

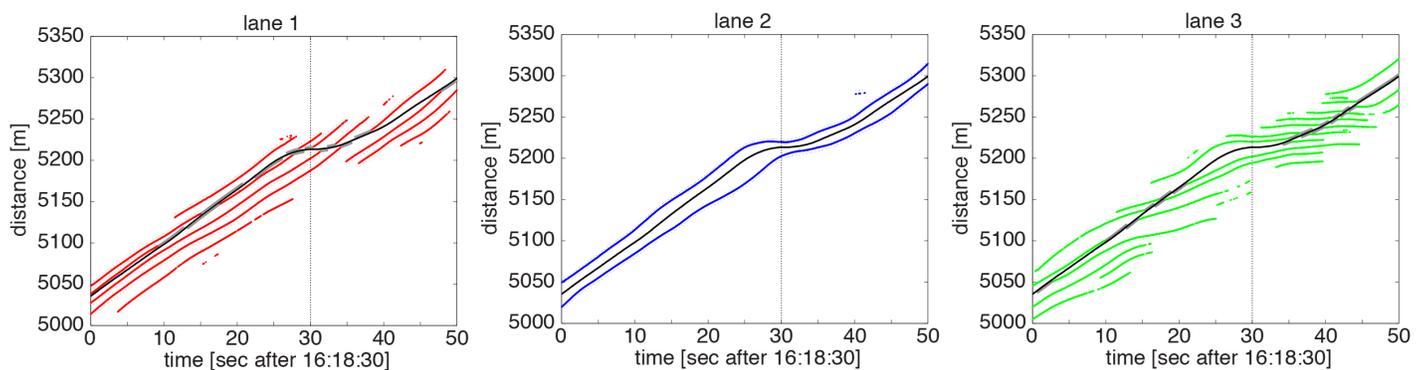
# An overview of the on-going OSU instrumented probe vehicle research

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- Our group has instrumented a probe vehicle with numerous positioning and ranging sensors to monitor the ambient traffic around it (Figure 1)
- The probe vehicle drove two different overlapping tour routes on I-71 in Columbus, Ohio. The longer tour route covered roughly 28 miles round trip while the shorter tour route was roughly 14 miles round trip and covered the most congested portion of the longer tour.
  - Between October 2008 and Aug 2011 the 14 miles where the two tours overlapped were traversed 184 times, while the remaining portion of the longer tour was traversed 70 times.
  - Between June 2005 and October 2008 the 14 miles of the short tour was visited an additional 638 times while the remaining portion of the longer tour was visited 188 times. However, these older data were collected at a much lower sampling rate.
    - New data: LIDAR @ 37 Hz, DGPS @ 5 Hz
    - Old data: LIDAR @ 3 Hz, DGPS @ 1 Hz or 5 Hz
- This corridor has loop detector stations spaced roughly 1/3 mile apart. For most of the time between 2005 and 2011 the individual vehicle passage data from these loop detectors were collected (Figures 2 and 5).
  - These data can be used to reidentify vehicles and estimate vehicle trajectories between successive detector stations [1-5]
- Our data is a strong complement to the NGSIM effort
  - Our data collection spans years, capturing those vehicles within the immediate vicinity of the probe vehicle, whereas NGSIM captured all vehicles over periods on the order of an hour.
  - We are examining a corridor that is many miles long (roughly 70x larger than NGSIM), our study corridor spans upstream and downstream of several bottlenecks
  - Because we use LIDAR and radar our data are not vulnerable to the machine vision errors that undermine the NGSIM data quality
  - Like NGSIM, we anticipate that our collected data will reveal behavioral phenomena and allow us to capture previously unknown influencing factors
  - Our raw data contain roughly 40x the VMT contained in the I-80 NGSIM data set
- While we have collected the raw data over several years, we have not secured sufficient funds to develop the tools necessary to extract the vehicle trajectories from the LIDAR data.
  - The LIDAR data are rich in information (Figure 3), but there is also a lot of noise that has to be dealt with, e.g., usually only a small portion of a given vehicle is seen and so the tracker must be dynamic enough to handle changing appearance, while also accommodating the fact that targets can disappear due to poor returns (Figure 4). The software tools still need to be developed to track vehicles under these challenging conditions.
  - Furthermore, the concurrent loop detector data are not time synchronized with the probe vehicle data

- In spite of limited funding to extract the vehicle trajectories, the efforts have progressed at a low level.
  - We are developing tools to precisely position the probe vehicle within 1 m
  - We are developing the first generation vehicle tracker for the LIDAR data (Figures 5-6). It still has many challenges, e.g.,
    - The LIDAR sensors are mounted at a height that often shoots below some vehicles with high clearance, e.g., semi-trailer trucks and school buses (Figure 4B).
    - While the range of the LIDAR sensors extends to 80 m, few targets have a strong enough return to be seen at that distance, with many targets exhibiting an effective range of only 30 m or 40 m
      - Targets near their effective range will flicker in/out over time. These partial tracks need to be recognized and stitched together (Figure 4A)
    - The pitch of the LIDAR is such that at times it will hit the ground if there is much of a grade, we need to develop tools to detect and handle these collisions with the ground
    - There are subtle issues with the mounting angles of the LIDAR sensors (e.g., the precise angle might be off by 1°-2° and change over time, which leads to a large positioning error for targets at 40-80 m) that could and should be corrected in software
- The automated tracker does a good job, but sometimes there are so few returns or other challenging conditions. To accommodate these periods, the automated results are reviewed. Any incorrect targets are fixed, e.g., missed vehicles or non-vehicle targets in the three lanes of interest.
- With no additional funding, our current goal is to extract data for a single day (trajectory data from two round trips over the long tour, plus the concurrent loop detector data).
- So far these efforts are limited to the new van data, we hope to someday extend the tools to the old van data sets mentioned above.
- As the data become available, they will be posted to:
  - <http://www2.ece.ohio-state.edu/~coifman/documents/>

