NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Washington, D.C. 20594

October 24, 2008

Video Study

NTSB Case Number:
HWY-08-MH012

A. ACCIDENT

Location:	Mexican Hat, UT
Date:	January 6, 2008
Time:	8:02 PM MST
Vehicle:	2007 MCI Model J4500, 56-Passenger Motorcoach

B. AUTHOR

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C. ACCIDENT SUMMARY

On January 6, 2008, at about 3:30 PM MST a 2007 MCI 56-passenger motorcoach with 51 passengers on board departed Telluride, CO en route to Phoenix, AZ, as part of a 17-motorcoach charter. The motorcoach was returning from a three-day weekend of skiing. The vehicle was diverted to an alternate route that included US Routes 191 and 163 in Utah, due to the closure of Colorado State Route 145 because of snow. Colorado State Route 145 is the normal route used from Telluride to Phoenix.

At about 8:02 PM MST, the motorcoach was traveling southbound on US Route 163 descending a 5 percent grade leading to a curve to the left, 1,800 feet north of milepost 29. After entering the curve, the motorcoach departed the roadway at a shallow angle striking the guardrail with the right rear wheel about 61 feet before the end of the guardrail.

The motorcoach began rotating in a counterclockwise direction as it descended an embankment. It began to overturn and struck several rocks in a creek bed at the bottom of the embankment. The motorcoach came to rest on its wheels after overturning 360 degrees. During the rollover sequence, the entire roof of the motorcoach separated from the body, and 50 of the 52 occupants were ejected. As a result, nine passengers were fatally injured, and 42 passengers and the driver received various degrees of injuries from minor to critical.

The weather in Mexican Hat was cloudy and the roadway was dry at the time of the accident.

D. DETAILS OF INVESTIGATION

The purpose of this investigation was to estimate the speed of the motorcoach just prior to roadway departure. The speed was estimated based on video recorded by a DriveCam II vehicle camera that was installed on the motorcoach. NTSB developed a computer program to facilitate the estimation of speed based on video from a vehicle-mounted camera and used it to estimate the speed of the motorcoach prior to roadway departure.

DriveCam II Camera Details

The MCI J4500 motorcoach in the Mexican Hat, UT accident was equipped with a DriveCam II camera that recorded video, accelerations and sound. DriveCam II records color video frames at the rate of 4 per second (i.e., at 0.25 second frame spacing) in 640×360 (H×V) format. The recording starts 10 seconds prior to a triggering event and lasts 10 seconds after it, for a total of 81 frames. The triggering event is an acceleration level that exceeds threshold. The thresholds settings were 0.5G for forward acceleration, 0.45G for lateral acceleration, and 1.5G for shock in either direction. The specific triggering event in this accident was shock acceleration above the threshold. DriveCam successfully captured the events prior to and during this accident. The camera was mounted on the right front windshield of the motorcoach, close to the center post. DriveCam II includes two camera sensors, one forward looking and one rearward looking. Only the video from the forward-looking camera sensor was used in this study. The accelerations and sound recorded by DriveCam II were not used in this study.

DriveCam II uses a wide-angle lens that exhibits barrel distortion near the edges of the images it captures. NTSB calibrated the camera and mathematically corrected the distortion. The corrected images matched closely the images that an ideal pinhole camera that the analysis program is designed to handle would capture. Appendix A includes more details on correcting the barrel distortion.

Site Survey Data

The site of the Mexican Hat accident was accurately surveyed by Utah authorities. The survey included many fixed points on and off the roadway and locations of many vehicle debris. This study used 183 surveyed points as landmarks for vehicle speed estimation. These were points on solid white lines, solid yellow lines and broken yellow lines on the roadway, and reflector locations. There were twelve reflectors that were mounted on a guardrail. Closely past the last reflector and higher than it was a post that was painted with reflective paint. Some distance past the last reflector was a large rectangular ‘Valley of the Gods’ road sign that was reflective.

Vehicle Speed Estimation

The developed video analysis program can be used to determine the location of a moving vehicle by comparing locations of landmarks in a camera image to their locations in a mathematically synthesized image. The synthesized images are generated by the program. If at an assumed vehicle location the landmarks and the synthesized landmarks coincide, then the assumed vehicle location is the location where the vehicle was when the camera image was acquired. Appendix B includes more details on modeling of camera geometry and on the use of the synthesized images for estimating vehicle locations.

