Title

Video-Based Vehicle Signature Analysis and Tracking Phase 1: Verification of Concept Preliminary Testing

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Publication Date

1998

CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

Videobased Vehicle Signature Analysis and Tracking Phase 1: Verification of Concept and Preliminary Testing

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California PATH Working Paper
UCB-ITS-PWP-98-10

This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation; and the United States Department Transportation, Federal Highway Administration.

Report for MOU 262

May 1998

ISSN 1055-1417

CALIFORNIA PARTNERS FOR ADVANCED TRANSIT AND HIGHWAYS

PATH

California Partners for Advanced Transit and Highways

Final Report
Video-based Vehicle Signature Analysis and Tracking
Phase 1: Verification of Concept and Preliminary Testing

Prepared for California PATH, Caltrans, and US Dept of Transportation FHWA
by the Transportation Electronics Laboratory, Dept. of Electrical Engineering
California Polytechnic State University, San Luis Obispo, California

Caltrans/PATH MOU 262 Task A, Cal Poly Foundation Project No. 5881a
Document No. TEL5881A97F
Revision History: January 10, 1998 (Rev 1), May 8, 1998 (Rev 2)

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Executive Summary

This report describes the results of the PATH/Caltrans-funded project *Video-Base Signature Analysis and Tracking (V^2SAT) System, Phase 1: Verification of Concept and Preliminary Testing*. The V^2SAT System was conceived in 1995 by Loragen Systems, of Glendale, California, as a means for non-intrusively tracking individual vehicles on freeways for data collection purposes. The concept involves the use of a computer vision methods to make simple measurements of external dimensions, points of optical demarcation, and predominant colors of each vehicle. A conventional color video camera serves as the primary sensor in a self-contained detection module including a dedicated image processing computer and wireless communications components. Detection modules are placed directly above traffic lanes on an overcrossing or similar support structure, with one detector for each lane. For each passing vehicle, as Video Signature Vector (VSV) would be measured and transmitted by the detection module to a central correlation computer, via a local site repeater or a low-power local commercial digital service. The correlation computer continuously receives VSV's asynchronously transmitted by all detection modules, and attempts to match VSV's to re-identify each vehicle at each detectorized site, in order to determine the progress of the vehicle through the freeway network.

If proven accurate and cost-effective, V^2SAT is potentially useful as a means for tracking the progress of individual vehicles in freeway traffic for such purposes as traffic flow model validation, generation of origin-destination data, travel time estimation, validation of local modal-based emission models, and possible applications in law enforcement. Potential advantages are low cost in widespread deployment, simplicity and reliability of detection, minimal bandwidth and storage requirements for transmission of the signature vector, and reasonable identification ability without violation of privacy rights.

Phase 1 of this four-phase study involves field data collection and laboratory data reduction for the purpose of validating the operational concept of the method, Phase 1 was restricted to an assessment of the detectability and uniqueness of the video-based Vehicle Signature Vector (VSV). Two identical portable field data acquisition systems were designed to permit the synchronized recording of video images of vehicles flowing beneath two successive freeway overcrossings. These were used at three pairs of test sites along US Highway 101 in the Central Coast area of California. Each pair of sites consisted of two accessible overcrossings separated by approximately 0.5 miles. Field tests were conducted over a range of traffic conditions and times of day. Time-synchronized video-tapes from both overcrossings and each test site were studied in the laboratory on a frame-by-frame basis.

The S-VHS video tapes from each pair of sites were post-processed and analyzed in the laboratory on a frame-by-frame basis using video editing equipment and a reference video monitor. For each vehicle recorded by each camera, manual screen measurements were made of dimensions between points of optical demarcation (such as the windshield-to-hood transition) along a virtual centerline through each vehicle. Extremal length and width were also measured from the images of each vehicle. A PC-based computer vision system was programmed to provide an objective characterization of the predominant color for each vehicle. From this collection of measurements for each observed vehicle, a VSV was manually generated. Time-indexed lists of the VSVs for each vehicle, and all possible pair-wise comparisions of VSVs for each of four test conditions were created in Microsoft EXCEL spreadsheets.

Data sets were segregated by four test conditions, corresponding to four ambient lighting conditions: overhead sun (mid-day), 45 degree sun (afternoon), reduced light (dusk), and low light (night). For each test condition, VSV's were compared for each vehicle at the first site with every vehicle at the second site. A correlation error factor was developed based upon a normalized sum of the absolute difference between the vector components from each site. Used for comparison purposes, a "match" is detected if the correlation error for the pairing is below some fixed threshold, which was generally set to be inversely proportional to the intensity of the ambient illumination for the test condition. Results were accumulated on the accuracy of matching the same vehicle at consecutive sites (auto-correlation) and the possibility of falsely matching dissimilar vehicles at consecutive sites (cross-correlation).

Auto-correlation was assessed by comparing the VSV of each vehicle observed at the first overcrossing with its VSV at the second overcrossing. Cross-correlation was assessed by comparing the VSV for each vehicle at the first overcrossing with the VSV of all other vehicles observed within the data collection period at the second overcrossing.

Correct (auto-correlation) matches were observed for 97.27% of all vehicles at mid-day, 98.89% in the afternoon, and 95.15% at dusk. False (cross-correlation) matches occurred for 0.22% of all possible vehicle pairings at mid-day, 1.66% in the afternoon, and 2.02% at dusk. For daylight conditions, we also assessed the relative value of color as a VSV component, and the relative value of restricting vehicle comparisons at successive sites to a “reasonable time of arrival window”. The additional color information was found to increase correct matches from 98.3% to 99.0% and reduce false matches from 5.4% to 0.3%. The restriction to “reasonable time of arrival window” was found to add almost no additional accuracy beyond the addition of color information for either metric, although we do not consider the sample size in this test large enough to be statistically sound. Informally, it appears that the use of an adaptive correlation threshold may improve accuracy with respect to both metrics, but the design and evaluation of adaptive algorithms were not within the scope of this study.

Accuracy during data reduction was limited primarily by the ability to make manual measurements of VSV components - vehicle dimensions from the video CRT display, and color intensity and hue via computer image processing. The VSV was found to be difficult and sometimes impossible to measure at night (low light), with 75.49% correct matches and 27.05% false matches (without arrival window).

General conclusions are that the VSV is a reliable and repeatable means for the characterization and successive re-identification of vehicles under daylight and transitional illumination conditions. The VSV is unusable if the illumination level is inadequate to produce an acceptable video image. Overall, we conclude that the V^{2}SAT method is valid for the tracking of individual vehicles through a highway network, but only during conditions of adequate ambient lighting, or with either supplemental illumination or the use of improved dynamic range video cameras.

Keywords

Video, detection, sensing, sensor, computer vision, image processing, traffic monitoring, vehicle tracking, transportation electronics, video signature vector, video signature analysis, advanced traffic management, surveillance, monitoring, correlation, ensemble averaging, network tracking, object identification.

Disclaimer

Acknowledgements

The author gratefully acknowledges the support of the California PATH / U.C. Berkeley, the California Department of Transportation, and the U.S. Department of Transportation Federal Highways Division. In particular, I wish to acknowledge the guidance and direction of the contract monitor, Robert Tam of PATH / U.C. Berkeley.

This report was written by the project director, C. Arthur MacCarley, Professor of Electrical and Computer Engineering and Director of the Cal Poly Transportation Electronics Laboratory. Research assistants Matt Cotton and Jan Nimick assisted with field data acquisition, and handled all of the manual generation of vehicle signature vectors from video tape images. Technical advice and review comments were provided by Joseph Palen of the California Department of Transportation, New Technology Division. Joy Dahlgren and Bill Stone of PATH provided detailed and insightful review comments leading to improvements in the final version of this report.