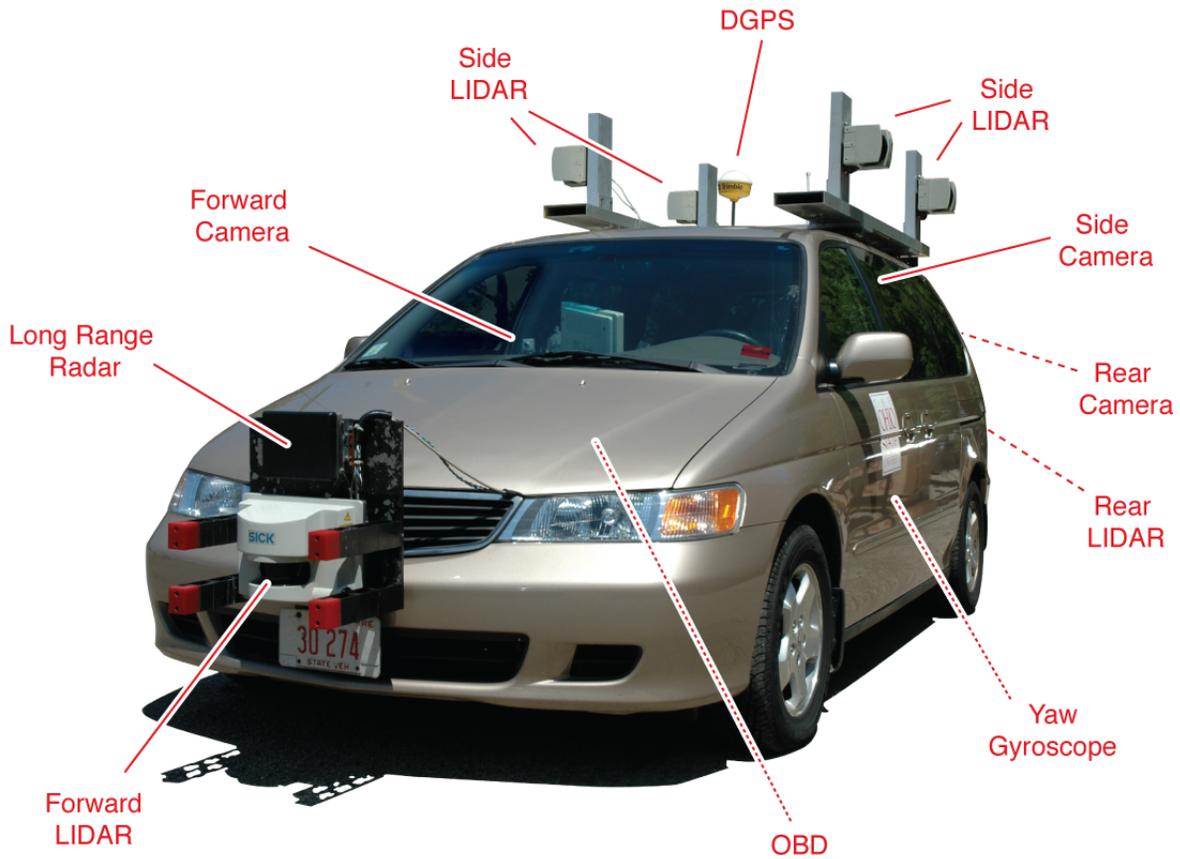


Figure 1, The OSU instrumented probe vehicle with the various sensors highlighted, including forward and rearward LIDAR, forward radar, DGPS, OBD data, and cameras collecting low resolution video at 10 Hz for validation (not all sensors are available on all runs).

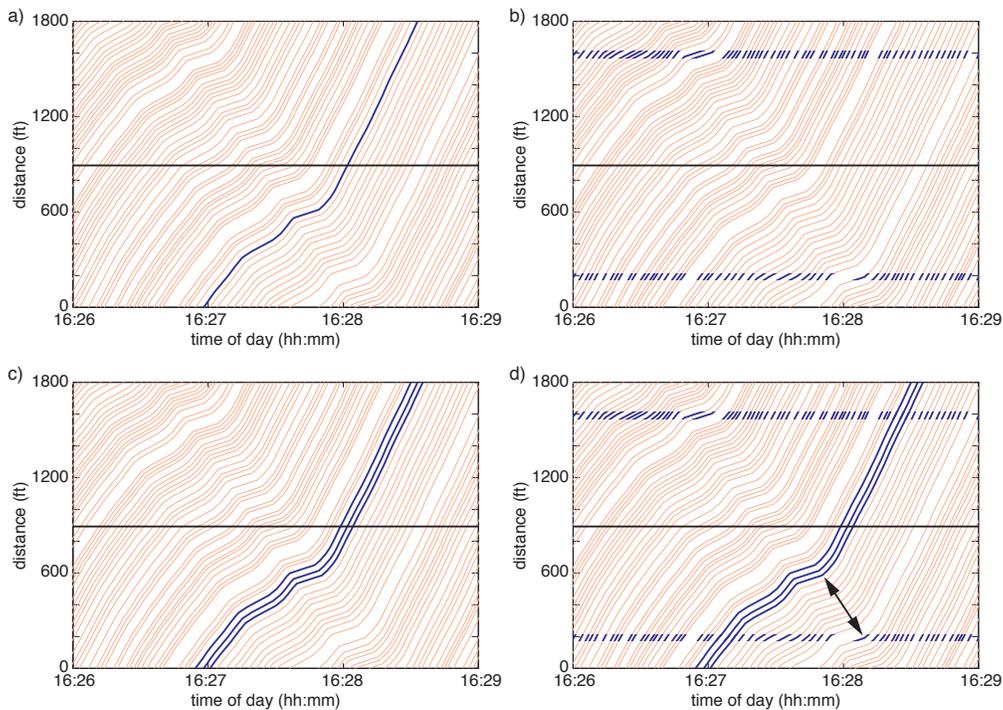


Figure 2, Hypothetical vehicle trajectories over 1/3 mi, dark blue observed, light red unobserved, as seen by (A) conventional probe, (B) individual loop detector actuations, (C) ambient vehicles from LIDAR, (D) our ultimate goal a combination of B and C; thus, as shown by the arrow, allowing events seen in the LIDAR to be associated with events seen in the loop detector data. Although not shown, the loop detector actuations can also be used for vehicle reidentification between detector stations [1-3], trajectory estimation [4], inflow measurement [5], and density estimation [5].

