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Modeling HVE Environment from Drone Scans

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Abstract

Many roadway accident scenes have limited or restricted access such as freeways and highways. In addition, the area needed for an HVE environment or final animation can be quite extensive. These types of environments are often difficult to document using ground-based laser scanners. Drones, however, can move over these environments with the operator based safely away from the roadway surface. A drone can also capture large environments in a fraction of the time required by ground-based scanners.

This paper will discuss the tools and software necessary to document a scene with a drone, convert the imagery into accurate three-dimensional point clouds, and create HVE scenes for simulation. Several case studies will be covered where large, heavily travelled environments were captured and modeled from drone imagery.

Introduction

For almost every accident reconstruction performed, the analyst needs documentation of the location of the collision. Traditionally this documentation may take the form of a survey, laser scan, or Google Earth aerial photograph. The emergence of cheap and reliable small unmanned aerial systems (UAS) or drones which can easily carry high-quality cameras and have the capability to store many images has changed the way collision scenes can be documented. Restricted-access roadways can be documented safely in a fraction of the time it would take using ground-based laser scanners or total stations.

A small drone can easily be used to take a high-resolution aerial photograph of a scene. The application of photogrammetric techniques to large numbers of photographs taken from a drone allows for the creation of an accurate three-dimensional point cloud and model of the accident scene.

Mechanics of Information Gathering

In order to gather the necessary data to create a site model using aerial photogrammetry, the drone is flown at the scene. First, the user must determine whether it is permissible to operate the drone at the desired location. This can be accomplished by reviewing data available from the Federal Aviation Administration (FAA) or by using one of several mobile device applications to visualize the types of airspace and Unmanned Aerial System (UAS) restrictions. Some iOS applications which are used for this purpose are Kittyhawk, B4UFly, and AirMap, among others.

Upon review of the various flight restrictions, there are three possible outcomes: operation of a UAS is not permitted, operation of a UAS is permitted subject to 14 CFR Part 107 restrictions, or operation of a UAS may be permitted but with further authorization. In general, operation of a UAS is not permitted in National Parks, close to controlled airports, and near sensitive locations. When the operation of a UAS requires further authorization, there are two ways to obtain authorization: submission of a waiver to the Federal Aviation Administration (FAA) subject to a 90 day review lead time, or Low Altitude Authorization and Notification Capability (LAANC) an automated authorization system in which permission for a flight can be requested from a mobile device at the time of flight or in advance.

For the best accuracy in generating 3D point clouds, ground control points may be used. Prior to taking aerial photographs at the scene with the drone, reference points are marked on the ground (typically using spray chalk) which will be visible in the photographs and the point cloud generated from the photographs. These reference points are labeled, and the locations are logged using a high-precision GPS receiver with the ability to apply local correction factors in post-processing or survey-grade measurement equipment. We use a Trimble GeoExplorer 6000 Series GPS receiver with a Trimble Zephyr Model

2 external antenna on a two-meter survey pole. This system allows us to measure the locations of our reference points with a stated sub-ten-centimeter accuracy after local correction factors are applied. Typically, we would collect less than ten ground control points for a one-thousand-foot by one-thousand-foot measurement area.

Once it has been determined that a drone can be flown at the location of interest, the drone is flown in a double-grid pattern with photographs taken at regular intervals using the on-board camera. This process can be automated using a mobile device application such as Pix4D Capture. Figure 1 below shows a sample double grid pattern laid out over an intersection. With multiple drone batteries available, multiple flights can be done to capture larger sections of roadway.

Figure 1. *Example Double Grid Pattern for UAS Flight*

As an example, a DJI Phantom 3 Professional drone has a nominal flight time of about 20 minutes using one battery. Using this drone, approximately 700 feet of two-lane roadway can be captured during a 15-minute flight, leaving a battery allowance to maneuver back to the takeoff/landing location. Flight time can be drastically reduced by the presence of wind, so the operator must take care to plan the flight while accounting for environmental conditions. If the operator has multiple drone batteries available, the operator can quickly land the drone and swap batteries to perform many flights consecutively. Pix4D Capture allows the operator to pause an automated flight pattern to switch batteries, as well as allowing flight planning to occur while the drone is disconnected or powered off.