Background

The V^2SAT project was motivated by the California Department of Transportation Division of New Technology's interest in the development of a vehicle discrimination and network tracking system to support the study of vehicle flow patterns on freeways and arterials. Systems meeting the Caltrans' specifications must provide (1) reliable delineation and re-identification of a wide variety of vehicles under all possible traffic flow, environmental, and illumination conditions, (2) operate at very low power consumption to permit autonomous battery-only or photovoltaic operation, and (3) be of low-to-moderate cost.

In response to this request, and in conformance with the stated criteria, a system configured as a network of vision-based detection, discrimination and wireless communication modules was designed by Loragen Systems of Glendale, California, and proposed for preliminary testing in partnership with PATH and Cal Poly, San Luis Obispo. The Video-based Vehicle Signature Analysis and Tracking (V^2SAT) system is conceived as a means to possibly meet all stated criteria. V^2SAT utilizes a low-cost NTSC (National Television Standards Committee) color videocamera as its primary sensor. Individual sensor modules are to be mounted on a freeway overcrossing, positioned above each lane. The video signal is processed via a video detection processor which generates, for each vehicle passing beneath the detector, a simple vehicle signature vector (VSV), consisting of metrics extracted from the vehicle optical signature. Each detection module is to be self-contained, powered by batteries with the option for photovoltaic power for continuous operation. Individual modules communicate on a vector-by-vector basis with a proximate (mobile or mounted in roadside controller cabinet) network hub via low-power intermittent radio transmissions. Vehicles are detected and re-identified at successive detectorized sites by processing and correlating the vector streams from all deployed modules.

The overall project is divided into four phases: Phase 1 involves preliminary work to test the accuracy, reliability and robustness of the basic phenomena upon which the detection method is based. Phase 2 involves the development of experimental hardware and software for automated detection, as described in detail herein. In Phase 3, a production prototype will be designed, refined and tested, and based upon this prototype, several detection modules will be fabricated, deployed and tested. Phase 4 includes the development of the wireless network components for telemetry between individual lane detectors and a local site transponders, and hardware and software components for telephone/modem communications between overcrossing transponders and the central correlation computer. Efficient correlation algorithms for tracking large numbers of vehicles will be developed, and a graphical interface and traffic flow display module will be developed. Direct links to adaptive traffic flow simulation models will be studied to calibrate, validate, and extend the utility of these models.

Objectives

In Phase 1 work reported herein, preliminary tests were conducted to verify the operational phenomena of the Loragen V^2SAT detection system. Video images were acquired and recorded on S-VHS videotape from several freeway overcrossings, using video cameras mounted approximately 0.5 meters out from the side of the overcrossing deck, facing downward. Tests were done at pairs of consecutive overcrossings, with video image sequences stored for each vehicle passing in the lane under the camera at each site.

This facilitated testing of the detectability and uniqueness of a characteristic signature vector for each passing vehicle, and the robustness of re-identification and tracking utilizing this vector. Lighting conditions and traffic conditions varied to the normal extent over the course of a typical commuting day, and night conditions were also acquired to allow assessment of the detection method under low-illumination conditions. The effects of camera shutter speed (electronic aperture time) were studied to assess the impact of vehicle blurring on the accuracy of the signature vector.

Detection Requirements

The need for accurate information on individual vehicle travel characteristics on freeways is well established. This data is essential for support of transportation resources and facilities planning, traffic management, and roadway engineering. In recent years, the need for this data has become more pronounced, with the advent of fully integrated network-wide traffic management strategies.

In addition to and in support of these strategies, a wide range of computer simulation models have been developed for the characterization and prediction of traffic flow patterns. These generally fall into two classes: *macroscopic* models, in which vehicle flow is treated as a continuum much like compressible fluid flow, and *microscopic* models, in which individual vehicle behavior is simulated [3]. This latter class of models, while more sophisticated and more useful in transportation engineering, is much more difficult to validate since data including individual vehicle lane and turning movements, traveler origin-destinations, and diversion behaviors must be recorded over extended time periods.

Current technology does not support automated data collection at reasonable cost. Existing data collection techniques are typically manual or semi-automated in nature., e.g., extrapolation from loop detector data, human observation, floating car studies, and traveler surveys. Accuracy and adequate sample size are known weaknesses, and cost per data unit is a key obstacle. Existing automated detection means, such as computer-vision-based license plate readers, have been generally unsuccessful and are considered non-cost-effective. Related legal issues such as individual privacy rights and access to collected license plate based travel data have yet to be definitively tested in legal forums. Intrusive monitoring means, such as characteristic vehicle tags or markers have been generally considered unsuitable since they require the consent and cooperation of a large number of routine travelers in the test network area. Issues associated with this class of detection have been recognized in the context of several detection methods [8,9,10].

This void in technology is potentially addressed by the method subjected to evaluation in this report. The general detection system requirements were established by Caltrans New Technology Division [9] in 1996, and are repeated below:

- Detectors shall be mounted on freeway overcrossings or similar rigid structures above traffic lanes on freeways.
- Detectors shall be self-powered and fully self-contained.
- Ability to uniquely identify each vehicle passing beneath detector, characterizing the vehicle with a simple information vector, which is communicated via wireless medium to proximate information processing hub.
- System shall have capability to re-identify detected vehicles as they progress through detectorized segments of freeway network.
- Detection and re-identification shall attempt to be reliable and robust to reasonably anticipated operating conditions changes and system disturbances.
- Detection means shall be safe and non-intrusive.

- System shall be low cost on per-site basis.
- Detection elements shall be easily installed without disruption to traffic flow.
- Detection elements shall be suitable for temporary installation at freeway overcrossings.
- System shall provide for ease of integration into network-wide traffic data collection system.

The unique function of this system is the detection in real time of a reasonably unique video-derived *Vehicle Signature Vector (VSV)* for every vehicle, which adequately characterizes the vehicle with an adequate amount of information to allow re-identification of the vehicle at subsequent detector sites. Successive re-identification of each vehicle may be used to track the progress of vehicles through the study area. The *uniqueness* and *redectectability* of the VSV vector must be balanced against cost, practicality and deployability factors for the overall system. Additional traffic flow metrics of possible value in traffic management may also be generated and collected by the system: individual or traffic-averaged vehicle speed (both instantaneous or segment averaged), accumulated or time averaged traffic counts, traffic density, and vehicle class (passenger auto, light truck, heavy truck, tandem, triple, etc.)

Our objective under Phase 1 was to assess the basic accuracy of the V^2SAT operational concept under a range of operational conditions, and to refine the signature vector based upon lessons learned in the course of data collection and reduction.

V^2SAT System Architecture

The V^2SAT System is intended to serve as a low-cost solution for the delineation and re-identification of vehicles along a freeway network. The system utilizes a low-cost EIA-RS170/NTSC video camera as a sensor to provide scanned optical information adequate for the development of a unique but simple signature vector for each vehicle. Testing was conducted with the assumption of one detector per lane, although this may or may not represent the ultimate system deployment. The video signal is processed to generate a VSV for each vehicle passing beneath the detector. Each detection module is intended to be self-contained, powered by batteries with the option for photovoltaic power for continuous operation. Individual modules communicate in burst mode on a vector-by-vector basis with a proximate site repeater located in a traffic controller cabinet. Information will be relayed to a central vector correlation computer, which identifies individual vehicles via their signatures and (possibly) feasible arrival times at successive detectorized sites along the freeway network. The central tracking system should be capable of utilizing the individual vehicle flow information in a number of ways, including validation and adaptation of predictive traffic flow models, real-time graphical display of traffic flow patterns, and real-time reporting of traffic incidents based upon disruption of logical vehicle travel patterns.

