OmniPreSense

AN-021 Vehicle Classification

Vehicle Classification and Lane Detection are valuable pieces of information which the OPS243 radar sensor may provide. Knowing which vehicle is speeding when multiple lanes are present can advise which license plate number will be sent the ticket. Or being able to understand large truck flow patterns can help with noise abatement guidelines. A new API feature has been added to the OPS243 radar sensors which may enable development of machine learning (ML) models for accurate reporting of vehicle classification and lane detection. The following describes the details of the new OC API command which reports these parameters and discusses how they may be used for vehicle classification and lane detection.

OC Command

The OC command was implemented in version 1.2.1 (OPS243-A) and v1.2.5 (OPS243-C) firmware. The OC command provides several parameters which can help identify the vehicle type and/or lane in which the vehicle is located. The command is built on the Detected Object feature of the API. This feature detects when a moving object of interest is present in the sensor field of view (FOV) and gathers the processed speed and signal magnitude data into an array for further processing. Once the object of interest leaves the sensor field of view, the data is processed, and several parameters are reported. The OC output is reported in JSON format with an example below:


```
{"classifier" : "object_inbound",
 "end_time" : "523.998",
 "start_time" : "521.621",
 "delta_time_msec" : 2377,
 "max_speed_mps" : 12.75,
 "min_speed_mps" : 11.53,
 "max_magnitude" : 189,
 "avg_magnitude" : 44,
 "total_frames" : 43,
 "frames_per_mps" : 3.3735,
 "length_m" : 30.3,
 "speed_change" : 0.096
}
```


The following is an explanation of the parameters reported followed by more detailed comments on some of the calculations and how they may be used for vehicle classification or lane detection.

Start Time (t_S) - initial timepoint object detected or when it has entered the sensor FOV

End Time (t_E) – final timepoint object is detected or when it has left the sensor FOV

Delta Time (**t_D**) – total time the object is in the sensor FOV ($t_D = t_E – t_S$)

Max. Speed (v_{MAX}) – maximum reported speed in the gathered data array

Min. Speed (v_{MIN}) – minimum reported speed in the gathered data array

Max. Magnitude (m_{MAX}) - maximum returned signal magnitude in the gathered data array

Avg. Magnitude (m_{AVG}) – average returned signal magnitude in the gathered data array

Total Frames (f_{TOTAL}) – total frames of captured data for the object in sensor FOV. This includes frames where 0 speed may be reported. Total Frames is related to Delta Time by the sensor report rate.

Frames/Speed (f_{DIV_SPEED}) – value of the frame count divided by the speed, removes the speed aspect of the vehicle ($f_{DIV\_SPEED} = f_{TOTAL} / v_{MAX}$)

Length ($d_{FOVLENGTH}$) – calculated length of the vehicle while detected in the FOV($d_{FOVLENGTH} = v_{MAX} \times t_D$). Note this will be longer than the real length of the vehicle due to detection when the vehicle has initially entered the FOV but the majority of its length is outside the FOV. See below for further explanation.

Speed Change Ratio ($v_{MIN\_MAX\_RATIO}$) – this is the ratio of the max. speed detected to the min. speed or effectively the rate of change of the speed as seen by the sensor ($v_{MIN\_MAX\_RATIO} = (v_{MAX} – v_{MIN})/ v_{MAX}$)

For vehicle classification, max. magnitude, avg. magnitude, frames/speed, and length may be good indicators of the vehicle type. It should be noted that the values reported will vary depending on the mounting position of the sensor. For example, a sensor mounted at a given height, down angle, and horizontal angle that is 4m from the center of the lanes of interest compared to an equivalent mounting but 7m from the lanes of interest, will provide different ranges of max. and avg. magnitudes for equivalent vehicles. The mounting relative to the lanes of interest must be considered.

For lane detection, max. magnitude, avg. magnitude, frames/speed, and speed change ratio can provide indications of the vehicle lane. These measurements are provided for vehicles traveling in the same direction. The current implementation is good for single vehicles in the sensor FOV. Further enhancements will report two reports for multiple vehicles in the FOV at the same time. For two vehicles traveling in different directions, an OC report for each vehicle will be provided.