Each flight's double grid pattern can be slightly overlapped with the next flight to create one large set of photographs which will connect to form a model. In-flight photographs are taken with the onboard camera at an angle of 80 degrees below horizontal (almost, but not quite straight overhead). We typically fly the drone at an altitude of 100 to 150 feet above ground level. Figure 1above shows that using the Phantom 3 Professional drone at an altitude of 120 feet results in a ground separation distance of 0.64 inches per pixel.

The metadata for each photograph taken also includes the GPS location of the drone at the time of the photograph. DJI Phantom drones have barometric pressure transducers used to determine and maintain altitude; this data is not encoded in the photographs, but the GPS altitude is. GPS altitude is significantly less accurate than the onboard barometric altimeter. Spreading high-precision control points across the area to be modeled allows for correction of altitude during processing.

The drone stores the photographs and any recorded video on a MicroSD card onboard the drone. The size of the memory card should be chosen to allow for complete recording of the flight. As an example, capturing the Truckee River bridge on I-80 in California resulted in 1365 photographs from a DJI Phantom 4 drone, for a total file size of 11.6 GB.

Processing Data

Once the data has been captured at the scene the photos are imported into software for processing. The first step in processing the images is to perform a camera alignment. This process will initially generate a sparse point cloud. Figure 2 below shows a sparse point cloud of a roadway intersection in a commercial area. A sparse point cloud can be generated in a fraction of the time it would take to create a dense point cloud. The sparse point cloud allows the user to review the results of the photogrammetric processing without committing several hours of processing time.

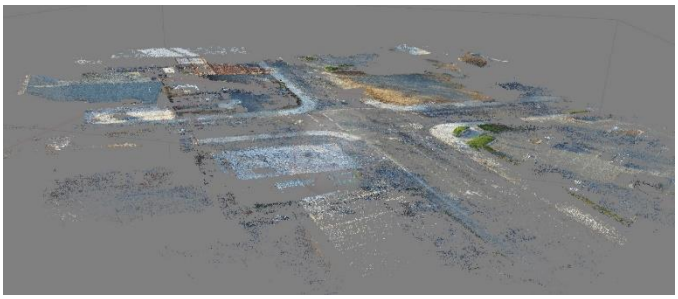

Figure 2. *Sparse Point Cloud*

After the sparse point cloud has been generated, obvious outlier points can be removed. These outlier points come from things like moving vehicles or poor photographic alignments which result in points which do not represent physical objects that are present (i.e. points below the roadway). Once all the outlier points have been removed, the photographs can be re-processed to improve the photogrammetric alignment. Once the alignment is satisfactory, the ground control points that are marked on the roadway surface and measured with the high precision GPS unit at the time of the drone flight can be included.

The next step is to create the dense point cloud. Figure 3 below shows the dense point cloud from the same project as the sparse point cloud in Figure 2. The dense point cloud is analogous to a scan from a traditional laser scanner and can be used in the same manner as a laser scan to make measurements or build models.

Figure 3. *Dense Point Cloud*

Once the dense point cloud has been created, it can be used to build a digital elevation model (DEM). A DEM can then be used to generate an orthomosaic photograph and a 3D model. Figure 4 below shows an automatically generated 3D Model created using Agisoft Metashape. The 3D model can be exported to a VRML file format for use with the new HVE VRML input and scissor tool features.

Figure 4. *3D Model*

Figure 5 below shows an orthomosaic photograph from the same project. An orthomosaic photograph is a composite image using all the photographs used in the project. Since the software has already computed the location and orientation of the camera for every photograph used in the project, the photographs can be combined to create one large image. This image is then rendered from a straight overhead perspective, producing a true ortho-rectified aerial image. Since there is significant overlap between the various photographs taken by the drone, Agisoft Metashape has a feature which allows the user to choose between the various photographs which cover a given area, allowing for simple removal of cars and pedestrians in the final image.