In this section, we will discuss the sensor, the detection/discrimination procedure, and the content of the information vector.

The key components of the V^2SAT architecture are described in Figure 1. The overall system is comprised of three elements: (1) **detection modules** located on a physical structure (such as an overcrossing) directly above each traffic lane, (2) a local **transponder / repeater**, one per detectorized site, that receives low-power UHF/spread spectrum bursts from as many as ten proximate detector modules, and retransmits the received information in raw form via a conventional telephone modem to (3) the **network hub**, which receives the data stream from all detectors and correlates the vector data to identify the progression of each particular vehicle signature through the freeway study area.

The component plan form and power requirements for the detection module are expected to make it suitable for self-contained operation and for extended use in the field. With a maximum expected continuous power draw of under 3 Watts, power requirements could be met by an internal 12 volt gel cell

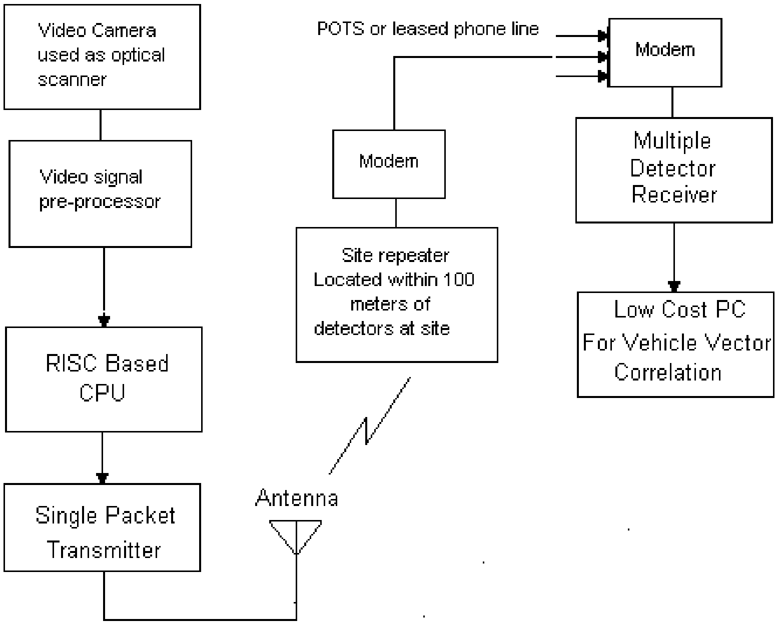

Figure 1: Block diagram of the V^2SAT System

battery. An optional small photovoltaic array[1], mounted on the detector module, is expected to provide adequate power for continuous unattended operation.

Detected attributes for each vehicle include: vehicle width, overall length, length measurements from the front to optical features along the vehicle centerline, and primary color components. This information is then incorporated into the video-derived Vehicle Signature Vector (VSV). The 112-bit (14-byte) VSV packet or is then transmitted as a packet of information to the network hub, via the site transponder/repeater.

Vehicle Signature Analysis

In the V^2SAT system, the VSV is to generated by processing successive video fields with several elemental operations:

1. Accumulation of a time-average background image via a first-order IIR filter operating on individual pixels.
2. Subtraction of image from accumulated background along selected scan lines to identify object edges and points of contrast.
3. Field-to-field ensemble-averaging of centerline traces from successive images to distinguish true object features from image artifacts and transient shadows.
4. Dimensional measurements along true vehicle centerline, and maximum vehicle width.

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[1] 0.25 m^2 surface area @ 40 W/m average power over 10 hour insolation period. Recommend “unbreakable” amorphous photovoltaic array such as United Solar Systems UPM-11R (11 Watt), or Solarex MSX-10 (10 Watt) module. Photovoltaic array provides minimum of 100 WHr per day. Average power draw of detector over 24 hour period is 60 WHr.

5. Trigonometric correction of image coordinates to scene coordinates, including camera height and angle compensation, to yield normalized measurements.

6. Primary and (optionally) secondary color hue and saturation measurement from parsed RGB values of selected areas along vehicle centerline.

If the camera is oriented perpendicular to the road surface, directly above the lane under detection, only the height of the detector above the traffic lane is needed in the system setup in order to derive physical measurements from image measurements. A tall vehicle will still appear longer than a low one, but site-to-site differences can be normalized with respect to camera height. A simple correction factor, based upon the detector height, is used in the proof of concept work reported herein, to assure correct dimensional correlation between detector sites. It is recognized that for less-than-ideal camera placements, including positions not aligned with the vehicle lane a two-dimensional angular correction will be necessary to assure that image-based measurements are accurately mapped to actual scene measurements.

The algorithm determines the true (image) center line of the vehicle, even if it is significantly off-axis with the lane, such as during a lane-change transition. The algorithm then extracts metrics from the optical signature of the vehicle, to the extent possible for an individual signature: physical lengths between key points of abrupt intensity and chromatic change along the vehicle centerline, which typically correspond to the distance from bumper to windshield (L1), distance from bumper to rear windshield (L3) and two optional distance metrics (L2) and (L4). These measurements are illustrated in Figure 2.

Background subtraction and rejection of shadow artifacts is accomplished by using a combination of the color hue (H) and intensity (I) components extracted from the composite NTSC video signal by simple processing of 24-bit RGB pixel values[2] produced by a color frame grabber. In NTSC composite encoding of color video, hue can be measured as the angle of the color “vector” in degrees, and saturation measured as the color vector magnitude. The inclusion of color measurements in the VSV are considered optional, since they are not expected to be available under low-light conditions. The ideal components of the VSV are shown below. Each is encoded as an 8-bit integer, with the exception of the site code S and time code t, which occupy two bytes each. The overall vector length is 14-bytes (112 bits). Not all components may be known for a particular vehicle; the lack of a component in the vector is encoded as a zero value.

$x_{i,l,t} = (L0, L1, L2, L3, L4, W, C1, C2, V, N, S, t)$.

where:

L0 =Total vehicle length along vehicle centerline.
L1 = Length from front of vehicle to first optical feature, typically the bottom edge of the windshield.
L2 = Length from front of vehicle to second optical feature, typically the top edge of the windshield.
L3 = Length from front of vehicle to third optical feature, typically the top of the rear window on a conventional sedan. (optional)
L4 = Length from front of vehicle to fourth optical feature, typically the bottom edge of the rear window on a conventional sedan. (optional)
W = Vehicle body extremal width, exclusive of mirrors or other small side projections.
C1 = Primary color intensity component, measured as a normalized magnitude.
C2 = Primary color hue component, measured in degrees.
V = Vehicle velocity in K/h. (optional)
N = Lane number at site.
S = Site code number.
t = Absolute time code, resolution to one video field interval, 1/60 second.

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[2] RGB = Red-Green-Blue color signal decomposition. HSI = Hue-Saturation-Intensity color signal decomposition. The HSI decomposition is derived from RGB by simple trigonometric calculations.