Max. and Avg. Magnitude

The returned signal magnitude of the object is a good indicator for the classification and location of the object of interest. In general:

signal_mag_truck > signal_mag_car > signal_mag_motorcycle > signal_mag_bike > signal_mag_person

However, values reported can have a wide variation making classification challenging. This is due to the shape, size, distance/location, and material of the vehicle. For instance, a large truck in lane 2 (further out lane) may have the same signal magnitude as a car in lane 1.

Fortunately, gathering a dataset over many vehicles can provide distributions associated with particular vehicle types. An example of this is shown in Figure 1. As seen, the distribution of trucks max. signal magnitude for those in lane 1 is very wide and crosses over with the distribution for cars in lane 1. A general guidance using max. magnitude greater than 200 could be used to give higher confidence the vehicle is a truck. Similarly, a spread in the distribution of cars in lane 2 versus lane 1 can be seen although in this case the overlap is much higher.

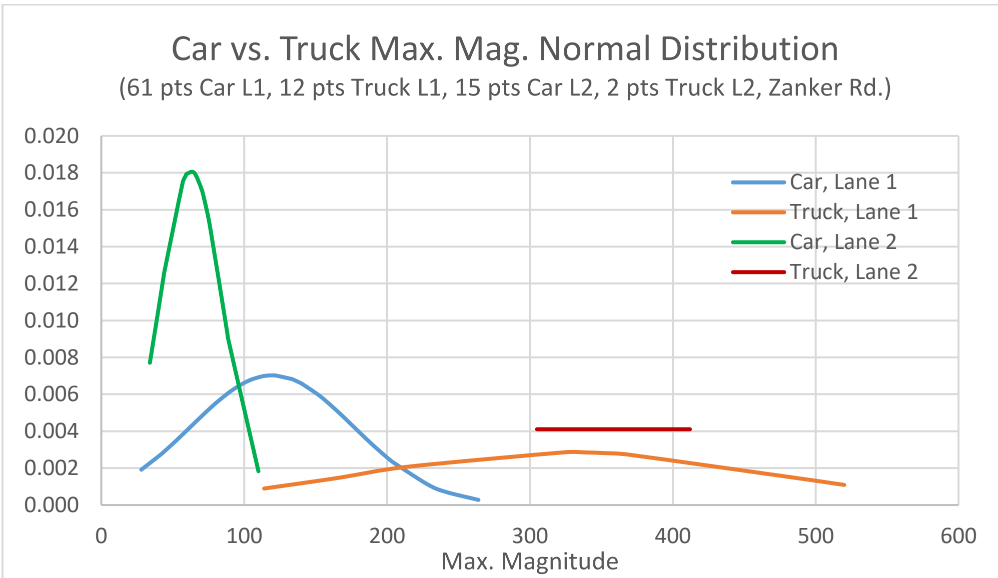

Figure 1. Vehicle Signal Magnitude Distribution

Frames/Speed

The ratio of the frames over speed provides a rough understanding of the vehicle length by taking out the speed aspect. Trucks are longer than cars and therefore at an equivalent speed will be seen by the sensor over a longer period of time resulting in higher frame count. But the frame count on its own cannot be used as the speed of the vehicle will determine the number of frames. Taking a ratio of the frame divided by the speed removes the speed factor and provides a better indication of the vehicle length. This is straightforward for a single lane but when 2 or more lanes are present, vehicles in the 2nd or 3rd lane will tend to have fewer frames than those in the 1st lane for equivalent vehicle type and speed. This is due to the vehicle being further from the sensor and providing a weaker reflection signal which reduces FOV detection. This assumes mounting to the side of the lanes of interest. An overhead gantry mounting provides similar but different data which will not be discussed here but saved for a later update. This concept is shown graphically in Figure 2.

