State Job Number: 134874

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# Adaptive Video-based Vehicle Classification Technique for Monitoring Traffic

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| FHWA Report Number: | FHWA/OH-2015/20 |
| Report Publication Date: | August 2015 |
| ODOT State Job Number: | 134874 |
| Project Duration: | 16 Months |
| Start Date: | April 1, 2014 |
| Completion Date: | August 1, 2015 |
| Total Project Funding: | $40,000.00 |
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## Project Background

Federal Highway Administration (FHWA) recommends axle-based classification standards to map passenger vehicles, single unit trucks, and multi-unit trucks, at Automatic Traffic Recorder (ATR) stations statewide. Many state Departments of Transportation (DOT), including Ohio DOT (or ODOT), adapts the FHWA's scheme F, axle-based classification standards in defining length-based classification boundaries to map various vehicles, such as passenger vehicles, single unit trucks, and multi-unit trucks, at Automatic Traffic Recorder (ATR) stations statewide. It is suggested that no single set of vehicle lengths work "best" for all states, because truck characteristics may vary from state to state. It's also technically difficult to estimate each of the FHWA 13 categorized vehicles by the length-based approach.

Comparing to the intrusive length-based (e.g., from dual-loop data) and axle-based vehicle classification methods and models, video traffic data outperforms with its potential of generating more accurate vehicle classification and speed. To promote the application of video-based detection systems, and develop a fast and effective method for processing videos to produce accurate traffic information under varied traffic conditions, the investigation of the image processing technology is needed on its adaptation in the vehicle classification, either length-based or axle-based approaches under various traffic conditions.

To overcome the weakness in dealing with congested traffic, the Vehicle Video-Capture Data Collector (VEVID) software using the video-capture-based technique, developed by the authors, will be considered as an supplementary model to deal with cases that would be difficult to be done by the image processing model. VEVID is capable of extracting trajectory data from video files using video-capture functions embedded in many computer programs (e.g. MATLAB). VEVID's accuracy of vehicular trajectories is satisfactorily high under congested traffic conditions. It has also been proven that the VEVID-based approach is efficient with low cost in extracting the ground-truth vehicle event trajectory data. However, its weakness lies in its half-automation, i.e., manually clicking distinguished points of the subject vehicles while running. It is therefore a good idea to combine the image processing technique and the VEVID tool as a "hybrid" system to deal with various traffic conditions when vehicular trajectories, in particular, vehicle classification and speed data, are targeted from videos. This idea led to the motivation of developing a computer-vision-based computer system for video-based vehicle classification, which will be implemented in C++ with its Computer Vision and Image Processing libraries.

In the proposed research framework, two separate models are involved in the "hybrid" approach: (1) the Rapid Video-based Vehicle Identification System (RVIS), an image processing technique based tool with attempt to identify the number of vehicle axles, which is particularly applicable to light traffic condition; and (2) VEVID, a semi-automatic tool to be particularly applicable to heavy traffic conditions. In this project, the algorithm as needed for the development of the RVIS is focused with functionality testing by using real-world video data to be obtained on a segment of the I-275, which is near Exit 47 and close to the traffic monitoring station 626, in the Cincinnati area, Ohio. The second phase is planned to be proposed after completion of the research addressed in this proposal. The working title of the "hybrid" system is "Video-based Information Extraction in Wide Traffic Range with Assured Fast Identification Capability" (VIEW-TRAFIC). This methodology is expected to be cost-effective, efficient and capable of being integrated to the current ODOT facilities to add options and mobility to the current classification data sources. This methodology is expected to be cost-effective, efficient and capable of being integrated to the current ODOT facilities to add options and mobility to the current classification data sources.

The proposed research addresses the challenges and identified research gap through the development and testing of the proposed RVIS with the aid of VEVID via a case study. The advantage of the proposed RVIS system is its nature of ground-truth video data, non-intrusive, rather than model-based, intrusive classification method. The ground-truth based method is reliable since it bypasses the modeling and malfunctioning errors which conventional sensors might have. Moreover, it is expected that the performance of the proposed hybrid vehicle classification system outperforms the conventional sensors under congested traffic conditions. Through the demonstrated system architecture and functionality, the RVIS system has a great potential to be flexibly incorporated into the existing ODOT facilities, such as the existing video surveillance network for the Ohio buckeye traffic system. This is compliant with ODOT's mission to "take care of what we have, make our system work better, improve safety, and enhance capacity".

## Study Objectives

The primary goal of the project is to explore a "hybrid" approach to combine the axle-based and length-based methods by using existing image processing and video-capture based techniques to enable vehicle classification at either light or heavy traffic conditions. The basic principle and mathematical modeling based on the image processing technique will be clarified and modified to ensure the applicability and reliability of the proposed method to both axle-based and length-based vehicle classifications at freeways or other major arterials. The project result is to provide solid basis for the second phase of the research for complete integration of the RVIS and VEVID into the VIEW-TRAFIC "hybrid" system in the future. To achieve the goal, the proposed research project is designed to fulfill the following objectives:

- To clarify and develop image processing based and machine vision models with enhanced capability of measuring the length and finding tires of the vehicles. Major focus is placed on the capability to determine the accurate locations of the tires through identifying correct corners and contours of wheels (or tires) from the vehicle images.
- To calibrate and validate the proposed models for axle-based vehicle classification and length-based vehicle classification (4-Bin scheme is targeted in the testing study).
- To proposed a detailed conceptual framework for integrating RVIS and VEVID for further development of the new hybrid vehicle information extraction system (i.e., VIEW-TRAFIC)

## Description of Work

The key modeling challenge lies in the way to correctly identify the length of each vehicle and the number and position of vehicle axles. To address this challenge, innovative models for segmenting out a vehicle from image through adjusting perspective effect on length of the vehicle and then identifying the wheel or tire locations and the number of the tires by validated image processing models. With all these gained information about vehicle length and axle locations, it becomes possible to conduct length-based and axle-based vehicle classification. 4-bin vehicle classification scheme is applied in the model testing study of the length-based vehicle classification, and then the axle-based groups of vehicles involved in each bin will be selected by the automatic computing algorithm that is developed via the project.