Speed estimation is performed interactively. The user moves the vehicle that is displayed in the program GUI until the landmarks coincide. Vehicle speed can be estimated by dividing the distance between two vehicle locations by the time difference between the corresponding camera image frames. Figures 1, 2 and 3 show the program GUI at times –7 s, –6 s and –5 s, respectively. The vehicle is positioned at its estimated locations at these times.

In these figures, the lower plot shows the surveyed landmarks and the vehicle. Blue points in the plot correspond to survey points on white solid lines on the pavement. Green points correspond to survey points on the solid yellow lane-dividing line. Yellow points correspond to survey points on the ends of broken yellow line segments. Magenta points correspond to locations of reflectors.

The upper plot is the camera image (shown as negative of the original) with superimposed circles showing the locations of the survey points as computed by the camera model that is built into the analysis program. Note that each reflector is marked by two magenta circles. One is at the elevation of the reflective surface and the other is at ground level under it.

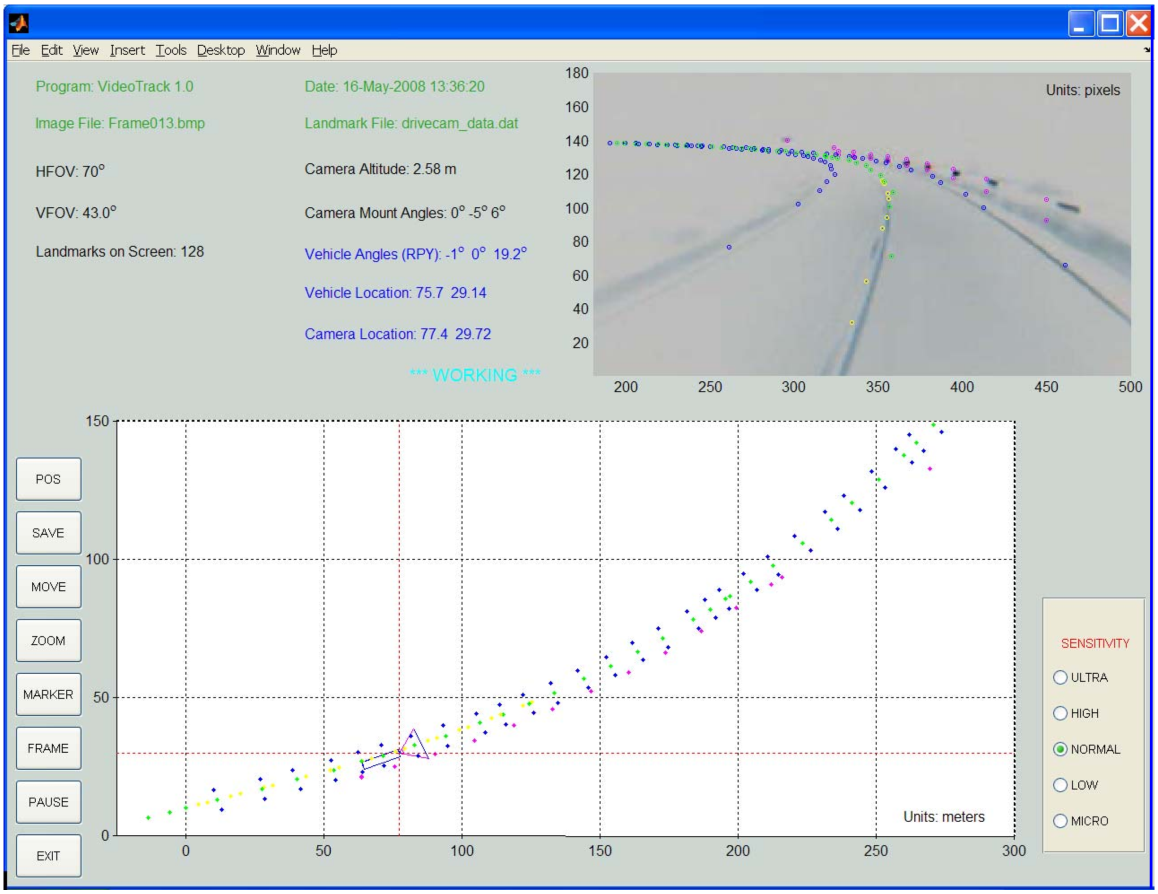

Figure 1 Vehicle at Time –7 seconds