Figure 5. *Orthomosaic Aerial Photograph*

Since the orthomosaic image is generated by combining many high-resolution photographs, the final image generated by this process is much higher resolution than

an aerial photograph from services like Google Earth or Nearmap. The spray paint markings used to denote the locations of underground utilities that have been painted on the roadway are easily visible. Figure 6 below shows a close-up of the orthomosaic image shown in Figure 5.

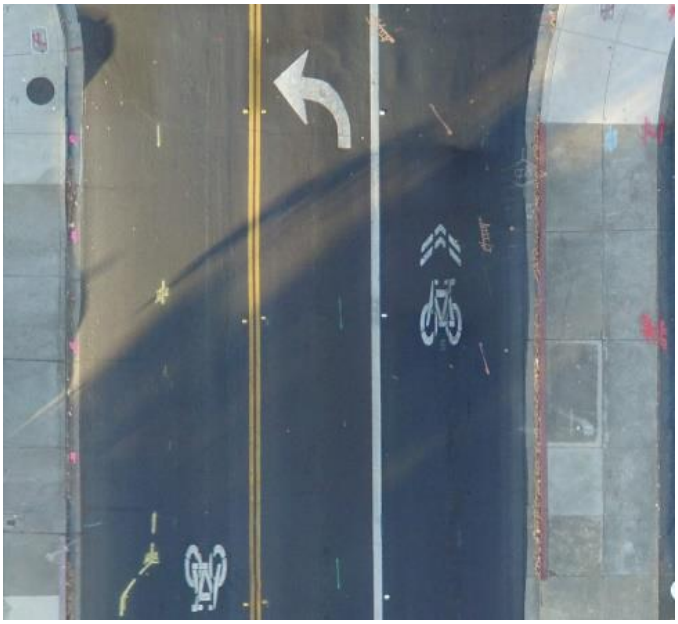

Figure 6. *Closeup of Orthomosaic Photograph*

Software

The authors currently use Metashape by Agisoft to create point clouds, 3D models, and orthomosaic images from drone photographs. Some similar software packages are: Drone Deploy, Pix4D, and Raptor Maps among others.

The processing of the drone photos takes substantial computing power. For example, the current processing machine used by the authors has a 16 Core AMD Ryzen 1950x processor with 128 GB of RAM and two NVIDIA GeForce GTX 1080 TI graphics cards.

Typically, a scene documented with a droneconsists of approximately 1000 feet of roadway. It takes about 1 to 2 hours to perform alignment of the images and create a sparse point cloud. The dense point cloud can take up to 6 to 8 hours of processing time. Larger scenes can take much longer, but the processing time can be shortened by using a network of computers or by using cloud processing services.

Advantages and Limitations of Drone-Based Data Gathering

Documenting accident locations using drone-based aerial photography has several advantages as well as several limitations. As mentioned above, there are restrictions on where a drone can be flown due to proximity to airports, national parks, and other sensitive areas. Figure 7 below shows a screen shot from the Kittyhawk iOS mobile application showing the Sacramento, CA metropolitan area.

Much of the Sacramento area is covered by restrictions related to the Sacramento International Airport (SMF, upper left) McClellan Air Force Base (MCC, upper right) Mather Field (MHR, lower right) and Sacramento Executive Airport (SAC, lower left). The colored rectangles around each airport relate to the ability to request authorization to fly using LAANC. The colors correspond to permissible authorization altitudes using LAANC. Gray rectangles indicate that LAANC is unavailable and a waiver must be submitted to the FAA for approval, which can take up to 90 days.