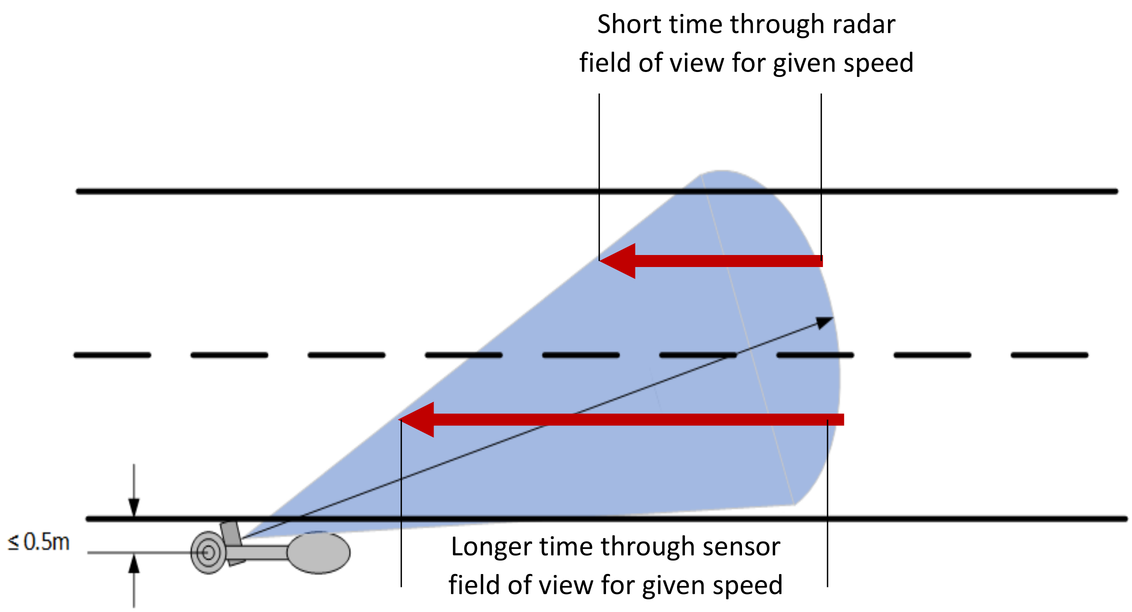

Figure 2. Vehicle Path Through Sensor Field of View for Different Lanes

Length

The length calculation is a more direct indication for vehicle classification. It's based on the assumption:

truck_length > car_length > motorcycle_length > bike_length > person_length

The value provided for the length is not a direct length of the vehicle but its length while detected in the FOV which is greater than the vehicle length. Trying to use a metric such as a typical car being 4.7m (15.4 ft.) and the length reported is not a good approach. The length measurement is based on the speed multiplied by the delta time. The start time, t_S, typically is the point at which the front of the vehicle enters the edge of the sensors FOV (Pt. A of Figure 3). As the vehicle moves through the FOV, additional speed reports are sent by the sensor (Pt. B). This will continue until the vehicle leaves the sensor FOV at which the back portion of the vehicle is just exiting the FOV (Pt. C). The overall length reported is the length of the vehicle **and** the length of the FOV that it has transited through. Given a fixed mounting position, the FOV length for a given lane will be approximately a fixed length providing a good indication of the length of the vehicle for classification purposes. It should be noted, trucks may be detected a little further outside the FOV due to their size/shape while a motorcycle may not be detected until fully within the FOV. Fortunately, this effect helps further separate the reported values. Note, the length value will be different for equivalent vehicles in lane 1 and 2.