A)



B)

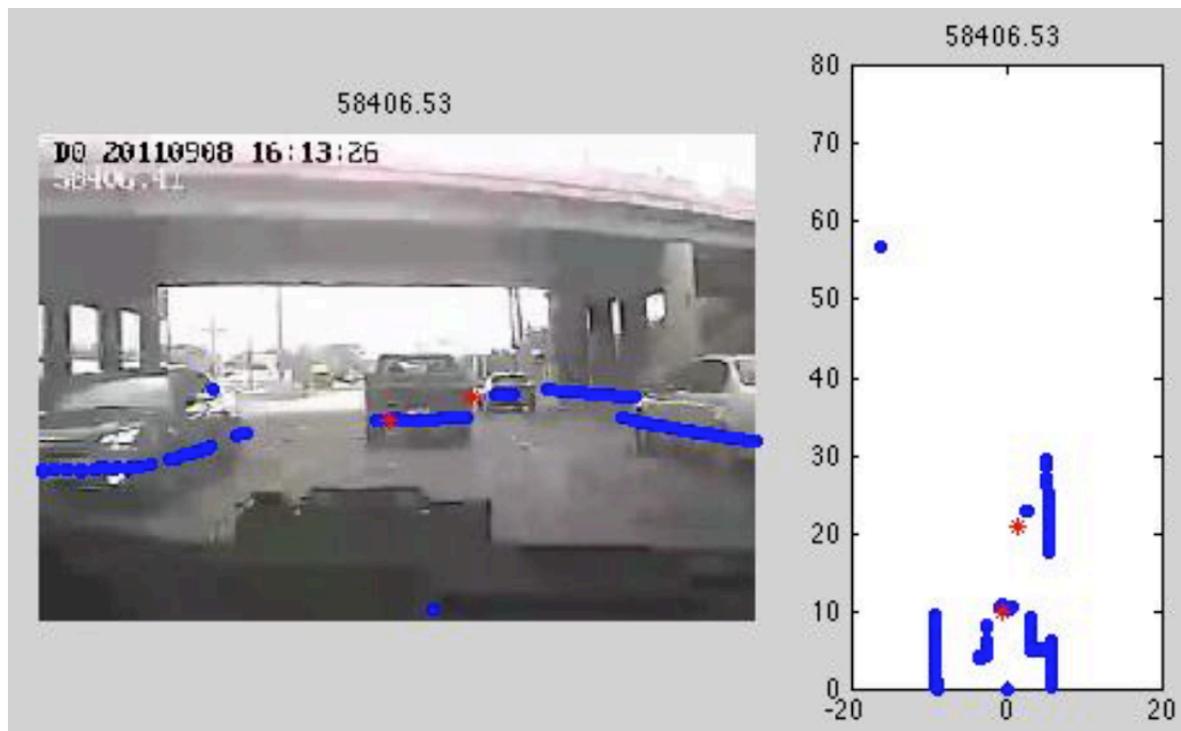


Figure 3, Forward LIDAR (blue) and radar (red) superimposed on the corresponding (low resolution) video frame on the left and as viewed from "above" on the right. The two frames were captured 1.25 sec apart. When superimposed over the video it is clear how much information the LIDAR contained, but when viewed from above, it becomes clear how difficult it is to differentiate between vehicles and non-vehicle objects in a single frame.

A)



B)

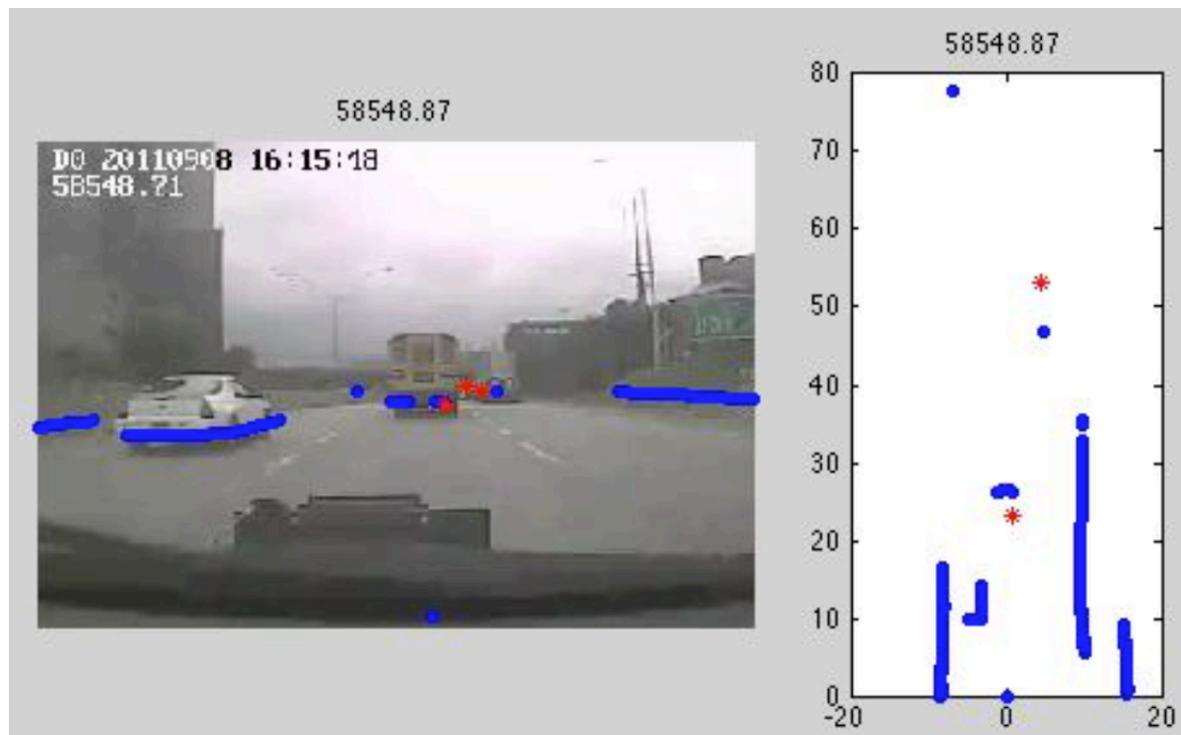


Figure 4, This figure illustrates some of the remaining challenges faced when processing the LIDAR. Again, forward LIDAR (blue) and radar (red) superimposed on the corresponding (low resolution) video frame on the left and as viewed from "above" on the right. (A) A vehicle is clearly evident in the radar and video 40 m ahead of the probe, but the LIDAR returns were not strong enough for the LIDAR sensor to detect, so the LIDAR tracker must be smart enough to differentiate between "no return" and "no vehicle". (B) The school bus immediately ahead of the probe vehicle at about 25 m is seen at different distances in the LIDAR and the radar data. In this case both sensors are correct, the LIDAR sees the rear wheels in its scanning plane while the radar sees the rear wall of the bus. Nonetheless, a driver is likely to respond to the rear wall of the bus, so the LIDAR processing must be robust enough to identify situations where it may be scanning under part of a vehicle. This problem can also arise under semi-trailer trucks, particularly in adjacent lanes. While the radar could help in these examples, it has roughly  $14^\circ$  of coverage compared to  $180^\circ$  for the LIDAR, and there is no rear facing radar.