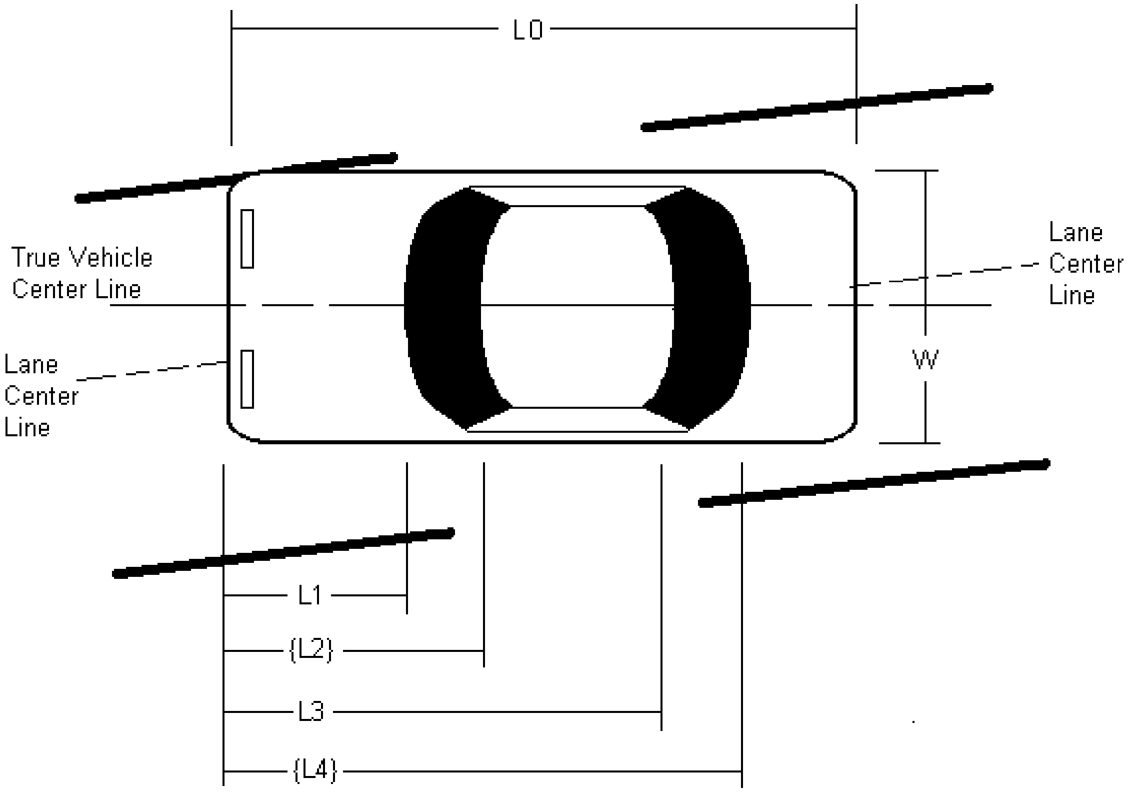

Figure 2: Diagram of the proposed vehicle metrics based upon true vehicle centerline.

Overlaid upon a digitized video frame of typical vehicle, these measurements are shown in Figure 3.

In general, the height and placement geometry of the detection camera must be known and the computer vision algorithm must map image-based dimensions to physical (scene-based) dimensions, a process involving trigonometric correction in two dimensions. For narrow angles of view and camera placements directly over and perpendicular to the center of a lane, angular aberration is minimized, such that reasonably accurate measurements can be generated and matched between sites by compensating only for the camera height above the road surface. This was the camera placement we used exclusively for Phase 1 validation studies. If the detector is placed 25 feet above the road surface, the detection area, with 8 mm lens and 1/3 inch imaging element, is about 15 feet wide x 20 feet long, along the roadway axis. This is based upon the US standard video aspect ratio of 4:3 and 90% scanned line utilization [1].

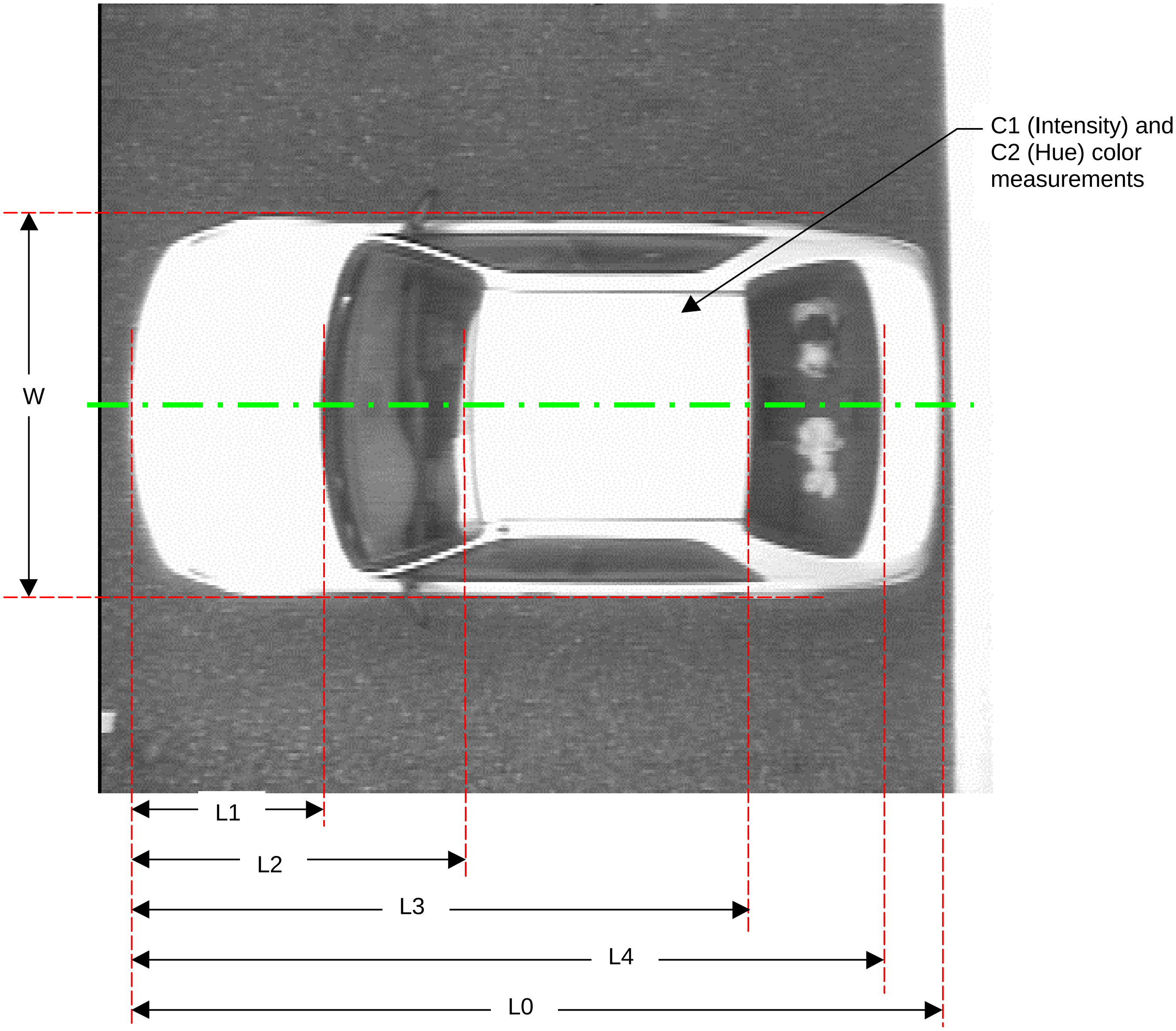

Figure 3. VSV Vector Component Measurements for Typical Raw Vehicle Image.