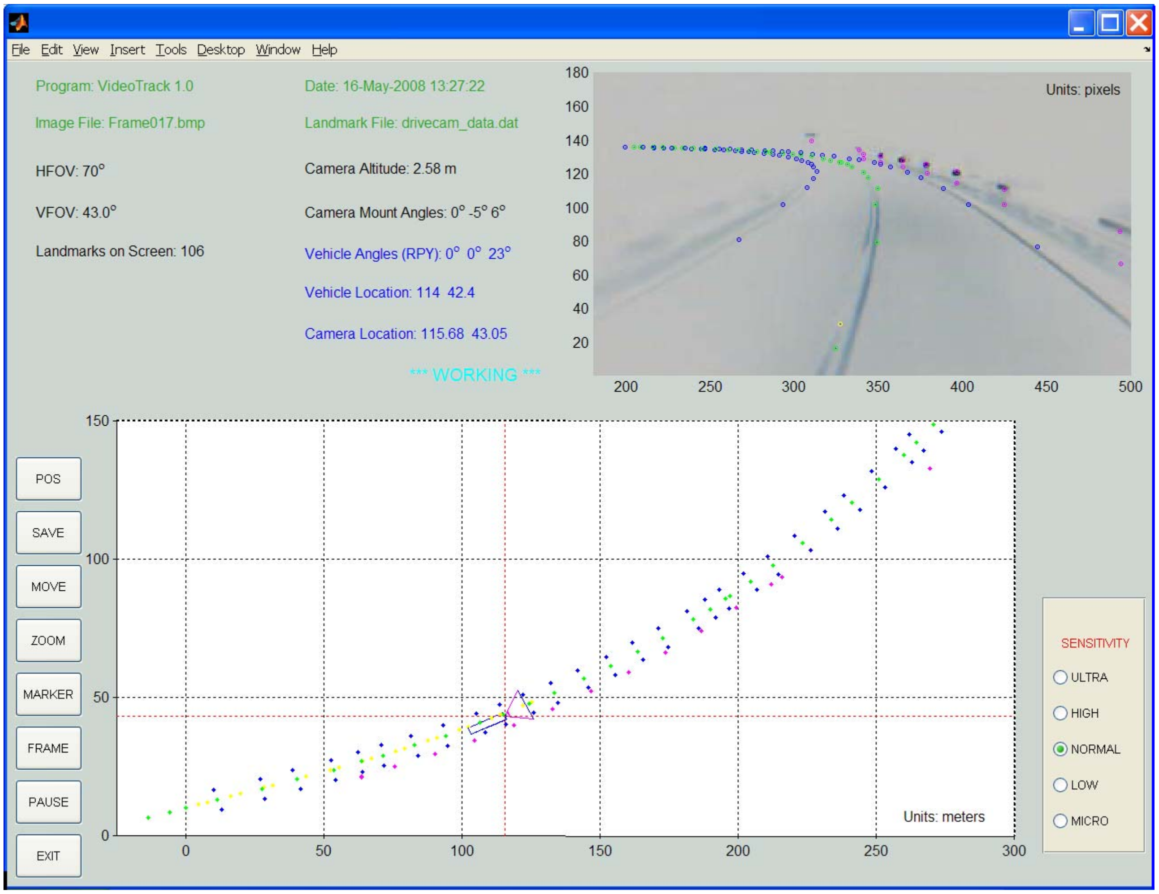

Figure 2 Vehicle at Time –6 seconds

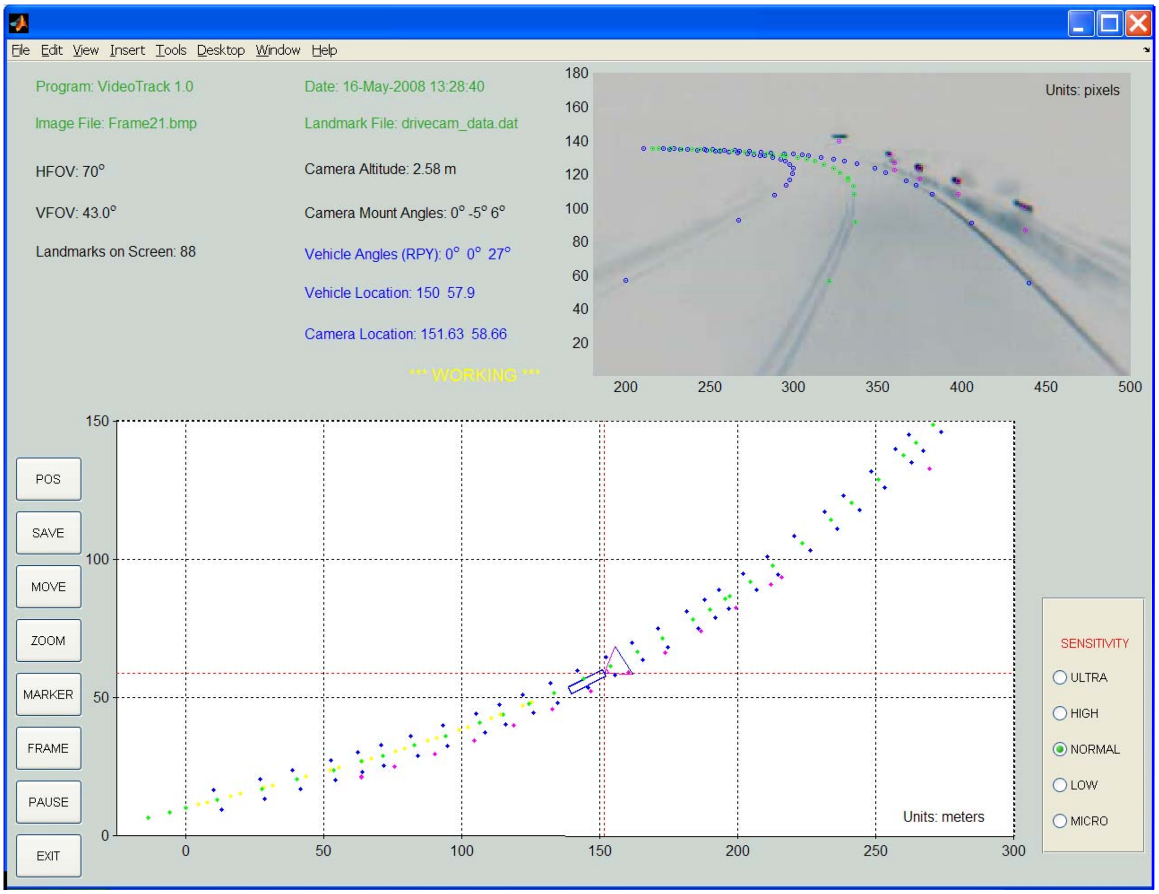

Figure 3 Vehicle at Time –5 seconds

The location of the motorcoach was estimated at 19 positions, corresponding to 19 camera frames spanning the time period from –8.75 s to –4.25 s. The speed of the vehicle was estimated using the formula $V_n=\Delta x/\Delta t$, where Δx is the total travel of the vehicle during n contiguous time intervals and Δt is $0.25\times n$. The solid blue line in Figure 4 is this nominal speed estimate. The estimate becomes more accurate as more contiguous intervals are considered.