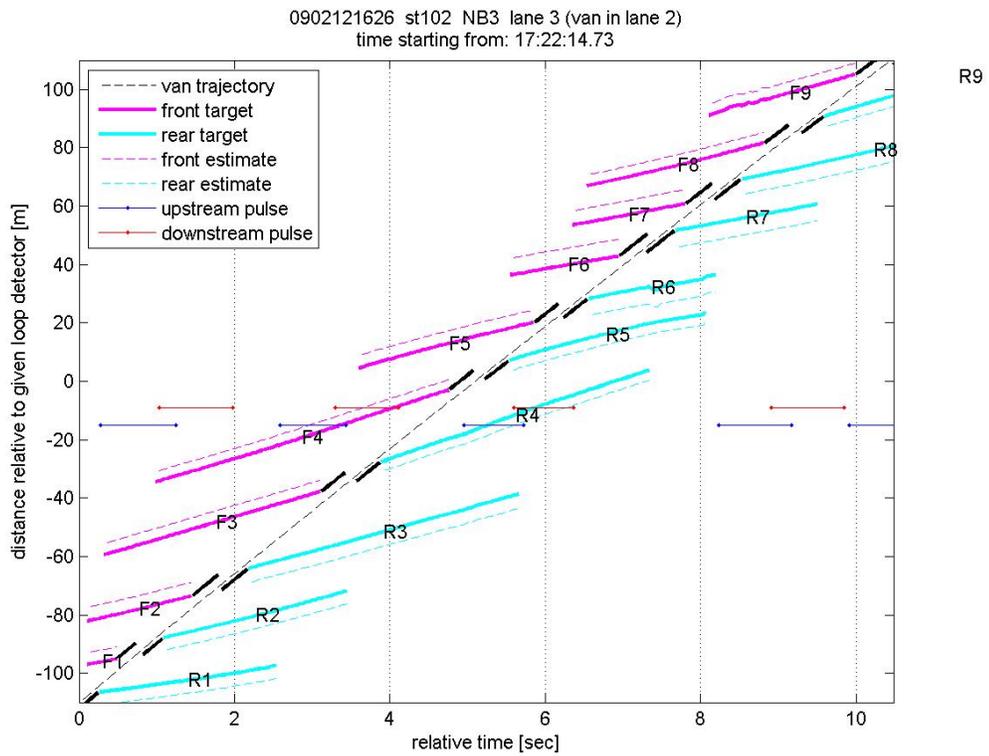
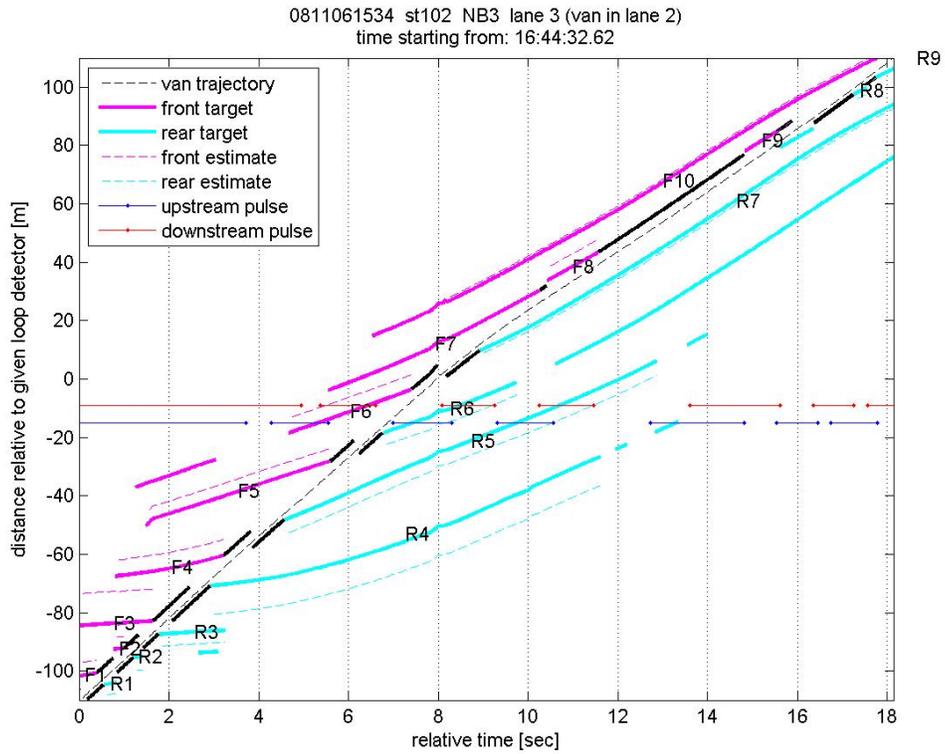


Figure 5, Preliminary examples of our current work associating targets between the front LIDAR (magenta), rear LIDAR (cyan), and a dual loop detector (blue upstream, red downstream) as seen in the time space plane. In both cases the figure only shows traffic in the lane immediately to the right of the instrumented probe vehicle, and for reference, the probe vehicle's trajectory. The two examples come from different days at the same location.