As shown in Figure 4, as a vehicle passes under the detector (of known height above the road surface), a minimum of twelve video fields are acquired under worst case conditions (low camera placement, 70 mph vehicle speed, 20 ft detection path):

Capture rate = 60 fields/second
Vehicle rate = 70 MPH = 102 Feet/Second
1 Second = 60 Video Fields
102 Feet / 60 Fields = 1.7 Feet traveled between each field
Video detection path / Distance traveled between each field = 20 Feet / 1.7 Feet = 12 Video Fields

Video Capture Area = 15 x20 Feet
Capture Length = 20 Feet

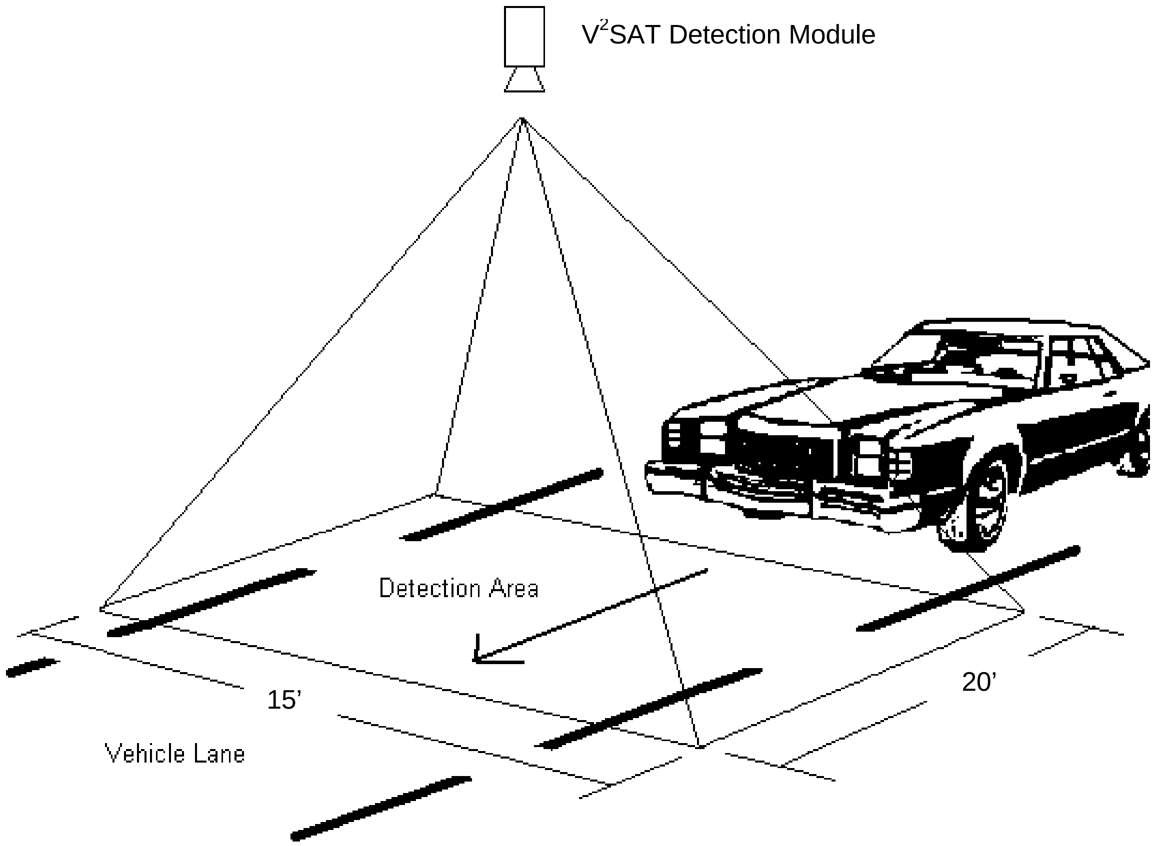

Figure 4. Detector placement and field of view.

Chromatic hue, saturation and intensity characterize each color pixel. Since shadows manifest as changes in Intensity (luminance) level only, and do not effect the color phase (hue) value, shadow rejection is enhanced. As the transition from day to night occurs slowly, the adaptation for illumination source color and intensity must be implemented. The effects of this transition on the accuracy and robustness of the method represented a potential weakness of the method, and were a key area of study under the present Phase 1 investigation.

The true vehicle centerline is determined by locating the locus of equidistant points between the symmetric boundaries of level changes on both sides of the object in the image. Optical signature features are detectable by differentiation along the vehicle centerline, as illustrated in Figure 5.

While only a secondary consideration in the VSV, the speed of the vehicle as it traverses the detection area can easily be detected. Since the overall geometry of the detection area is known, this measurement is easily found from temporal (frame-to-frame) "time of flight" measurements [2,5,7]. As the vehicle moves through the detection zone, the optical flow front is detected as a change in H (hue) and I (intensity) compared with the accumulated background. Along the vehicle centerline, H and I level changes occur at features such as the windshield and rear window. These inflection points in the video signature constitute the basis for the length metrics (L0 - L4). This collection of information is packaged and transmitted as a VSV for each detected vehicle.

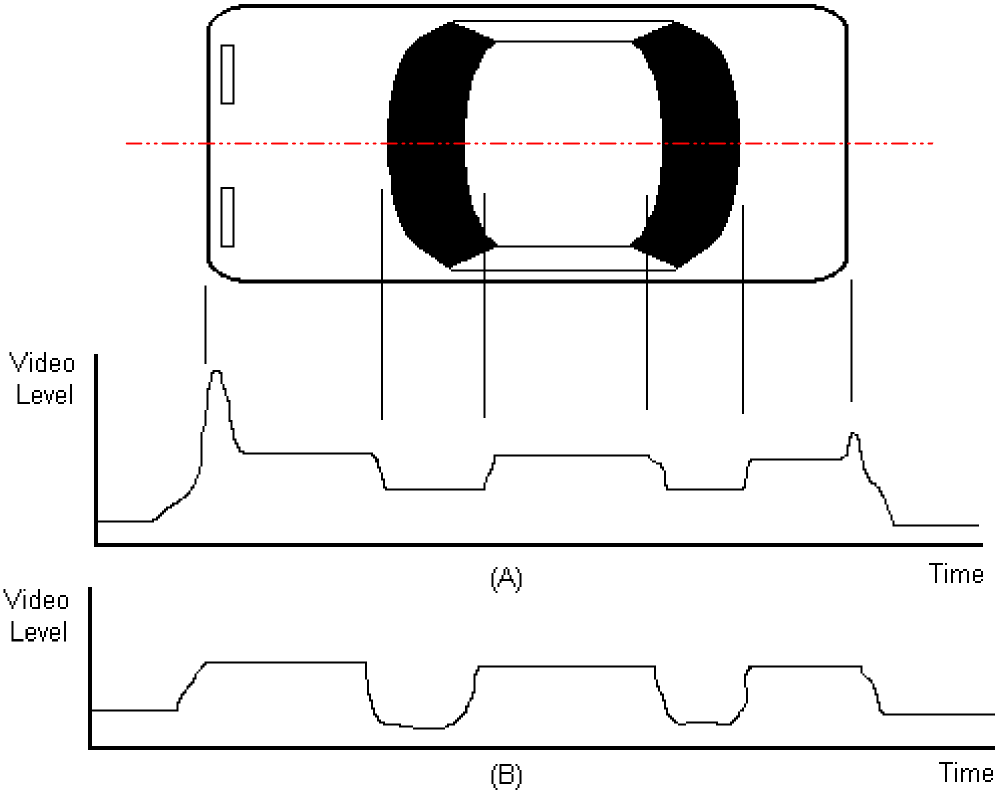

Figure 5: A typical video (optical) signature of a vehicle (A) at night with the head and tail lights illuminated, and (B) during daylight hours.

Field Data Acquisition

Two time-synchronized video data acquisition apparatuses were deployed at consecutive overcrossings, spaced 0.5 to 0.6 mile apart, on US Hwy 101 in three different locations in the California Central Coast area. Traffic conditions were light to moderate (LOS B-C) for all cases. For Phase one study purposes, these traffic conditions were ideal for data collection and ease of data reduction. Note that traffic density should (theoretically) not have any direct effect on the system accuracy, provided that the computer vision hardware can process vehicle images at a rate fast enough to keep up with traffic flow. These implementation factors will be assessed in phases 2 and 3. Data was collected on three different dates, to cover four different illumination conditions:

Trip #1a and Trip #1b (2/8/97)

US 101, Monterey St. and California St. overcrossings.
0.5 mile separation.
Dusk (1a) (16:00-17:30) and night (1b) (17:30-19:00).
Number 2 lane, south bound traffic.
Cameras: Monterey – Minitron, California – Burle.
Shutter speed: Day - 1/4000 sec both cameras;
Night - Minitron: 1/4000, Burle: Autoshutter
Road surface: Asphalt (dark) both locations.
Vehicle totals: Trip1a: 103 vehicles in 31 minutes. Trip1b: 102 vehicles in 26 minutes.