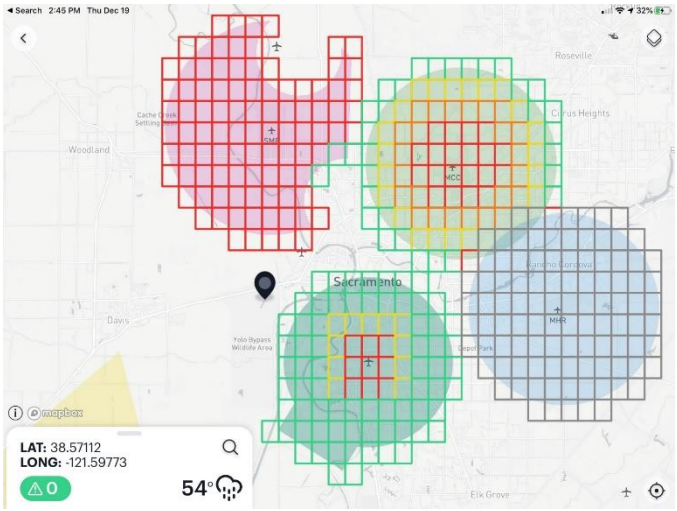

Figure 7*. UAS Operating Area Restrictions Near Sacramento, CA*

Additionally, drones cannot be flown in inclement weather or in high wind conditions. However, drones also have many advantages over traditional data-gathering methods.

It is advantageous to use a drone when the area of roadway to be documented is large. This is particularly useful when working on cases involving incidents which occur on high speed roadways. Typically using a laser scanner, the operator would need to place the scanner every 50-100 feet along the roadway and typically along both sides of the roadway in order to get enough scan points to make a high-quality model. In a typical

configuration, a FARO laser scanner takes approximately 8 minutes to take one scan. If an operator is placing the scanner every 50 feet along the side of the roadway, it would take over 5 hours of non-stop scanning to cover 2000 feet of roadway. If the road is sufficiently wide to require a second set of scans on the other side of the road, then the time is doubled. Using a total station would be similarly tedious and would result in many fewer measurements of the roadway. A drone can document a similar section of roadway in under two hours.

With wider roads such as multilane highways, stationary laser scanners may require road closures or traffic control so that the scanners can be positioned in the roadway. Additionally, there is some risk involved in standing along the shoulder of a roadway, which is required to operate the laser scanners. A drone can be operated anywhere within visual line-of-sight of the operator. This allows the operator to launch and monitor the drone from a safe area removed or shielded from the roadway such as on top of a knoll along the roadway, or behind a guard rail or retaining wall, or even from a frontage road along an interstate highway.

Documenting a scene with a drone also allows for creation of a high-resolution ortho-rectified aerial photograph; if the operator is documenting evidence from an incident which just occurred, gouges, tire marks, fluid trails, and spray paint marks from law enforcement all show up in the aerial photograph, removing the need to draw a scale diagram of the evidence.

Case Studies

Single Vehicle Loss of Control

This incident occurred on a 2-lane undivided highway in the Sierra Mountain foothills. At the location of the incident the roadway is a winding, mountain road with a speed limit of 55 mph. A 2006 Volkswagen Jetta was negotiating a left-hand curve when the vehicle departed the roadway near the end of the curve. The vehicle came back onto the roadway towards the centerline. The driver then attempted to steer the vehicle back to the right, the vehicle began to rotate clockwise, and eventually departed the road. After the roadway departure the vehicle continued down a hill and struck a tree on the driver side of the vehicle.

The authors inspected the scene and surveyed the roadway using a Phantom 4 Professional drone. 599 drone images were captured, covering over 1,000 feet of roadway. Three laser scans were also performed near the area where the vehicle departed the roadway and contacted the tree. The drone flights were completed in a total of one hour.

The entire point cloud of the scene is shown in Figure 8. A driver view of the turn just prior to the roadway departure is shown in Figure 9. This view is showing a dense colorized point cloud that is directly made from processing the 599 drone images. Figure 10 shows the area of the scene that was also scanned with a Trimble TX5 laser scanner. The scanned area shows up as lighter points on top of the point cloud created from the drone. The results show how accurate the drone point cloud is in capturing surfaces, and the amount of roadway that can be captured and modeled safely using a drone compared to ground-based scanners.