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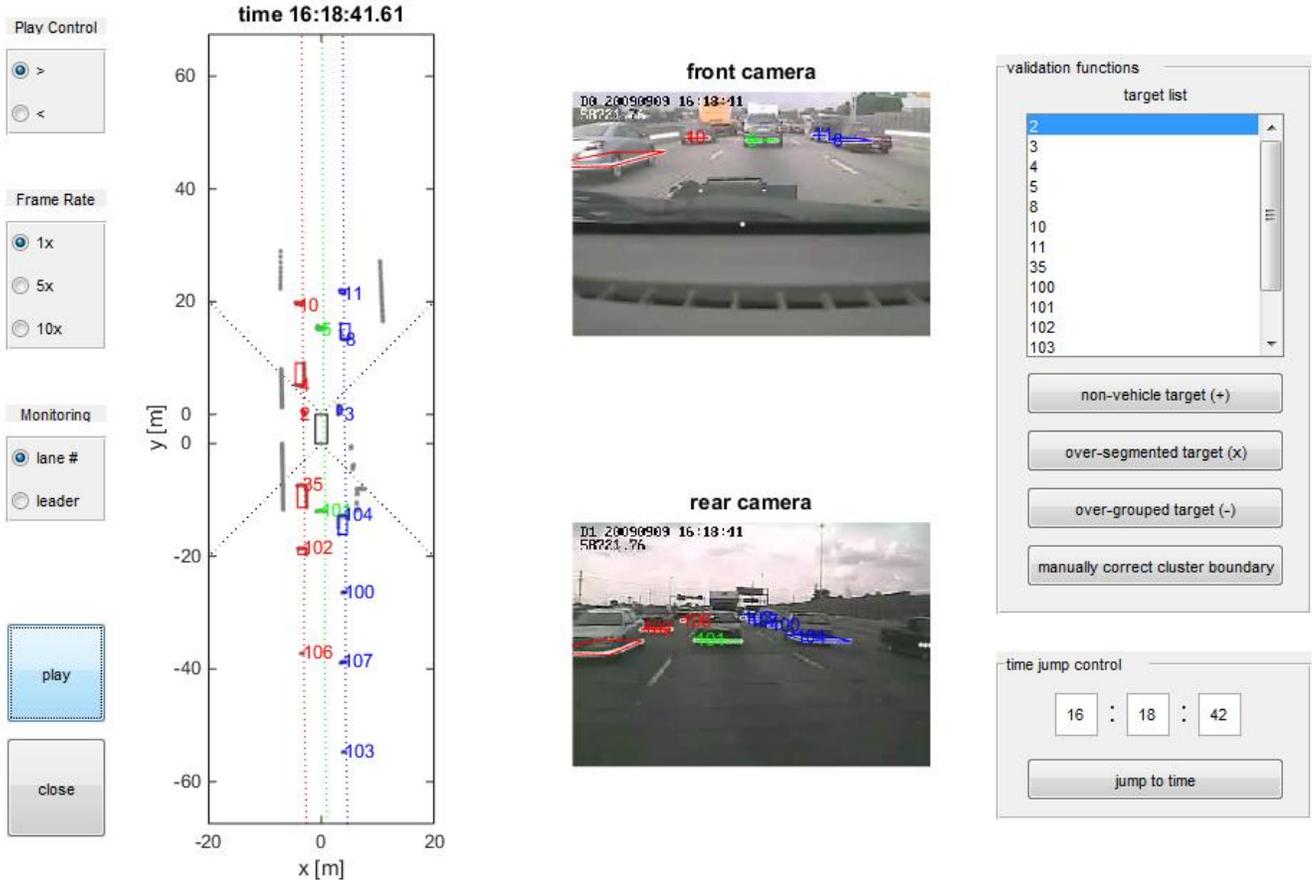


Figure 7, After automated tracking, a few vehicles were incorrectly segmented. This tool is used after the automated tracking to identify and fix any of the following within the three lanes of interest: missed vehicles, non-vehicle tracks, over-grouping, over-segmenting.

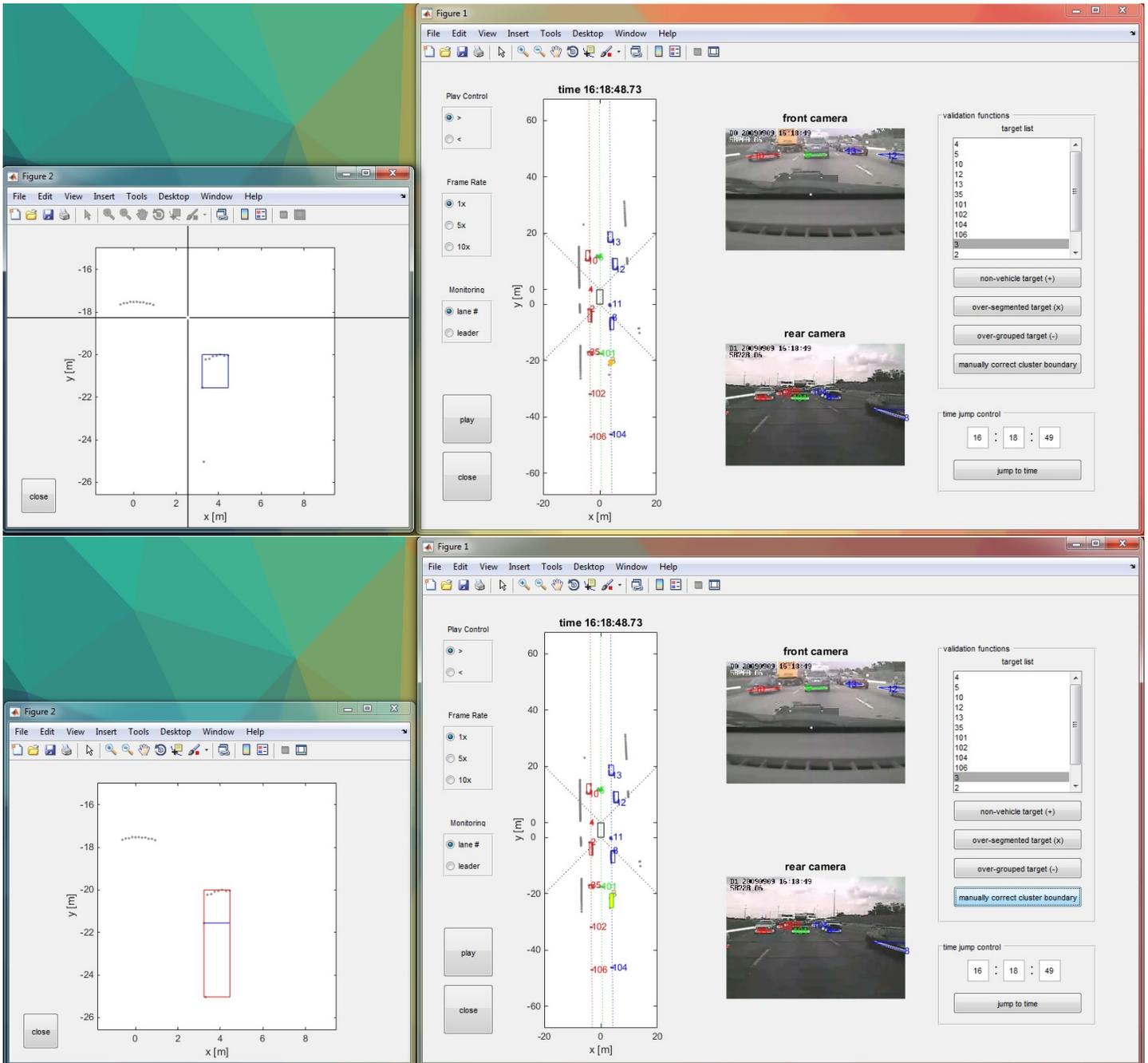


Figure 8, Using the tool from the previous figure, after clicking on a cluster in the top right, that cluster turns yellow and a detail is shown in the top left. The user modifies the bounding box, resulting in the bottom left and updated in the bottom right.