Trip #2 (4/15/97)

US 101, California St. and Santa Rosa St. overcrossings.
0.6 mile separation.
Daytime / early afternoon (13:00-15:00).
Number 1 lane, North bound traffic.
Cameras: California – Minitron, Santa Rosa – Burle.
Road surface: Asphalt (dark), both locations.
Shutter speed: 1/4000 sec fixed, both cameras.
Vehicles total: 102 vehicles in 20 minutes.

Trip #3 (4/29/97)

US 101, Highway 246 and North Buelton Rd. overcrossings.
0.5 mile separation.
Daytime / late morning (10:00-12:00).
Number 1 lane, North bound traffic.
Cameras: Highway 246 – Minitron, N. Buelton – Burle.
Road surface: Concrete (light colored), both locations.
Shutter speed: 1/4000 sec fixed, both cameras.
Vehicles total: 110 vehicles in 60 minutes.

Trip #4 (4/29/97)

US 101, Monterey and California St. overcrossings.
0.5 mile separation.
Night (19:00 – 21:00).
Number 2 lane, North bound traffic.
Cameras: Monterey – Burle, California – Minitron.
Road surface: Asphalt (dark), both locations.
Shutter speed: Autoshutter, both cameras.
Low or no ambient illumination restricted useful detection.

Figure 6 shows a digitized photograph of the apparatus deployed on the Santa Rosa Street (San Luis Obispo) overcrossing over north-bound US Hwy 101 during mid-day conditions. Figure 7 shows the apparatus deployed on the California Street (San Luis Obispo) overcrossing over northbound Hwy 101 at night.

Figure 6. Typical Daytime Deployment of Data Acquisition System on Freeway Overcrossing.

The video cameras for each apparatus were deployed approximately 0.5 meter horizontally off the side of each overcrossing deck, facing straight down, with a field of view slightly larger than one lane. Cameras were oriented such that when viewed on a monitor vehicles appear to flow laterally across the screen. S-VHS video tape recorders in each apparatus were used to record concurrent records of individual vehicles as they pass below the video cameras at each of the two sites. Radio communication between the sites was maintained to assure exact vehicle-to-vehicle synchronization. Approximately fourteen total hours of S-VHS video tape were recorded at each pair of sites.

Figure 7. Typical Night Deployment of Data Acquisition System on Freeway Overcrossing.

Figures 8a and 8b are digitized and printed video frames of a randomly selected vehicle at two different overcrossings, located approximately 0.6 miles apart. Both sites observed lane number 2 on a four-lane (two in each direction) section of the highway. An adjoining on/off ramp at the second site effected the consistency of the traffic flow. The vehicle speed at the time of acquisition was approximately 65 mph at both sites. Time of day: 4:30 PM, from the afternoon data set. Long stationary shadows were present at both sites, which extended completely across the vehicle detection zones. Cameras at both sites were color with electronic shutters, both set to 1/4000 second. At this shutter speed, blur due to vehicle motion was found to be virtually nonexistent. The reduced resolution observed at the second site can be attributed to the use of a 1/3 inch CCD imager, while the first site used a ½ inch CCD imager, with approximately twice the number of available pixels. The test conditions for this sample frame pair were considered approximately average for the detection problem - adequate light for clear color information and dimensional measurements, but some challenges associated with reduced intensity and steep incidence angle illumination.

Graphical measurements made on both these images show a clear and repeatable measurement of L0, L1, L3, L4 and W. C1 (color intensity) and C2 (color hue angle) are also clearly discernible in both images. In this particular situation, the proposed VSV vector provided very good characterization and unique re-identification of most vehicles with a high degree of reliability. As the sun set (dusk), however, it became difficult to discern color measurements, and eventually (night), the dimensional measurements as well.