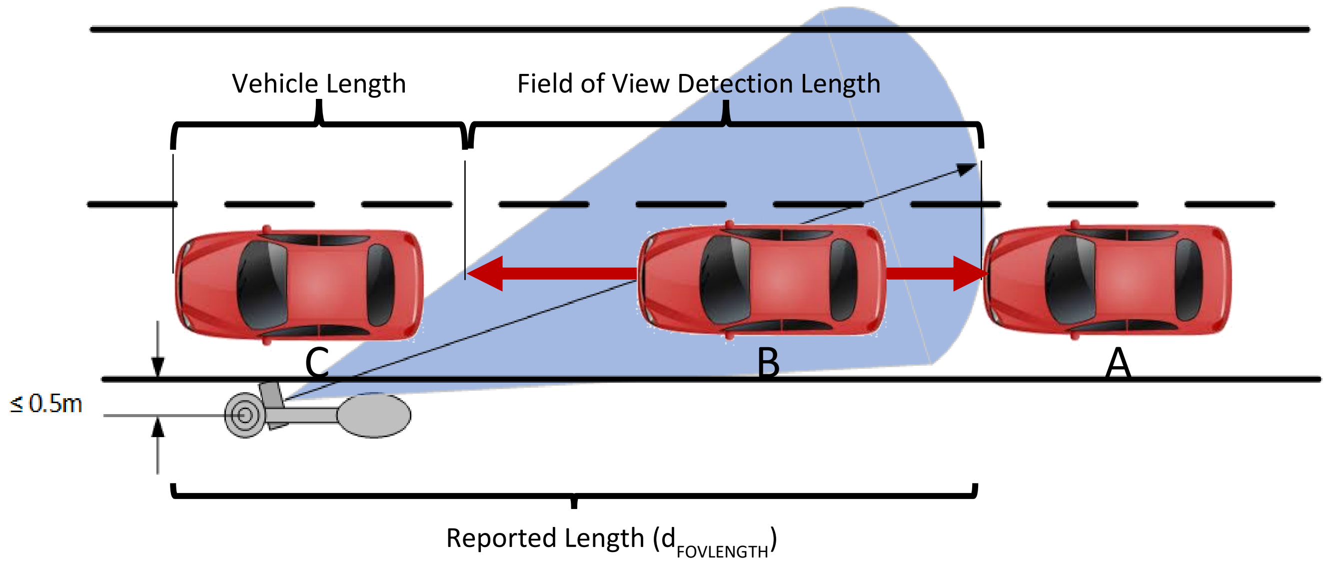

Figure 3. Length Measurement

A distribution for trucks in lane 1 versus cars is shown in Figure 4. Again, there's a wide distribution for trucks but a good separation is seen from cars in lane 1.

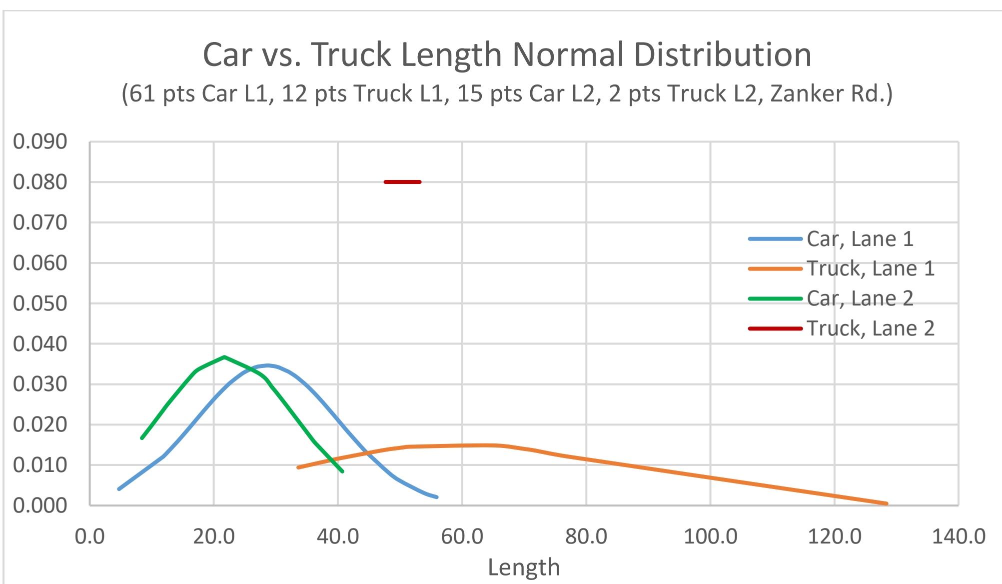

Figure 4. Vehicle Length Distribution

Speed Change Raio

The speed change ratio is a probable indication for the lane the vehicle is traveling through. As vehicles transit through the sensor FOV, the angle at which they are detected changes over time. This results in changing speed reports from the first to the last speed due to the cosine error. For a vehicle that is inbound to the sensor, this is seen as a declining speed (increasing for outbound). The initial speed detected has minimal cosine error and tends to be the max. speed detected. As the vehicle moves through the FOV, the angle increases resulting in slower reported speeds although the vehicle can be considered traveling at a constant speed for the short detection time (typically 0.5-2.0 seconds). A vehicle in lane 2 compared to lane 1 experiences a much higher change in angle (cosine error) and therefore change in the delta speed. Example measurements are shown in Figure 5. Vehicles in lane 2 exhibit a sharper decline than those in lane 1 (1st vehicle in lane 1 was accelerating).