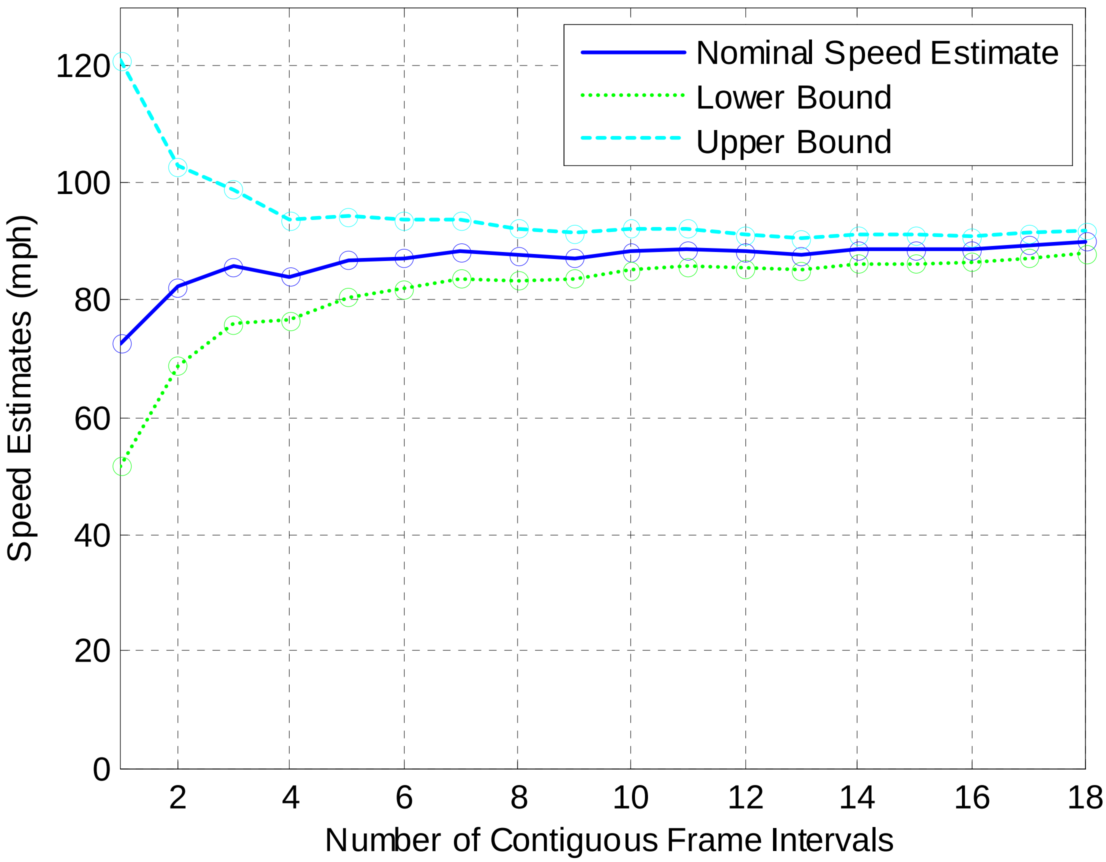

Figure 4 Vehicle Speed Estimate vs. Number of Frame Intervals

This speed estimate is based on exact 0.25 second timing of the camera frame intervals. If camera timing was not exact, this nominal speed estimate could be too high if the actual Δt was longer than $0.25 \times n$, or too low if it was shorter than $0.25 \times n$. The maximum possible speed estimation error due to such video frame timing was analyzed in detail and taken into account. The dotted green line in Figure 4 is the lower bound on the speed estimate and the broken cyan line is the upper bound. The lower bound is higher than 85 mph if ten or more camera frame intervals are considered. After eighteen frame intervals, the lower bound on the speed estimate is 88 mph and the upper bound is 92 mph.

E. <u>SUMMARY OF RESULTS</u>

Analysis of the video from the DriveCam II vehicle camera in the Mexican Hat, UT accident resulted in motorcoach speed estimate of between 88 mph and 92 mph shortly before roadway departure.

APPENDIX A

Correcting Barrel Distortion

The forward-looking camera sensor and lens of the DriveCam had rated horizontal field of view of 83.3°. As all wide-angle lenses do, this lens suffers from barrel distortion, in which image magnification decreases with increasing distance from the optical axis. Consequently, the distorted images have 'inflated' appearance and lines along the image edges that should be straight have outward curvature. We calibrated the camera and determined that objects near the center of the optical axis are projected onto the camera sensor with negligible distortion and as if the horizontal field of view was 70°. Objects near the edges of the image exhibited barrel distortion. Barrel distortion can be modeled by

$$r_d = r_u + k\, r_u^3 \tag{A-1}$$

where

r_d is radial distance from image center to where a pixel is located due to distortion
r_u is radial distance from image center to where the above pixel should be located
k is a distortion constant

Using Eq. (A-1), it is possible to correct the distorted image, thus significantly reducing the barrel distortion effect. The correction consists of replacing all the pixels in the image (each at its specific r_u distance from the center) with the pixel that is at a distorted distance r_d along the same radial direction as the pixel being replaced.

APPENDIX B

Estimating Vehicle Locations

With the capability to correct the barrel distortion of the lens, as described in Appendix A, the mapping of the 3D scenes in front of the motorcoach into the 2D DriveCam camera images can be represented very accurately by pinhole camera geometry.

Figure B-1 is a pinhole camera illustration that shows some of the effects of 3D to 2D projection. *A*, *B* and *C* are three objects in a 3D scene that are being photographed by the pinhole camera. The camera consists of pinhole O ('the lens') that is the only passage through which light can pass from the objects on the left to the image plane on the right. Since light travels in straight lines, the three objects, *A*, *B* and *C,* are projected onto the image plane as *A'*, *B'* and *C'*. The projected image is inverted, but this is not a problem because it is easily fixable in hardware or in software. The problems due to the loss of the 3-dimensionality are illustrated by *A'* and *C'* having about same height while in the 3D world *A* is taller than *C*. This is due to the different distances from the pinhole to *A* and *C*. Similarly, C' is taller than B', while in the 3D world C and B have about the same height.