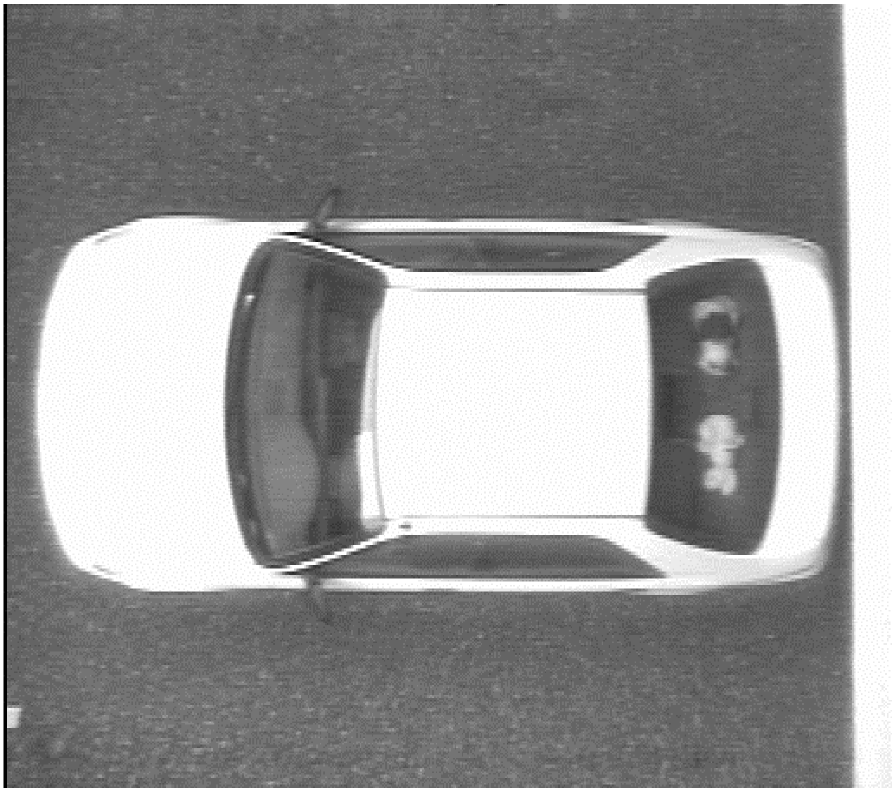

Figure 8a. Vehicle at Monterey St/Hwy101 Overcrossing

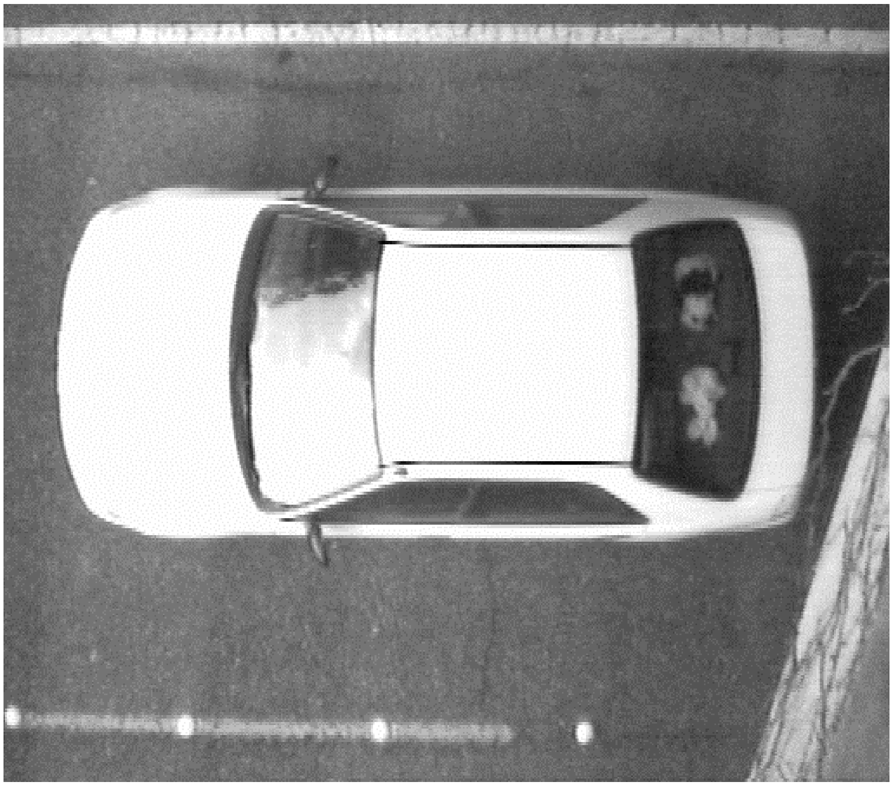

Figure 8b. Vehicle at California Ave/Hwy 101 Overcrossing

After preliminary tests, we standardized on the use of a relatively fast camera shutter speed (1/4000 sec). While this eliminated image blur, it pushed the limits of sensitivity of both video cameras. As a result, color perception was diminished fairly early in the dusk transition, and completely absent at night. The ramifications of allowing slower shutter speeds are illustrated in Figure 9, in which the automatic shutter feature of the Burle camera was enabled and the shutter speed defaulted to 1/60 second, the slowest possible speed. At 65 MPH, the vehicle travels 1.59 ft. (0.484 m) during this maximum integration interval. Color perception is retained even at low light, but the vehicle edges are severely blurred, probably beyond the capability of the computer vision algorithm to reliably determine the true points of optical contrast of the object. We opted for blur reduction over sensitivity for Phase 1 because the video data was to be reduced manually, without the benefit of the computer vision algorithm which should be capable of determining crisp points of optical demarcation from blurred image features. In future work using the machine vision system for VSV generation, we estimate that a shutter speed of about 1/1000 second would probably be a reasonable tradeoff between sensitivity and blur reduction.

Figure 9. Image Blur Due to Slow Shutter Speed Under Low-Light Conditions.

Data Reduction

The videotaped images from the field were then analyzed manually in the laboratory to test the accuracy and repeatability of the optical signature vector for characterizing and re-detecting vehicles, as well as to assess the general usability of the vector as a means for classifying a range of vehicles by dimensional measurements. Vehicle dimensional measurements were made from the CRT face of a Sony Trinitron PVM1344Q reference monitor, which was calibrated using a “pin cushion” electronic test pattern to maintain perfect geometric linearity. Primary vehicle color hue and saturation were determined by isolating a target area in the image, and processing the area using a Data Translation DT 2871 color image processing card and specialized image analysis software we wrote for this purpose. A copy of the C source code for this PC-based program, PCOL.C appears in the Appendix.

In our data reduction, we were attentive to issues related to the use of chromatic information to discriminate actual vehicles from shadows and headlight reflections, the effects of video blur at high vehicle speeds on dimensional measurements, and the impact of different and time-varying illumination conditions between successive detection sites. For our semi-automated data reduction, none of these posed a significant measurement problem. However, we had the benefit of human perception when determining object edges and corresponding feature length measurements. We expect that a purely machine-vision mechanization of the V^2SAT algorithm will encounter significant challenges in robustly discriminating true object features and color characteristics independent of ambient illumination.

Table 1. Preliminary Study of Uniqueness of VSV Elements.

Number	Lo	L1	L2	L3	L4	W	Vel In/s	color	comment	match
1	10.25	3	4	10.25	1.025	3	1	blue		
2	9	3.25	4.25	7	8	3.125	0.875	red		
3	8.5	3.875	4.5	6.5	7.25	2.625	0.75			
4	8.75	2.375	4	7	8.75	3	0.75	red		
5	9.75	3.5	4.25	9.75	9.75	3.5	0.75	white		
6	8.5	3.1875	4	8.5	8.5	2.75	0.625	silver		
7	8.5	2.75	3.75	4.375	5	2.875	0.75	blue	sun roof	
8	10.75	3.375	4.25			3.5	0.75	green	truck w/ stuff in back	
9	10.875	3.5	4.5	7.25	8.5	3.5	0.875	blue	truck empty	
10	10	3.875	4.75	10	10	3.5	0.75	grey	car w/light col rear window	
11	10	3.75	4	6.75	7.5	4.5	0.6875	blue	truck w/ stuff in back +mirror on side	
12	8.5	2.125	4.375	6.5	8.5	3	0.75	black		
13	10	3.125	4	6.5	10	3.5	0.75	white	truck w/ stuff in back	
14	8	3	3.75	7.5625	8	2.75	0.6875	lt yellow	great contrast	
15	9	2.875	4.5	9	9	3	0.75	dk red	Bk window too hard to detect w/lght	
16	11	3.5	4.25	11	11	4.125	0.75	lt yellow	truck w/side mirror (width measu)	
17	9.75	3.125	3.625	9.75	9.75	2.875	0.75	lt yellow	truck w/ no side mirror	
18	10.25	3.875	4.125	6.5	10.25	3.875	0.6875	lt yellow	truck w/ stuff in back	
19	9	1.75	3.5	9	9	3	0.75	black	mini van	
20	8.5	3	3.75	8.5	8.5	3	0.75	gold	too hard to det rear window	
21	8.5	3.125	4	8.5	8.5	2.9375	0.75	lt yellow	too hard to det rear window	
22	9.5	3.125	4.25	7	8.5	3.25	0.6875	dk blue		
23	8.25	2.75	3.75	6.5	7.5	2.875	0.75	dk blue		
24	9.75	3.75	5	9.75	9.75	3.25	0.75	grey	too hard to det rear window	
25	10.75	3.5	4.25	10.75	10.75	3.625	0.75	white	suburban truck with luggage rack	1
26	8.25	3	3.75	8.25	8.25	3	0.75	white	too hard to det rear window	
27	9.875	3.75	4.5	9.875	9.875	3.25	0.6875	gold	too hard to det rear window	
28	9.25	3.25	4.5	9.25	9.25	3.25	0.75	gold	too hard to det rear window	
29	9	2.5	3.5	5	9	3	0.75	dk red	truck w/ white boxes in back	
30	9	3.25	3.5	9	9	3.125	0.75	lt yellow	truck w/ no rear window poor contrast on window	
31	6.5	2.5	3	6.5	6.5	2.75	0.75	white	small hatch back car	
32	8	3	4	6.25	7	2.75	0.75	dk blue		
33	10.25	3	4.5	10.25	10.25	3.25	0.75	dk green	truck w/nothing in back	
34	9	3	3.75	4	5	3.25	0.75	lt blue	truck w/sun roof (toyota 4runner)	
35	6.75	2.5	4	4.25	4.75	2.75	0.6875	red	small hatch back car (hard to detect rear end)	
36	8.75	1.75	3.5	8.75	8.75	3.25	0.75	dk red	mini van	
37	10.75	3.5	4.25	10.75	10.75	3.625	0.6875	white	suburban truck with luggage rack	1

notes:
1) Monitor on underscan
2) Measured entire blur as car
3) Used Sony monitor
4) Used test tape with sideways approaching cars
5) Lane Width = 6.75 in which is equvallent to 12 ft in reality.

