13th International Conference on
Structural Health Monitoring of Intelligent Infrastructure
DOI: 10.3217/978-3-99161-057-1-055

Computer vision-based recognition of random traffic flow for live load performance analysis of existing bridges

Weilei Yu[1, 0000-0002-6492-6051], Mayuko Nishio[2, 0000-0003-1079-2577]
[1]Department of Engineering Mechanics and Energy, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki, Japan
[2]Insitute of Systems and Information Engineering, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki, Japan
email: s2336033@u.tsukuba.ac.jp, nishio@kz.tsukuba.ac.jp

ABSTRACT: The dynamics and complexity of stochastic traffic flows play a crucial role in the management of infrastructure such as bridges. This study presents a computer vision-based method for random traffic flow identification and load estimation that integrates the YOLOv8 object detection model and the DeepSORT multi-target tracking algorithm. By utilizing high-resolution bridge surveillance video, the method can accurately identify vehicle type, axle count, and traffic flow. A case study conducted on an actual bridge validates the effectiveness of the method. The results show that the accuracy of vehicle identification based on 24-hour video data is more than 93%, the statistical error is less than 10%, and the temporal distribution of traffic flow matches well with the actual situation. This study provides a new technical reference for AI-based bridge traffic management and low cost structural health monitoring solutions.

KEY WORDS: Random traffic flow; Computer vision; Bridge monitoring; Object detection; Object tracking; Traffic flow statistical analysis.

1 INTRODUCTION

Stochastic traffic flow is one of the key research areas in traffic flow analysis, which is characterized by randomness and uncertainty in dynamic parameters such as vehicle arrival time, spacing, speed and type. In bridges and other critical infrastructures, the characteristics of random traffic flow can lead to irregular spatial and temporal load distributions, which can seriously affect the design safety and operational efficiency of the infrastructure. Stochastic traffic flow is equally crucial to understanding the performance of bridges under dynamic loading.

Studies [1], [2] linked traffic-induced dynamic amplification factors to bridge fatigue life, while [3] emphasized bridge health monitoring under frequent heavy traffic flow. [4], [5] investigated the effect of random traffic flow on bridge dynamics under consideration of pavement roughness and proposed structural maintenance strategies.

Therefore, accurate identification and statistical analysis of stochastic traffic flow is not only the basis for understanding traffic dynamics, but also an important tool for optimizing transportation systems and improving infrastructure performance.

Traditional methods for stochastic traffic flow statistics usually rely on dynamic weighing systems or radar techniques. Although these methods can capture key traffic flow parameters to some extent, they face limitations such as lack of real-time performance, limited accuracy, and high cost. In recent years, with the rapid development of computer vision technology, its application in the field of intelligent transportation has become a focus of research. Deep learning-based target detection and multi-target tracking technologies provide new solutions for real-time traffic flow information acquisition. By analyzing video streaming data, computer vision techniques can efficiently identify and quantify vehicle types, numbers, speeds, and lane distributions, providing the possibility of real-time monitoring of random traffic flows. However, how to improve the robustness of recognition and the accuracy of statistical analysis in complex and changing environments remains one of the main challenges in current research.

The aim of this study is to develop an integrated approach for recognizing and statistically analyzing random traffic flows using computer vision to address the challenges in traffic flow research. The study integrates YOLOv8 object detection and DeepSORT multi-target tracking techniques to achieve real-time monitoring and accurate characterization of traffic flow in complex dynamic environments. The practical applicability of the method in stochastic traffic flow statistics is verified through a case study.

2 COMPUTER VISION-BASED FOR RANDOM TRAFFIC FLOW RECOGNITION

2.1 *Video data capture settings and processing*

High-resolution cameras are deployed on the bridge deck to capture real-time multi-lane traffic data, including vehicle types, counts, speeds, and directions. Data is collected across seasons and traffic conditions to ensure diversity. This non-intrusive method improves accuracy and efficiency over manual monitoring, avoids physical interference, and reduces costs compared to sensor networks.

Video data undergoes preprocessing (frame extraction, resolution normalization, and augmentation) to enhance model robustness. A labeled dataset of 12,000 images, annotated with vehicle types and axle counts, is split into training (75%), validation (15%), and testing (10%) sets for model development and evaluation.

2.2 *Traffic flow object detection and tracking principle*

This study employs an integrated approach combining YOLOv8 for vehicle detection and DeepSORT for multi-object tracking to analyze bridge traffic flows. YOLOv8, the latest iteration of the YOLO series, demonstrates superior speed and accuracy in vehicle detection. The algorithm processes images through a grid-based system (S×S), where each cell predicts bounding box coordinates (x,y,w,h) and classification probabilities via convolutional neural networks. Experimental

DOI: 10.3217/978-3-99161-057-1-055

validation yielded a training loss of 0.9 and F1 score of 0.88, with vehicle detection precision reaching 93% for cars, 85% for buses, and 89% for trucks.

