LOUISIANA TRANSPORTATION RESEARCH CENTER

Technical Summary

LTRC Report 724

SIO No. DOTLT1000515
LTRC Project No. 24-4SS

Improved Signalized Intersection Performance Using Computer Vision and Artificial Intelligence

Introduction

Signalized intersections are critical components of urban transportation networks where congestion, delays, and safety risks are most prominent. Traditional performance evaluation methods rely on manual field counts, loop detectors, or expensive infrastructure-based systems, which are often limited in accuracy, scalability, and adaptability. These methods may also fail to capture the full dynamics of intersection behaviors necessary for performance improvement. Recent advances in computer vision and artificial intelligence (AI) present a powerful opportunity to address these limitations. Cameras, including aerial footage, combined with state-of-the-art AI-based detection, tracking, and classification algorithms, can non-intrusively capture rich information about traffic conditions and automatically extract key performance measures, enabling a deeper understanding and providing critical data-driven insights into how vehicles turn, move, and queue, and how pedestrians respond to vehicles and signal changes.

Objective

The objective of this project was to develop and evaluate artificial intelligence (AI)-based computer vision tools for intersection performance analysis. The specific objectives were to:

- Develop a vehicle counting framework based on detection-tracking-counting pipeline for accurate turn-movement measurements;
- Develop an integrated framework for vehicle queue length estimation, with associated traffic light state recognition;
- Develop a vehicle-pedestrian interaction system to understand behaviors at intersections; and
- Develop a user-friendly graphical interface (GUI) for practical applications by transportation engineers.

Scope

This study focused on developing modern artificial intelligence (AI)-based tools for signalized intersection performance evaluation using video data from Louisiana intersections. The research investigated three primary methods: vehicle counting using virtual line-crossing strategies with advanced detection and tracking models; queue length detection with traffic light state recognition using adaptive region-based assignment; and vehicle-pedestrian trajectory extraction. These methods were evaluated on drone- and camera-based video data captured in Louisiana. The project included the development of a graphical user interface (GUI) to enable practical applications by Louisiana DOTD engineers.

Methodology

Vehicle turn-movement counting was implemented using a detection–tracking–counting pipeline that combines advanced deep-learning detectors with multi-object tracking. A virtual line-crossing strategy was used to accurately measure turn movements across multiple lanes.

Multi-lane queue length estimation was achieved by associating detected vehicles within lane-specific regions of interest (ROIs) and linking them to real-time traffic signal states. The regions were designed to adapt to drone motion, enabling consistent queue estimation. Additionally, a trajectory extraction framework was developed to analyze vehicle–pedestrian interactions.

Principal Investigator
Milhan Moomen, Ph.D.
225-767-9161

LTRC Contact
Julius Codjoe, Ph.D., P.E.
225-767-9761

Funding
SPR: TT-Fed/TT-Reg - 5

Read final report online:
www.ltrc.lsu.edu/publications.html

Finally, a user-friendly software tool with a graphical user interface (GUI) was developed to enable Louisiana DOTD engineers to operate the system, apply the artificial intelligence (AI)-based methods to video data, and generate automated reports.

Conclusions

- This research demonstrated the feasibility and effectiveness of applying computer vision and artificial intelligence (AI) to the performance evaluation of signalized intersections as a reliable and accurate alternative to traditional methods.
- The AI-based vehicle counting framework reliably automates turn movement counting using detection-tracking-counting with a virtual line-crossing approach, reducing labor and improving repeatability.
- The queue detection method, enhanced with traffic light state recognition, provides operational insight into queuing and congestion behaviors by linking queue conditions to signal phases for informed performance analysis and engineering decisions.
- The vehicle-pedestrian analytics provided useful information for engineers to understand regions of concentrated interaction and behaviors in response to traffic situations.
- Evaluation using Louisiana drone- and camera-based video data demonstrates that the proposed methods achieve high accuracy and robustness to environmental variation.
- The integrated graphical user interface (GUI) improves usability and supports practical deployment by enabling engineers to operate and generate reports directly from raw video.
- AI-based computer vision systems offer cost-effective, scalable alternatives to traditional sensors for intersection performance evaluation.

Recommendations

For Practice:

- Deploy artificial intelligence (AI)-based tools for routine monitoring to replace manual counts and supplement traditional sensors, leveraging their high accuracy and reduced labor effort.
- Provide the graphical user interface (GUI) to Louisiana DOTD engineers with training workshops to ensure efficient ROI definition and automated report generation.
- Expand video data collection across diverse intersections, weather scenarios, and lighting environments to support model fine-tuning and statewide deployment.
- Ground camera placement should cover the full intersection at sufficient elevation (minimum 25 ft) to minimize occlusions. Wide-angle or fisheye lenses require distortion correction prior to use.
- A flight altitude of approximately 22m (72 ft) is recommended for optimal drone operation, maintaining clearance from overhead cables and avoiding tree obstructions for clear vehicle visibility.
- Implement practical onsite synchronization using a synchronized master clock (millisecond-level preferred) or sound-based alignment methods for multi-drone operations.

For Future Research:

- Create larger, well-annotated Louisiana-specific datasets with variations in camera angles, queue formations, and signal types. Enrich dataset diversity with nighttime, adverse weather, and rural footage to achieve generalizable models.
- Extend queue measurement methods to estimate physical queue lengths using homography-based mapping.
- Integrate with adaptive traffic signal controllers by developing data pipelines to feed automated vehicle counts and queue detection directly, enabling closed-loop real-time intersection management.
- Explore tethered drone systems for unconstrained, extended video capture aligned with DOTD initiatives for continuous intersection monitoring.
- Incorporate fisheye cameras to capture wider fields of view, enabling comprehensive intersection coverage from single mounting points.
- Develop unified systems for both recorded and real-time video capture to enable continuous traffic performance monitoring.
- Extend capabilities to include vehicle speed estimation, truck classification counts, and congestion level metrics.
- Develop an AI-driven workflow to calibrate highway VISSIM models, automating the estimation of key parameters such as vehicle speeds, heavy-vehicle percentages, and traffic volumes.