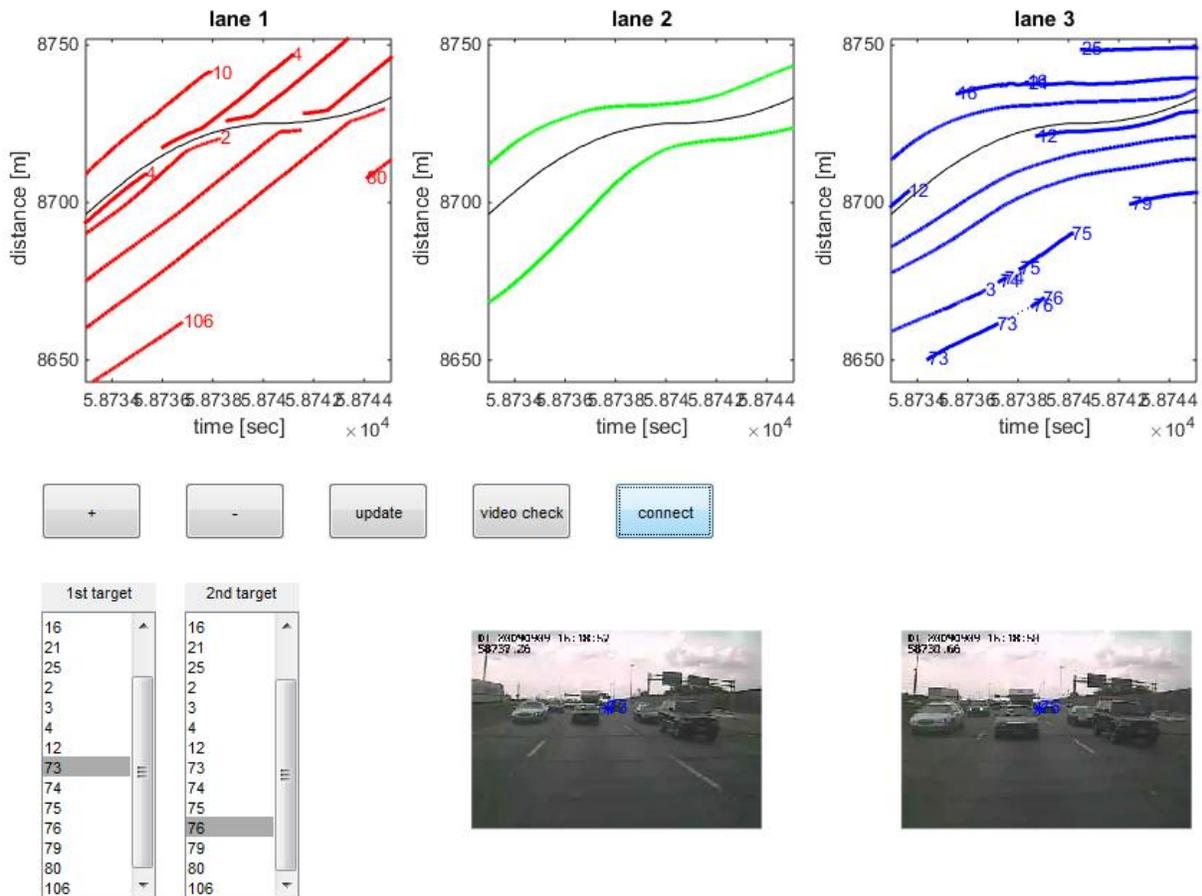


Figure 9, The LIDAR will suppress returns if their strength is too low. If all of the returns from a target are suppressed, that target disappears from the recorded data. If the dropout is too long a new track will begin when the vehicle is seen again. Of course the actual vehicle did not disappear. So after tracking this tool is used to join multiple target numbers from a given vehicle. In this case only one vehicle pair has been fixed in this example (73-76), several many more need to be joined. The images in the bottom right show the last video frame before the LIDAR drops out and the bottom right shows the first video frame after the vehicle is seen again.

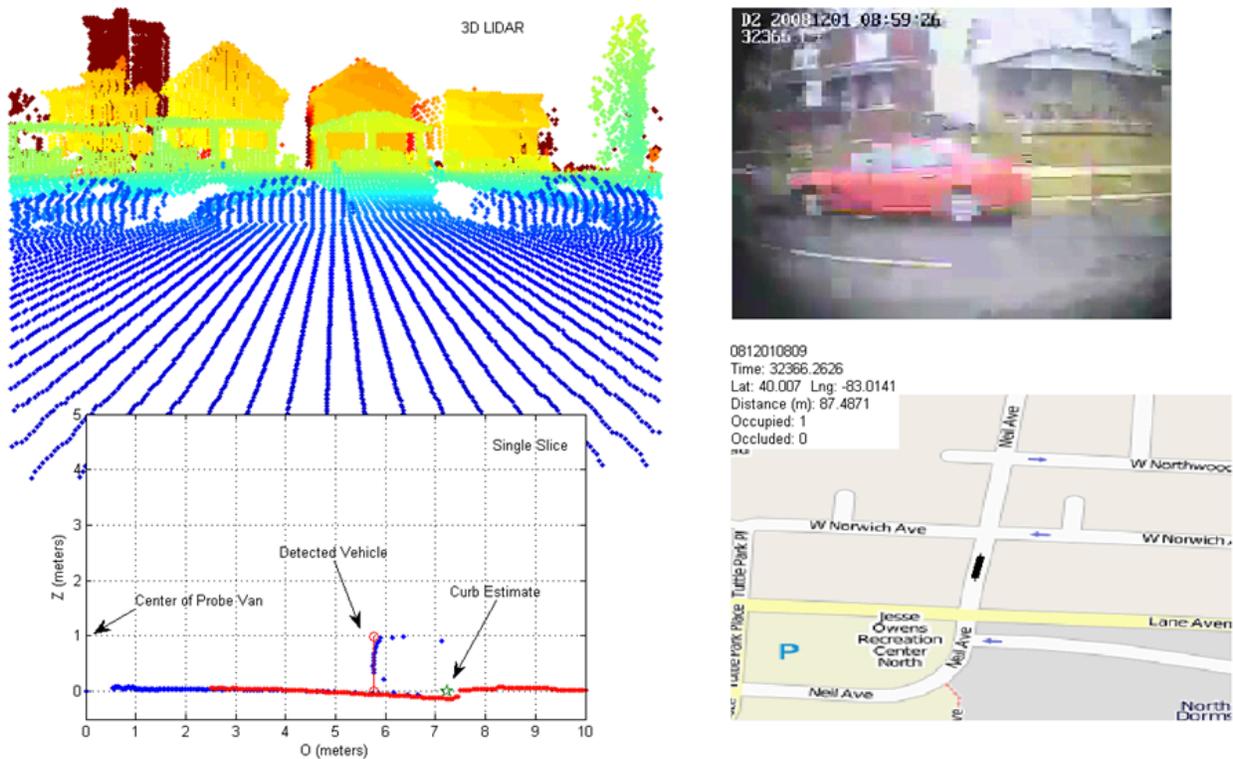


Figure 10, Top left shows an example of the LIDAR point cloud from the driver-side LIDAR. Scans are made at 37 Hz, in this case the probe vehicle is traveling to the right, near the posted speed limit on an arterial, resulting in the scan lines being approximately 0.1 m apart in this figure. In general the spacing is dependent upon the probe's speed. The inset on the left shows examples of the curb detection and parked car detection algorithms from [6]. The top right shows the corresponding frame from the side view video camera and bottom right is the probe's location on a map.