If shown only the image of *A'*, *B'* and *C'* as projected onto the image plane and captured by the camera sensor, one could not recover the actual position of *A*, *B* and *C* in the 3D scene. In fact, there is an infinite number of *A*, *B* and *C* configurations that map into the same *A'*, *B'* and *C'* image. Fortunately, the problem we are trying to solve is much simpler than reconstructing a 3D image from a 2D projection. We want to determine the location of the camera with respect to objects *A*, *B* and *C* based on the 2D image captured by the camera. However, we know the geometry of the camera, i.e., the focal length *f* and the size of the image plane. We also know the heights and locations of the objects in the 3D scene, i.e., distances such as *d* that define the scene.

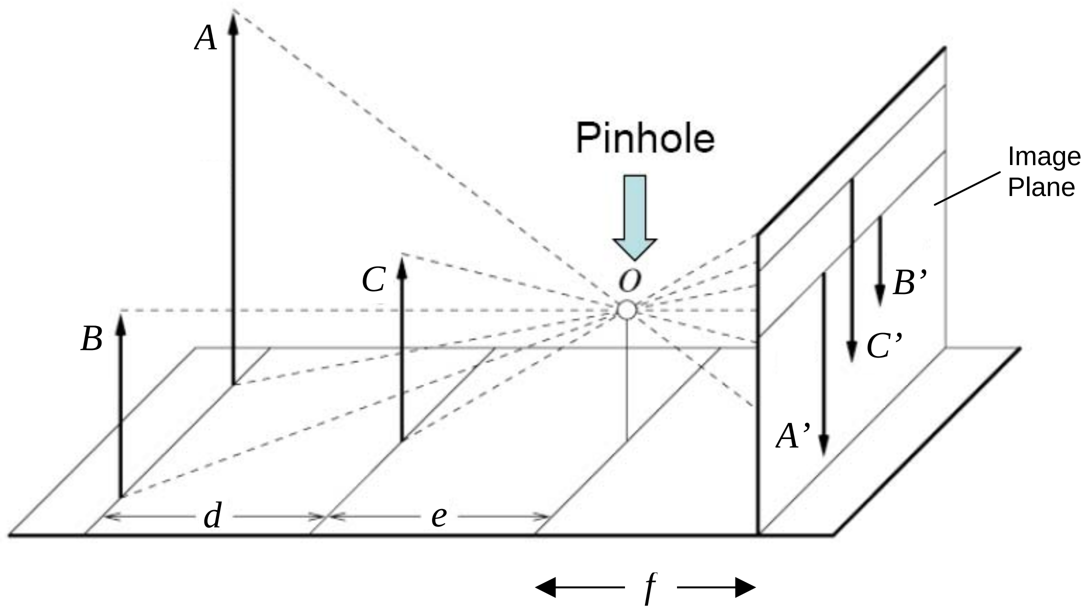

Figure B-1 Pinhole Camera Model

The unknown quantity to be estimated is *e*, the distance from the camera to the objects in the scene. By observing Figure B-1, it is apparent that a specific configuration of *A'*, *B'* and *C'* in the 2D image plane can be the result of only one specific value of *e*. Therefore, the distance *e* can be found by iteratively varying its value until one is found where the image on the screen coincides with an image synthesized by passing lines (light rays; the broken lines in Figure B-1) from points on the 3D objects, through the pinhole, until they intersect the image plane. When the points in the camera image and the points in the synthesized image coincide most closely, the assumed distance *e* is the optimal estimate of the camera location.

Since the camera is attached to the vehicle, estimating the camera location also estimates the location of the vehicle. Once the locations of the vehicle are known, the vehicle velocity can be estimated by dividing the distance between two estimated locations by the time difference between the camera frames used to estimate these two locations.

While the example in Figure B-1 illustrates estimation of the distance *e* that is shown to only vary in one direction, the method also applies to the general 3D case when the camera can move in three directions and can undergo rotations in three directions. This study used the general 3D case to estimate the locations and the velocities of the motorcoach.