Figure 8. *Point Cloud of Entire Turn*

Figure 9. *Driver View of Incident Turn Just Prior to Roadway Departure*

Figure 10: *Roadway-Level View of Drone-Based Point Cloud and Laser Scanned Point Cloud*

An HVE environment was created from the dense point cloud shown in Figure 8. This was done using 3D Studio Max to create an environment of the roadway, the roadway markings, the shoulder, the hillside where the vehicle departed, the tire friction marks documented on the road, and the tree that the vehicle ultimately impacted. The final HVE environment is shown in Figure 11 below.

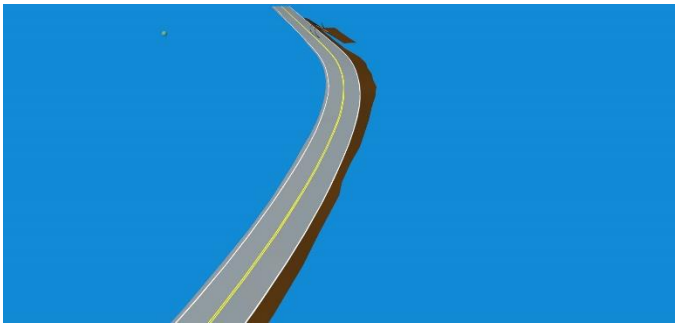

Figure 11: *HVE Environment*

The roadway departure and vehicle motions consistent with the tire marks and the tree impact were simulated using the HVE SIMON algorithm. The vehicle motions are shown in Figure 12 in one-second intervals. The lateral accelerations for a vehicle maintaining the lane using the HVE driver model at target speeds of 50 mph, 55 mph, and 60 mph are shown in Figure 13, along with the maximum capable lateral acceleration for a Volkswagen Jetta on a dry road.

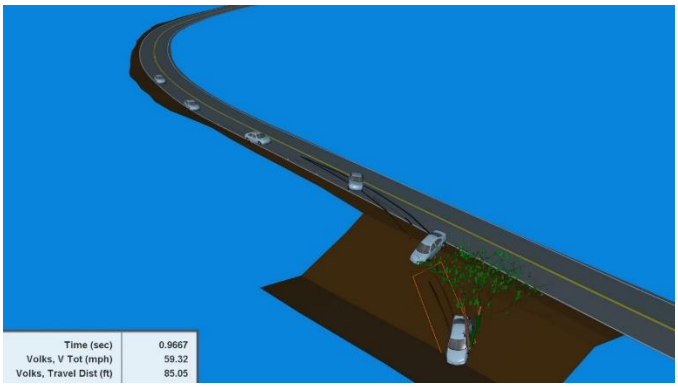

Figure 12: *Simulation Results*

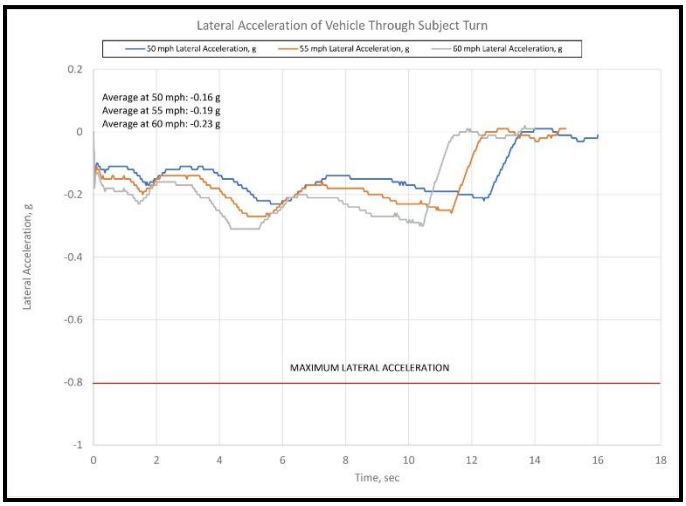

Figure 13: *Simulated Lateral Accelerations Through Turn*

The simulation and acceleration results depend on having a roadway environment that captures the entire turn and its profile. In this matter, another expert was able to use a high-end LiDAR mobile scanner. This is a device that contains inertial sensors, LiDAR, GPS, and cameras that are mounted on a vehicle's roof. Typical purchase costs for this type of system run between $500,000 and $1,000,000. A vehicle equipped with a mobile scanner can drive down the road at near freeway speeds and collect high density point clouds of the environment. The resulting HVE environment and results from the mobile scanner were almost identical to the results obtained from drone imagery.