In order to segment a vehicle out of a frame or image, a background subtraction technique based on Gaussian Mixture Models (GMM) has been applied. This technique is used to classify frame pixels into two categories: Foreground pixels and Background pixels. Every region residing on connected foreground pixels is an entity that is considered as a vehicle, and then the contour (boundary) of the vehicle is further identified. On the basis of the contour (or boundary) information, it's possible to extract two bottom corners of the vehicle, bottom-left corner, and bottom-right corner. These two corners and the perspective calculation give important outputs of the length of the vehicle and relative tire region. Then, the length of the vehicle is used to identify 4-Bin vehicle classification. Tire region information is used to eliminate a wide search area for tires (the frame) and then indicates a small region to search for tires. Every contour is identified in the tire region to result in a candidate representing a tire. From all the candidates, the candidates located in the same line are picked to find all the tires of detected vehicle, because the center of the tires in a vehicle is supposed to be aligned in the same line. As a result, the tires will be extracted, and then, the positions and number of tires will be further determined. Based on the defined vehicle axle groups in each bin, it's possible to find out the group that vehicle belongs to.

Since one vehicle appears in different frames, a similarity algorithm is developed to find the similarity between two vehicles. If two vehicles are similar, they will get the same stack and the overall result of length and tire positions will be aggregated with each other. More accurate information will come out in identification of vehicle's length and number of tires (or axles). Realistic traffic video data was collected at a place near I-275 close to traffic monitoring station 626 and GPS on the I-275 between Exit 44 and Exist 47 in Cincinnati area, Ohio. Those real-world datasets provide sample testing data for model development and validation. In order to well assess the performance of vehicle classification, the evaluation indicators and indexes are adapted to constitute the performance measurements, including True Positive, True Negative, False Positive, False Negative, sensitivity, Specificity and other related measurements.

## Research Findings & Conclusions

Of the 1185 vehicle samples that have been tested, the result shows a better classification in 4-Bin length – based classification than axle-based group classification. There may be two reasons for this conclusion. First, when a vehicle gets misclassified in 4-Bin classification, it definitely would be misclassified in axle-based group classification. The error of the 4-Bin classification will propagate to the axle-based group classification. Second, there may be some noises in the process of finding the tires and number of tires.

Three major problems are identified remaining unsolved. First, when two or more vehicles are close to each other, they visually get overlapped in the video frame. As a result, the algorithm is unable to distinguish them. Second, a vehicle is tracked by comparing its similarity to the previous frames; however, this similarity may not be identified when a vehicle is partially overlapped with other vehicles in images, or as the similarity gets compromised somehow, even though it is referred to the same vehicle. The current technique may have difficulty to identify a vehicle to be similar to the same vehicle in the previous frame, because of changes in color distribution. A great amount of changes in vehicle color distribution may result in failure of finding the same similarity in the next frames. The third problem is that our algorithm is highly dependent upon the appearance and vehicle colors. Thus, any conditions regarding having low contrast and low brightness will result in lower performance. Therefore, it is of high importance that camera should be placed somewhere with enough light projectors for dark hours of a day.

Some future research work and experiments are needed. For example, the accuracy of the system under different weather conditions, different light conditions, and different traffic volumes should be investigated with more data. The current study has been referred to the relatively light traffic with good lighting and weather condition. The tolerance of the system needs to be further measured for other conditions and varied lanes in the future.

## Recommendations for Implementation of Research Findings

The proposed method is the core engine of the RVIS model. The RVIS model is an assistant aid to the proposed "hybrid" vehicle information extraction system to perform vehicle classification and extract other travel features in an automatic way. However, the testing has proved that the RVIS seems to perform well under light traffic only and would have higher error rate against congested traffic. Another model VEVID that was developed previously by the authors has an advantage over the RVIS in extracting trajectories of all categories of vehicles, even under congested traffic conditions. However, VEVID needs labor effort by manually clicking the mouse onto a distinguished point of any targeted vehicles during the process of trajectory extraction. The error of the VEVID depends in great part upon how accurately the user manually clicks on the distinguished points over the targeted vehicles. The RVIS model is a machine vision method with automatic functionality, but it is much more sensitive to errors. Accordingly, it is recommended to combine the advantages of those two models and make them applicable to different traffic conditions in one system. VIEW-TRAFIC is therefore proposed as a hybrid system that includes RVIS and VEVID. In low traffic the VIEW-TRAFIC switches to RVIS if the light traffic is applied, and it switches to the VEVID in case of heavy traffic. The detailed framework and operation scheme for adapting the RVIS into the VIEW-TRAFIC with the VEVID are developed and delivered in the final part of the project report.