DeepSORT enhances the system's capability by maintaining vehicle trajectory continuity across video frames. The algorithm integrates five key phases: (1) initial detection using YOLOv8 outputs, (2) feature extraction for appearance-based identification, (3) motion prediction via Kalman filtering, (4) data association through the Hungarian algorithm, and (5) state updates for refined tracking. This multi-stage process ensures reliable vehicle tracking in complex traffic scenarios while assigning persistent unique IDs to each vehicle.

3 ACTUAL BRIDGE TRAFFIC FLOW IDENTIFICATION AND STATISTICAL RESULTS

This study validates a computer vision-based stochastic traffic flow analysis method through a case study of an urban bridge in eastern China. High-resolution cameras were strategically deployed on the bridge for continuous 24/7 monitoring over two weeks, capturing comprehensive traffic data including vehicle types, counts, speeds, and directions. The collected dataset enables evaluation of the method's performance in complex multi-lane environments, demonstrating its practical applicability for real-world traffic monitoring and analysis.

Using the YOLOv8 and DeepSORT algorithms, all vehicles on the bridge over a 24-hour period were successfully identified and tracked, shown in Figure 1. Vehicles, along with their axle counts, were categorized into seven types: 2-axle passenger cars, 2-axle buses, 3-axle buses, 2-axle trucks, 3-axle trucks, 4-axle trucks, and trucks with more than 4 axles. The recognition accuracy for each vehicle type was as follows: passenger cars 94%, trucks 90%, and buses 89%, with an overall vehicle recognition accuracy exceeding 93%. The model demonstrated robust performance during both peak traffic periods and low-traffic intervals.

Figure 1. Vehicle identification results

According to the statistics of one-day traffic flow, passenger vehicles accounted for the highest proportion of total traffic flow, which was 6,820 vehicles, accounting for 73.5% of the total traffic flow. In contrast, buses and trucks accounted for a relatively small proportion of 19% and 7.5% respectively, which is about 9.3% error compared with the actual total traffic flow on the bridge based on WIM data, proving its practical value in actual traffic monitoring and analysis.

The results of the statistical analysis of the distribution of traffic flow on the bridge in 24 hours are shown in Figure 2. The 7:00-9:00 and 17:00-19:00 are the peak traffic flow, with more than 400 vehicles passing through every half hour respectively; the off-peak traffic flow is relatively stable. Nighttime traffic is significantly reduced. The proportion of trucks in the nighttime traffic has increased, and buses account for about 20% of the total traffic, which is mainly concentrated in the morning and evening peak hours. The time series analysis of the traffic flow reveals the fluctuation pattern of the traffic flow throughout the day, and the intensive traffic flow period corresponds to the peak commuting hours in the city, which provides intuitive data support for traffic management and bridge maintenance.

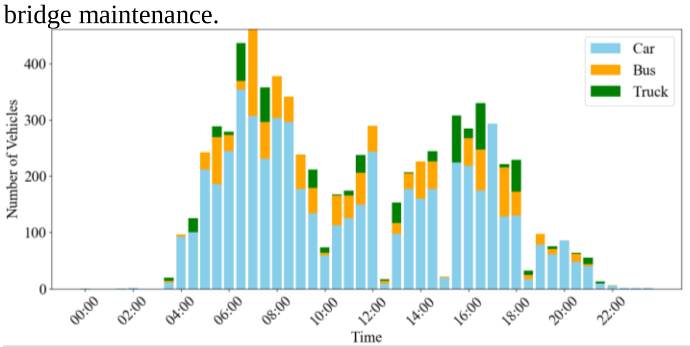

Figure 2. Full-day vehicle distribution

4 CONCLUSION

This study combines YOLOv8 and DeepSORT algorithm to propose a computer vision-based method for random traffic flow recognition and analysis of bridges. The method can efficiently and accurately realize real-time monitoring and statistical analysis of traffic flow and provide technical support for structural health monitoring of bridges, with the advantages of low cost and easy deployment. In the future, the performance can be further optimized through efficient deep learning algorithms, multimodal data fusion and edge computing.

ACKNOWLEDGMENTS

This work was supported by JST SPRING, Grant Number JPMJSP2124.

REFERENCES

[1] Li, Z., Cao, Y., Ma, M., & Xiang, Q. (2023). Prediction of ground-borne vibration from random traffic flow and road roughness: Theoretical model and experimental validation. Engineering Structures, 285, 116060.

[2] Maddah, N. (2013). Fatigue life assessment of roadway bridges based on actual traffic loads (No. 5575). EPFL.

[3] Saviotti, A. (2014). Bridge assessment, management and life cycle analysis. Modern Applied Science, 8(3), 167.

[4] Tang, T. Q., Caccetta, L., Wu, Y. H., Huang, H. J., & Yang, X. B. (2014). A macro model for traffic flow on road networks with varying road conditions. Journal of Advanced Transportation, 48(4), 304-317.

[5] Ho, H., & Nishio, M. (2020). Evaluation of dynamic responses of bridges considering traffic flow and surface roughness. Engineering structures, 225, 111256.