<u>Bridge Incident</u>

The second incident involves a loss of control accident that occurred on a bridge over the Truckee River just east of Truckee, CA. At the time of the incident there was snow and ice on the bridge. A pickup truck entered

the highway just before the start of the incident bridge. On the bridge the vehicle lost directional control and ultimately contacted and mounted the bridge wall. The vehicle tipped over the edge of the wall and landed in the Truckee River on the rear of the truck bed.

Over 2,000 feet of roadway was captured with a DJI Phantom 4 Professional drone, including the approximately 1000 foot long bridge and the terrain under the bridge. The total time for this drone survey was approximately 2 hours.

Figure 14 shows a top down view of the point cloud created from the drone imagery. The point cloud covers the area from the on-ramp that the pickup truck used and the entire bridge where the incident occurred. Figure 15 is a view of the point cloud showing the river that the truck landed in and the bridge wall that it fell from. Figure 16 is a view of the roadway in the direction the truck was driving and the bridge wall that the truck mounted.

Capturing this amount of area using traditional ground-based laser scanners would have likely taken a minimum of one full day, or multiple days to complete. Even mobile scanners would not be able to complete this project as a mobile scanner would capture the roadway surface but not the terrain below the bridge.

Figure 14. *Drone Based Point Cloud of Documented Area*

Figure 15. *Isometric View of Drone Based Point Cloud*

Figure 16: *Driver View of Point Cloud*

An HVE model of the roadway, the wall, and the river surface below the bridge was created from the detailed point cloud. This was used to understand how the vehicle fell off the bridge and the types of velocities necessary to mount the wall. Figure 17 shows the HVE environment used for the analysis. Figure 18 shows the simulated wall mount and fall of the incident truck into the river.

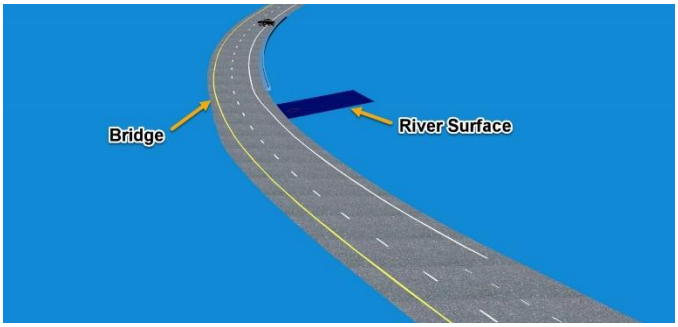

Figure 17. *HVE Environment*

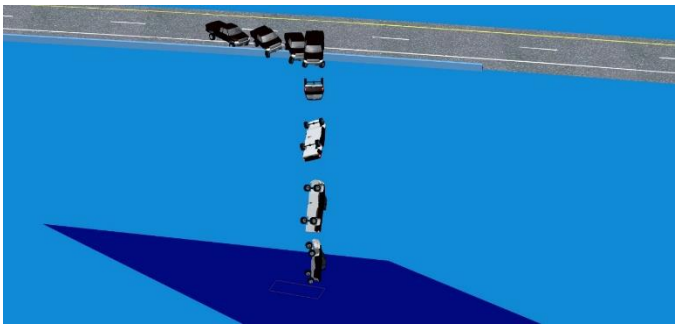

Figure 18. *Simulation Results*

<u>Truck-Trailer Position on Highway</u>

The last case study involves a tanker truck and trailer that were driving on a heavily traveled highway in southern California. A pickup truck had pulled over onto the shoulder and the driver was outside the vehicle standing on the driver's side of the vehicle. The tanker truck and trailer drifted over the fog line and struck the

pickup truck driver. The tanker truck was equipped with a Lytx DriveCam system that recorded the forward view from the truck. Principia was retained to determine the path of the tanker truck and trailer, the location of the pickup truck on the shoulder, and how far over the fog line it drifted.