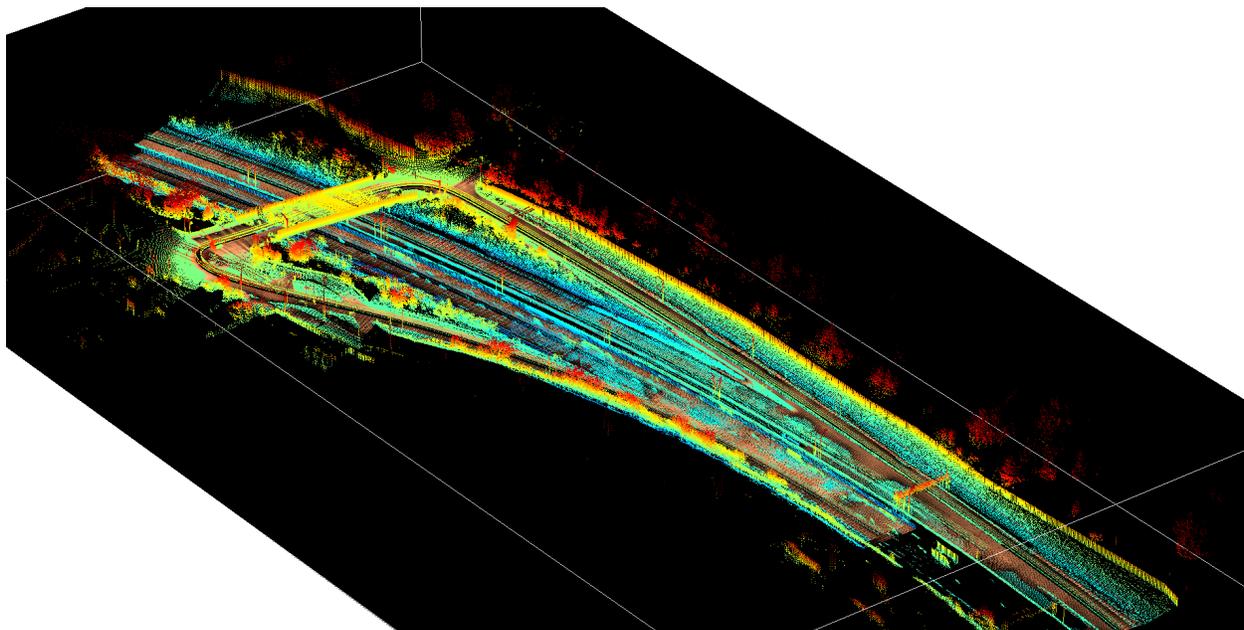


Figure 11, This figure shows a composite 3D point cloud from a few runs through the I-71 and North Broadway interchange in Columbus, OH, taken from side view LIDAR.

