Smart Traffic Management System

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1. Summary

Our project aims to address the issue of traffic congestion in Vietnam, with a particular focus on mitigating congestion caused by drivers' non-compliance with traffic rules. The solution leverages technology to detect violations contributing to traffic jams while ensuring the smooth passage of priority vehicles, such as ambulances, in emergency situations.

To achieve this, we implemented a dual-model approach using two fine-tuned YOLOv11 models, each adapted for distinct lighting conditions (day and night) to detect violations effectively even in challenging scenarios, including nighttime, rain, and glare. An audio detection model (an ensemble of CNN and LSTM networks) operates alongside a Large Language Model (LLM) like Gemini to identify emergency vehicles by detecting sirens and emergency lights. When a violation is detected, our system promptly alerts the traffic management team via email.

Furthermore, traffic density data and the count of detected violations are transmitted to the Wise-PaaS DataHub. This data is then visualized on the Wise-PaaS dashboard, providing traffic managers with an overview of traffic conditions, helping them assess the solution's effectiveness, and informing future traffic management strategies.

The YOLO model achieved a Mean Average Precision (mAP) of 53.7 on test datasets under adverse conditions, demonstrating its robustness in challenging environments.

2. Introduction

Traffic congestion remains a pressing issue in Vietnam, especially in major urban centers such as Ho Chi Minh City. The rapid surge in the number of vehicles, paired with infrastructure development that struggles to keep up, has led to frequent traffic bottlenecks, particularly during peak hours. According to VNEXPRESS, vehicle density, especially motorbikes, significantly contributes to severe congestion in central areas, major intersections, and routes leading to ports and airports.

Globally, extensive research on traffic management has focused on improving flow, such as optimizing traffic light timing based on real-time vehicle density. These studies have been instrumental in reducing congestion and improving traffic efficiency in many major cities. However, in Vietnam, despite implementing similar measures and even resorting to manual intervention by traffic police, the congestion problem remains alarmingly severe.

The impacts of traffic congestion go beyond environmental pollution and wasted time. Critically, it hinders the movement of priority vehicles, such as ambulances and fire trucks, during emergencies. The inability of these vehicles to navigate quickly during peak hours can pose serious threats to public safety and, in extreme cases, human lives.

A primary cause of this situation lies in the assumption underlying many traffic studies, which typically consider ideal conditions where all road users adhere to traffic laws. In reality, traffic compliance in Vietnam is still notably low, a factor that has not been fully accounted for in previous research.

Observing that congestion can be eased by enhancing traffic violation monitoring on key routes, we propose developing an intelligent system capable of automatically detecting traffic violations. This system not only alleviates the workload of traffic officers but also ensures that emergency vehicles, such as ambulances, receive green light signals when urgently needed.

By leveraging AI models, our project aims to create a safer and more efficient traffic environment for Ho Chi Minh City and other urban areas across Vietnam.

3. Methodology

3.1: Violation Detection

To effectively detect traffic violations, we fine-tuned two YOLOv11 models pre-trained on the COCO dataset, specifically adapted for distinct lighting conditions. One model was fine-tuned with 6,000 daytime images and the other with 5,000 nighttime images, including challenging scenarios such as rain, glare, and low visibility, which can hinder camera recognition accuracy.

Day/Night Image Classification

For optimal model selection, we implemented an image brightness analysis to classify each frame as either daytime or nighttime. This involved calculating the mean brightness and analyzing the histogram for dark pixel ratios. If the percentage of dark pixels exceeded a preset threshold, the image was classified as nighttime; conversely, if the average brightness was sufficiently high, it was categorized as daytime. Once a frame is classified, the appropriate YOLO model (daytime or nighttime) is deployed.

Violation Detection Process

1. **No Parking Detection (Green Light)**: If a green light is detected, the system counts vehicles within a specified region (Region 3) that have a speed of zero over a five-minute interval, flagging potential no-parking violations.
2. **Red Light Violation Detection**: During red lights, the system monitors for vehicles positioned outside of Region 3.
3. **Speed Monitoring**:
    - Every 20 seconds, the system checks vehicles in two regions:
        - **Region 1**: Counts all vehicles (classes 1, 2, and 3) with a speed not equal to zero.
        - **Region 2**: Counts motorcycles (class 0) with a non-zero speed.

- This 20-second interval helps mitigate detection errors from vehicles making necessary lane changes.

Every 20 seconds, the program reports any detected violations and the count within this period. If violations surpass a predefined threshold, an immediate alert is sent via email, even if it's within the 20-second interval.

3.2: Priority Vehicle Detection

We trained a Convolutional Neural Network (CNN) model and a Long Short-Term Memory (LSTM) model on a dataset of 400 three-second audio clips containing ambulance sirens and 400 clips of regular traffic noise. By ensembling these models, the system achieves robust detection of ambulance sirens in real-time.

Ambulance Detection Process

The system continuously listens for ambulance sirens every three seconds. Upon detecting a siren, the system captures five frames over the next three seconds, which are then analyzed by a Large Language Model (LLM) like Gemini to confirm the presence of an ambulance. If confirmed, a signal is sent to switch the traffic light to green. Once the light turns green, the LLM continues to process frames every two seconds to verify the ambulance's priority signal until the vehicle has cleared the intersection, at which point normal traffic light operations resume.

3.3: Data Analysis

The system continuously transmits data on traffic density and violations to a central data hub, enabling real-time visualization on a management dashboard. This dashboard provides traffic managers with a comprehensive view of current conditions, allowing them to assess the solution's effectiveness and make informed decisions or implement additional measures in the future to further optimize traffic flow and reduce congestion.

4. Conclusion

The project successfully addresses the critical issue of traffic congestion in Vietnam by implementing an intelligent system capable of detecting traffic violations and ensuring priority passage for emergency vehicles. By leveraging advanced technologies, such as fine-tuned YOLOv11 models for day and night detection and an ensemble audio detection model for ambulance sirens, the solution provides real-time monitoring under diverse and challenging conditions, including low visibility and inclement weather. The Mean Average Precision (mAP) of 53.7% achieved by the YOLO model underscores its robustness, even under adverse circumstances.

This dual-model approach, combined with a Large Language Model (LLM) for accurate ambulance identification, demonstrates a practical and scalable solution to alleviate congestion by targeting one of its root causes—drivers' non-compliance with traffic rules. Moreover, the integration with Wise-PaaS DataHub provides traffic managers with critical insights and data visualizations, enabling data-driven decision-making and strategic traffic management.

Overall, this system not only enhances traffic flow and safety in urban areas but also establishes a foundation for future improvements in traffic management strategies across Vietnam. It represents a significant step toward a more efficient and responsive traffic infrastructure, ultimately contributing to a safer and more sustainable urban environment.

5. Suggestions for Future Development

Given time constraints, we prioritized functionality over performance optimization. Moving forward, we plan to:

1. **Optimize System Performance**: Enhance the system's architecture for faster detection and reduced resource usage, improving scalability for large-scale deployment.
2. **Improve Detection Accuracy**: The system's mAP could be improved by relabeling the entire dataset and addressing data imbalance, especially for larger vehicles. We will apply data augmentation techniques to ensure balanced representation, which should enhance detection accuracy under diverse traffic conditions.

These enhancements will strengthen system reliability and effectiveness in managing traffic congestion in Vietnam.

6. Appendix

A1: Region for car/bus/truck

A2: Region for bike/mortorbike

A3: Driveway