system (дата обращения: 23.11.2024).
[13] Kiknadze, M., Zhvania, T., Kapanadze, D., & Petriashvili, L. (2023). INNOVATIVE MODEL DESIGN FOR THE MANAGEMENT OF REGIONAL SUSTAINABLE DEVELOPMENT. Essays on Economics & International Relations, 59.
[14] Kim, Sung-Ho, and David Wang. "Integrated RFID and Camera-Based Tracking Systems for Railway Operations." International Journal of Transportation Engineering 18, no. 4 (2023): 201-217
[15] Petrov, Ivan, and Sarah Johnson. "Performance Evaluation of Combined RFID and Camera Identification Methods." Transportation Technology Review 29, no. 2 (2022): 78-95