As part of this work freeway was surveyed using a Phantom 4 Professional drone. The drone flight covered approximately 1,500 feet of roadway during a high traffic time. The drone flights were completed in under one hour. An overhead view of the point cloud model is shown in Figure 19. Figure 20 shows another view of the freeway with the approximate position of the pickup truck on the shoulder. Figure 21 shows an approximate driver eye view from the slow lane that the tanker truck was traveling in prior to reaching the pickup truck.

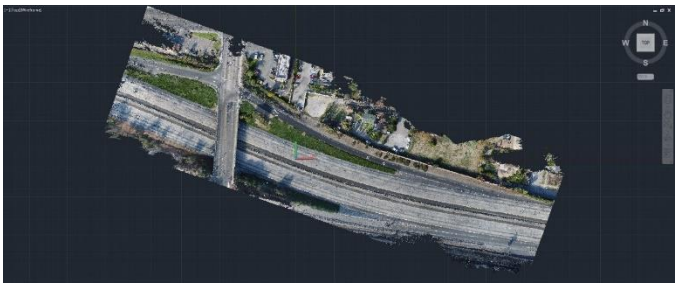

Figure 19. *Drone Based Point Cloud*

Figure 20*. Isometric View of Drone Based Point Cloud*

Figure 21. *Driver View of Point Cloud*

This case involved a multi-step analysis process. First, the video taken from the front camera of the tanker truck was used to match the camera locations with the point cloud of the scene.

At the completion of this process, the location and orientation of the camera are known for each frame of interest in the video. Knowing the exact camera location in the tanker truck allows the position of the tanker truck relative to the lane to be determined. This process for one frame is shown in Figure 22. The upper left shows a frame from the Lytx DriveCam. Although it is night and difficult to see the surrounding environment, lane lines, signs, and the bridge are visible. The upper right shows the camera matched three-dimensional environment created from the drone imagery. The lower image shows the camera matched position for the tanker truck without the trailer.

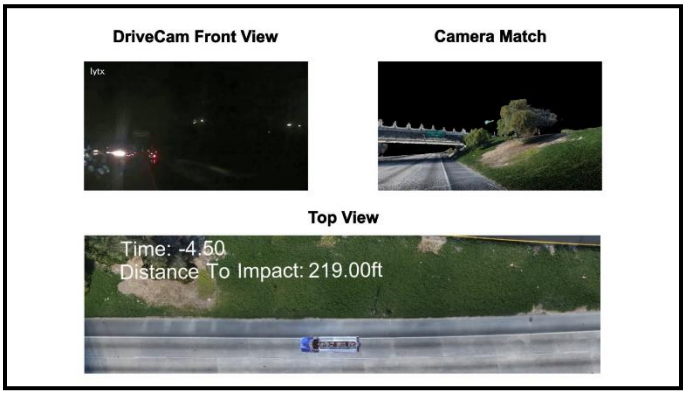

Figure 22. *Camera Match Results*

In this case, the purpose of running an HVE simulation was to determine the path of the tanker truck and trailer leading up to the collision with the pickup truck driver.

Figure 23 below shows the HVE environment created from the drone-generated point cloud. Laser scans of the vehicles were sent to Vehiclemetrics to create models of the tanker truck and trailer. The HVE model of the tanker truck and trailer is shown in Figure 24.