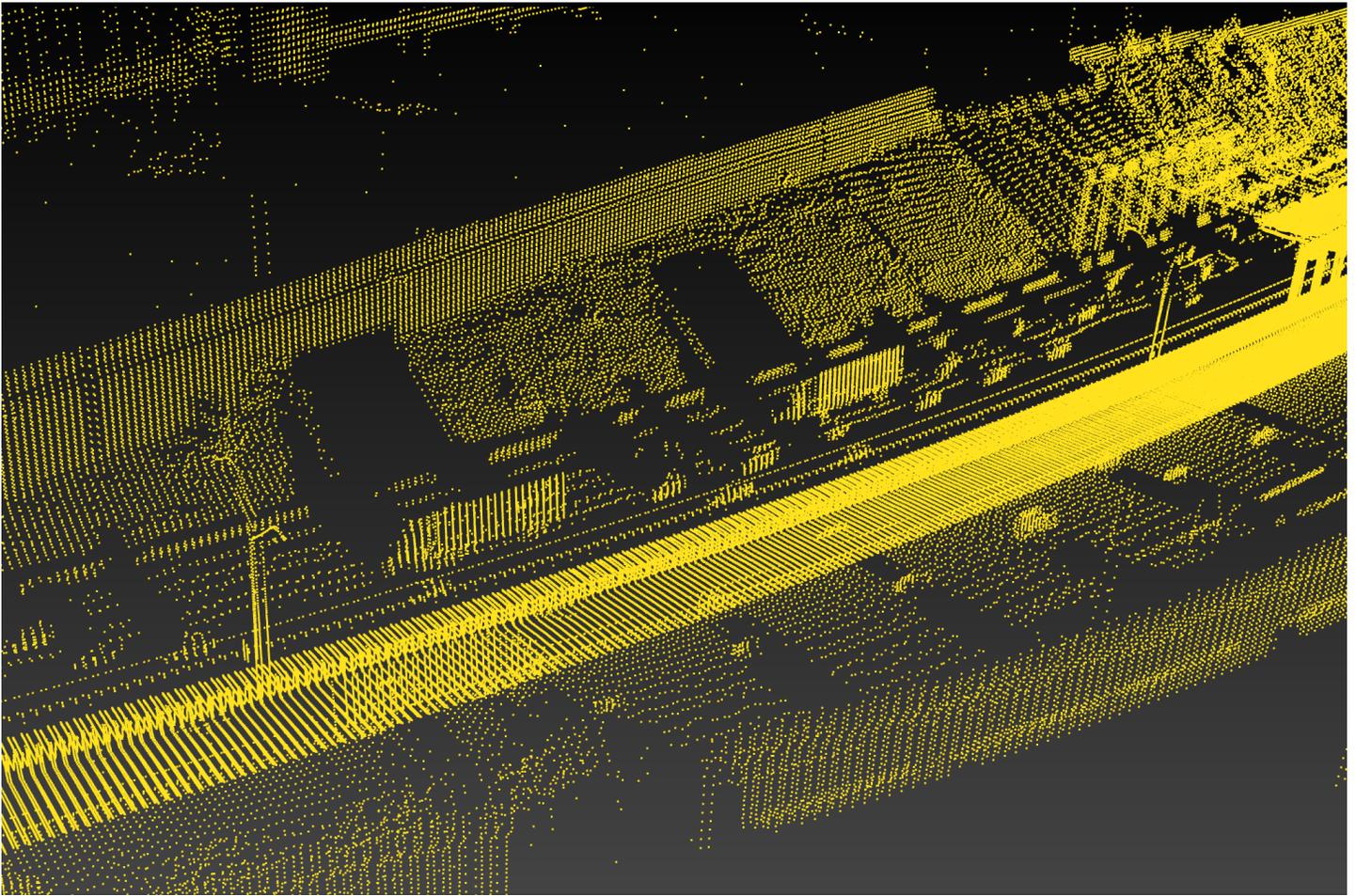


Figure 12, This figure shows a composite 3D point cloud of the driver's side LIDAR from one eastbound and one westbound run where I-70 and I-71 overlap on the southern "inner-belt" in Columbus, OH. This view is looking north by northeast. Note that several vehicles are evident on the freeway, including two westbound semi-trailer trucks. Various roadway features are also evident, including the median barrier, luminaires, and on the right of the image a bridge for the High St. overpass.

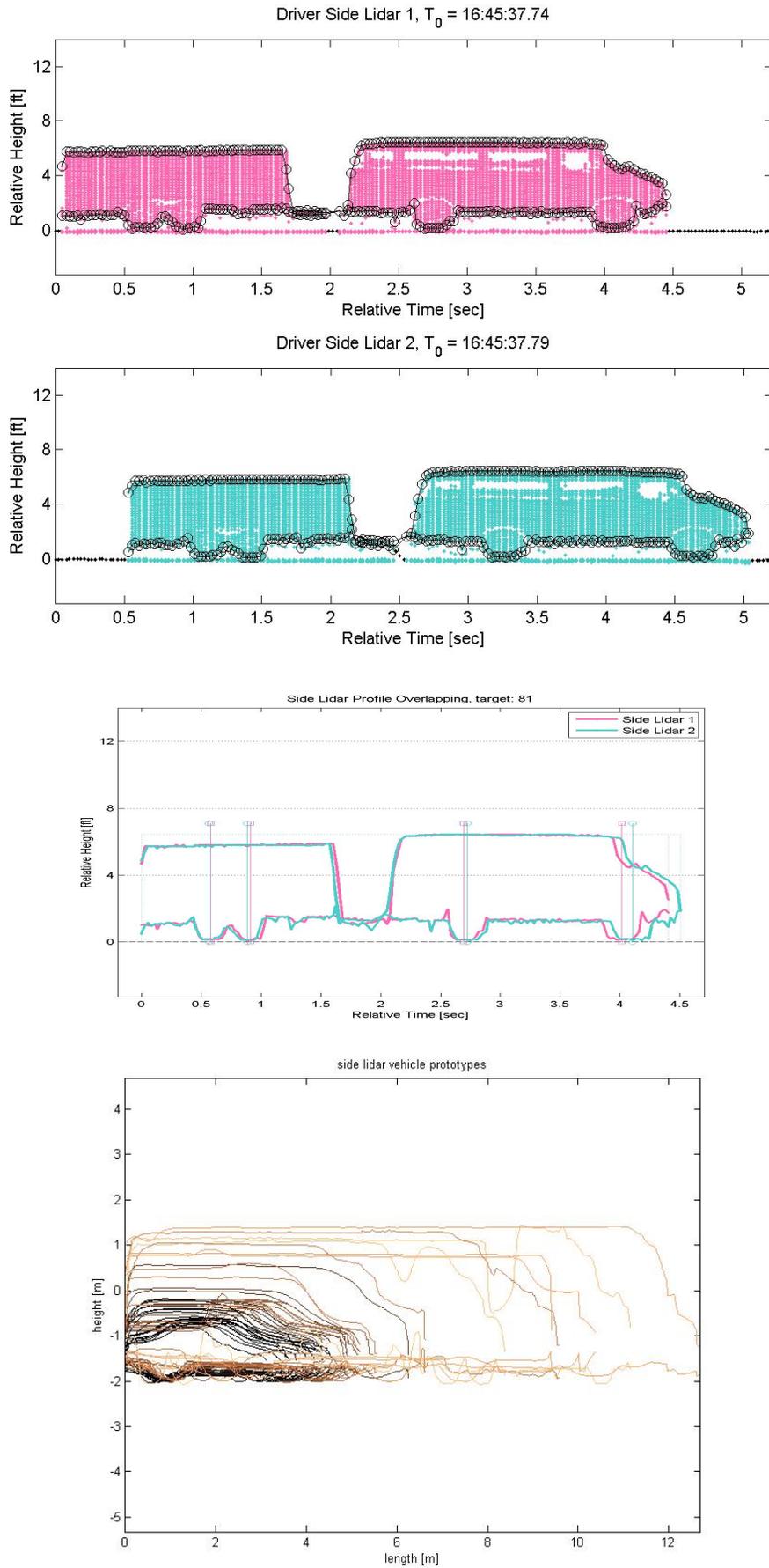


Figure 13, Examples of current research into classifying vehicles in the side view LIDAR (details of the previous generation of LIDAR based classifier can be found in [7]).

## References

- [1] Coifman, B. (1998) "Vehicle Reidentification and Travel Time Measurement in Real-Time on Freeways Using the Existing Loop Detector Infrastructure", *Transportation Research Record 1643*, Transportation Research Board, pp 181-191.
- [2] Coifman, B., (2003) "Identifying the Onset of Congestion Rapidly with Existing Traffic Detectors", *Transportation Research: Part A*, vol 37, no 3, pp. 277-291.
- [3] Coifman, B., Krishnamurthy, S., (2007) "Vehicle Reidentification and Travel Time Measurement Across Freeway Junctions Using the Existing Detector Infrastructure," *Transportation Research- Part C*, Vol 15, No 3, pp 135-153.
- [4] Coifman, B., (2002) "Estimating Travel Times and Vehicle Trajectories on Freeways Using Dual Loop Detectors," *Transportation Research: Part A*, vol. 36, no. 4, pp. 351-364.
- [5] Coifman, B. (2003) "Estimating Density and Lane Inflow on a Freeway Segment", *Transportation Research: Part A*, vol 37, no 8, pp 689-701.
- [6] Thornton, D., Redmill, K., Coifman, B., (2014) "Automated Parking Surveys from a LIDAR Equipped Vehicle," *Transportation Research- Part C*, Vol 39, pp 23-35.
- [7] Lee, H., Coifman, B., (2012) "Side-Fire LIDAR Based Vehicle Classification," *Transportation Research Record 2308*, pp 173-183.