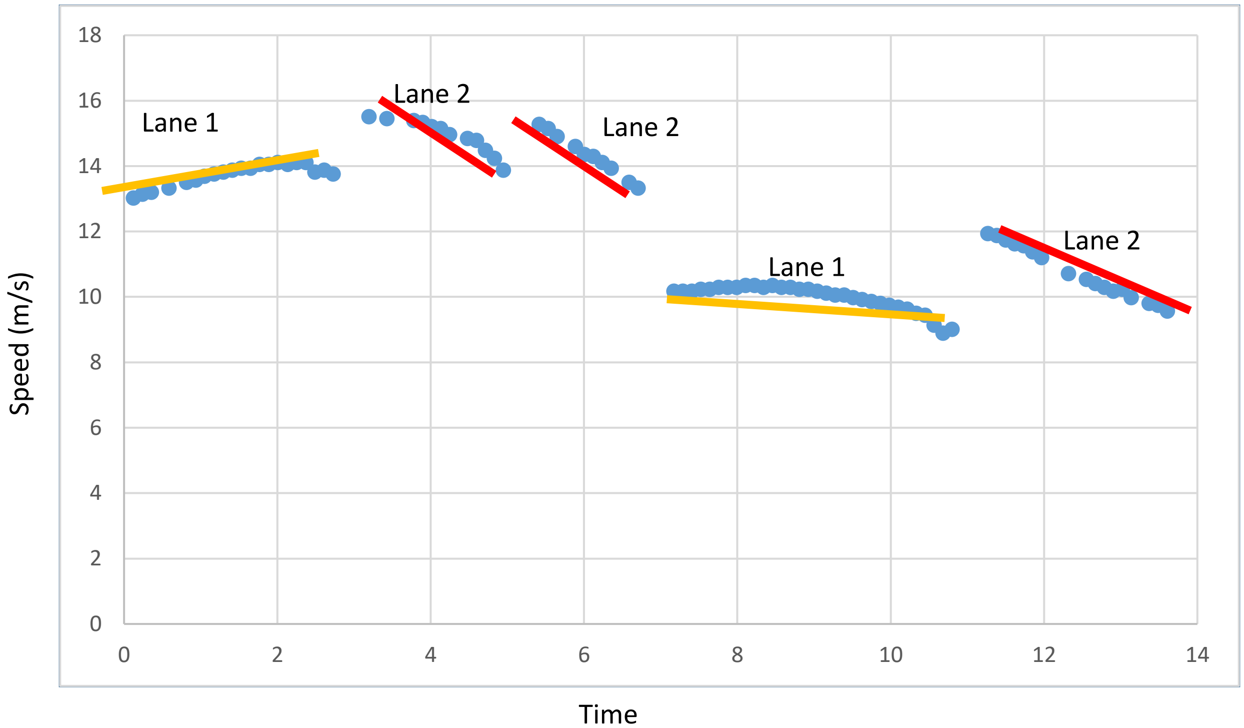

Figure 5. Change in Speed by Lane

As of this writing, the speed change ratio is reported in v1.2.5 firmware for the OPS243-C but not in v1.2.1 for the OPS243-A. It will be added to the v1.2.2 firmware for the OPS243-A when it is released.

Future Developments

OmniPreSense will continue to refine abilities to report data for accurate vehicle classification and lane detection. While providing indicators to assist with classification, it is advised that an implementation make use of combining two or three of the parameters to help provide improved classification accuracy. The parameters provided with the OC command provide a basis for future work with machine learning models to make these predictions.

Revision History

Version	Date	Description
A	June 27, 2024	Initial release.