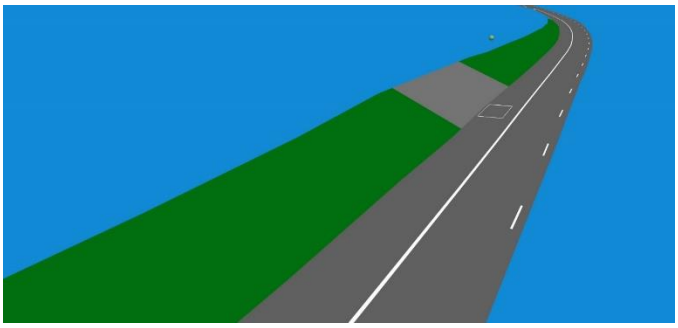

Figure 23. *HVE Environment*

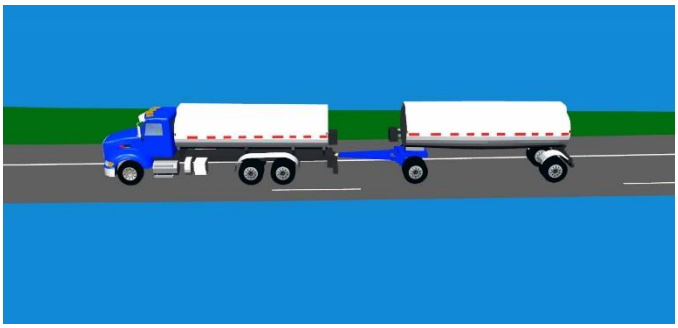

Figure 24. *HVE Vehicle Model*

The camera matched positions of the tanker truck were used to place vehicle targets in HVE. Driver inputs were selected to match the position and speed for the tanker truck at each camera matched position. The final simulation predicts both the intermediate positions of the tanker truck and the path of the trailer.

Figure 25 shows the path of the tanker truck and trailer from HVE as it passes the pickup truck on the shoulder. One of the benefits of having the drone point cloud is the ability to make full three-dimensional models of the roadway from the point cloud. In this case, final rendered videos of the tanker truck motion leading up to the collision were made. Figure 26 shows rendered stills of the path of the tanker truck as it passes the pickup truck on the shoulder.

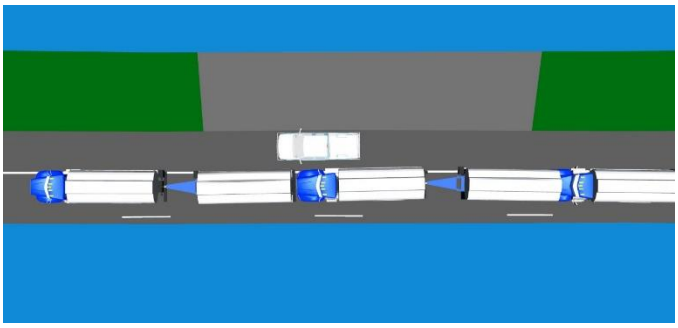

Figure 25. *HVE Simulated Path*

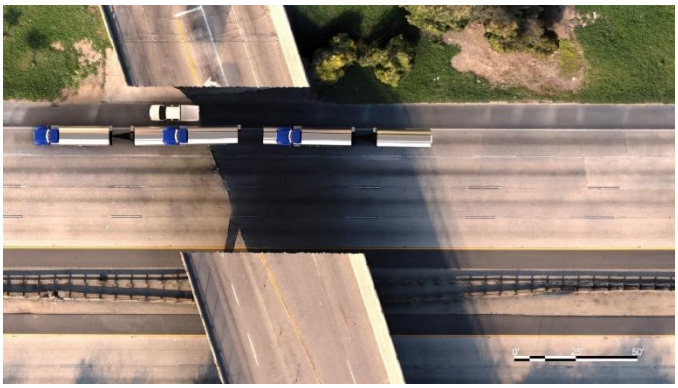

Figure 26. *Final Animation*

Conclusion

Drones give us the ability to quickly and safely document large areas and create accurate three-dimensional point clouds of accident scenes. These point clouds can be used to create accurate environments for HVE simulations. The three-dimensional model outputs created using this technique can now be used directly in HVE with the new scissor tool.