Table 1 shows the results of a preliminary data collection exercise, intended only to assess the relative uniqueness of the VSV vector for a random sample of vehicles. Data for this table was collected at one site only, northbound lane #1 US 101 at Los Osos Valley Overcrossing in Caltrans District 5. Test conditions were late afternoon, clear, traffic approximately LOS C-D. Among the 37 vehicles analyzed, all had sufficiently distinctive VSV vectors to discriminate them uniquely for detection purposes, with the exception of two, noted with “match=1”. These were identical white Chevrolet Suburban trucks with luggage racks. The time separation between them would probably have been sufficient to distinguish them as they pass through a freeway network. From this preliminary exercise, we concluded that the proposed VSV provided, in most cases, sufficient unique information about each vehicle to distinguish it from other vehicles. We also were able to determine the optimum camera field of view (lens focal length), shutter speed (set electronically), and aperture (F-stop) for our subsequent field data collection trips.

Correlation Method

VSVs generated for each vehicle at each detector site are correlated pair-wise using a normalized cost function that increases in value with increased differences between the elements of the compared vectors. It will be referred to as the *correlation error* **e**.

$$\mathbf{e}=\frac{\left(\begin{array}{l}\frac{c_0\left|L0_1-a.\cdot L0_2\right|}{L0_1}+\frac{c_1\left|L1_1-a.\cdot L1_2\right|}{L1_1}+\frac{c_2\left|L2_1-a.\cdot L2_2\right|}{L2_1}+\frac{c_3\left|L3_1-a.\cdot L3_2\right|}{L3_1}\\+\frac{c_4\left|L4_1-a.\cdot L4_2\right|}{L4_1}+\frac{c_5\left|W_1-a.\cdot W_2\right|}{W_1}+\frac{c_6 C1_1 C1_2\left|C2_1-a.\cdot C2_2\right|}{C2_1}\end{array}\right)}{c_0+c_1+c_2+c_3+c_4+c_5+c_6 C1_1 C1_2}$$

where subscript 1 $\Rightarrow$ vector component measured at first detection site, and subscript 2 $\Rightarrow$ vector component measured at second detection site.

a = dimensional correction factor = ratio of detector height at site 1 to height at site 2.

$c_k =$ component weighting coefficient. For Phase 1 tests:

$$c_0=0.4,\ c_1=0.2,\ c_2=0.2,\ c_3=0.1,\ c_4=0.1,\ c_5=0.3,\ c_6=0.3$$

If any component was not present in the vectors from both sites, the coefficient for the missing term was set to zero in the calculation of **e**.

For Phase 1 evaluation purposes, we defined two restricted versions of the VSV, since such elements as the site code, lane number and vehicle speed were irrelevant to the study. The first is referred to as the “full” vector, comprised of 8 measured elements:

VSV Components, Full: L0, L1, L2, L3, L4, W, C1 (Intensity), C2 (Hue Angle)

The second “reduced” vector lacks the last two dimensional measurements and all color information:

VSV Components, Reduced (preliminary tests only): L0, L1, L2, W

The reduced vector was used only for preliminary daylight data collection, since we had not yet developed the computer-based color analysis program which provided an objective quantitative indication of color characteristics for each vehicle. The full vector was used to process all field data to yield the results reported for all conditions. All results are summarized in the following section, and supporting EXCEL spreadsheets containing all raw data are included in the Appendix.

Results and Observations

Uniqueness and Repeatability of the VSV

The detectability and uniqueness of the VSV are tested by using the correlation error **e** as a means for comparing the VSV of each vehicle with the VSV of either itself or another vehicle at another detection site. A match is declared if the correlation error **e** for the two VSVs is less than some specified threshold $\mathbf{e_T}$. Detection thresholds for these tests were generally selected to be inversely proportional to the illumination level for each condition. Thresholds were not optimized. As previously discussed, **e** is an indication of the relative "closeness" of each pairing of VSVs. Data are segregated according to the average illumination condition present during each test. Four illumination categories are represented: late morning, early afternoon, dusk, and night. Table 2 below states the detection threshold used for each illumination condition.

Table 2. Detection Threshold for each Test Condition.

	Detection Threshold $\mathbf{e_T}$
Mid-day	0.03
Afternoon	0.04
Dusk	0.05
Evening	0.10

We will refer to the ability of the VSV to match the same vehicle at successive sites as the vector *auto-correlation*. The tendency of the VSV to incorrectly match different vehicles at successive sites is referred to as the vector *cross-correlation*. These definitions differ from, but are similar to the formal statistical definitions of auto-correlation and cross-correlation.

Auto-correlation (Correct Match for Same Vehicle at Different Sites)

For each vehicle that passes through both detection sites, the VSV generated for it at Site 1 is compared with the VSV generated for it at Site 2. A "match" is declared if $\mathbf{e} < \mathbf{e_T}$. We report in Table 3 the **Average % Auto-correlation** as the sample mean of $(1 - \mathbf{e}) \times 100\%$ for all pairs of VSVs measured at two consecutive detection sites. The percentage of the total number of vehicles which are matched is reported as a match the **% Correct Vehicle Match**. A failure to match is assumed to be due to measurement errors, usually attributable to the presence of image artifacts, inaccurate height correction, or the effects of uncorrectable angular aberrations which distort the translation from ground coordinates to image coordinates. Some errors may simply be due to poor precision in the dimensional measurements made by research assistants responsible for processing the raw video data.

False Correlation (Cross-correlation; Incorrect Match of Different Vehicles at Different Sites)

The VSV generated for each vehicle at Site 1 is compared with the VSV for *every* vehicle in the data set at Site 2, excluding itself. A (false) match is declared if $\mathbf{e} < \mathbf{e_T}$. The **% False Vehicle Match** in Table 3 is the percentage of times that vehicles were (incorrectly) reported as matches, over all possible pairings of different vehicles. False matches are usually observed in cases of different vehicles of the same or similar make, model and color, although measurement errors can also contribute to a random increase in some correlations to a degree necessary to satisfy the detection threshold criteria.

Microsoft Excel spreadsheets containing all data and calculations are included in the Appendix.

Table 3. Auto-correlation and Cross-correlation Test Results.

Illumination Condition	Total Vehicles	Average % Auto-correlation	% Correct Vehicle Match	% False Vehicle Match
Mid-day	110	98.70%	97.27%	0.22%
Afternoon	90	98.59%	98.89%	1.66%
Dusk	103	98.41%	95.15%	2.02%
Night	102	92.47%	75.49%	27.05%

Notes:

1. For auto-correlation: VSV generated for each vehicle at Site 1 and then at Site 2 are compared.
2. For false correlation (cross-correlation): VSV generated at Site 1 for each vehicle is compared with VSV generated for *all other* vehicles at Site 2.
3. VSV match thresholds specified in Table 2.
4. % false vehicle match performed over entire data set for each specified illumination condition.

Table 4. Detailed Match / no-Match Results for Each Test Condition.

a. Mid-day:

Summary of Correlation Results (Mid-day, Thresh=0.03):

	Same Vehicle		Different Vehicle	
Match	107	97.27%	26	0.22%
No Match	3	2.73%	11964	99.78%
Total Comparisons	110		11990	

b. Afternoon:

Summary of Correlation Results (Afternoon, Thresh=0.04):

	Same Vehicle		Different Vehicle	
Match	89	98.89%	133	1.66%
No Match	1	1.11%	7877	98.34%
Total Comparisons	90		8010	

c. Dusk:

Summary of Correlation Results (Dusk, Thresh=0.05):

	Same Vehicle		Different Vehicle	
Match	98	95.15%	212	2.02%
No Match	5	4.85%	10294	97.98%
Total Comparisons	103		10506	

d. Night:

Summary of Correlation Results (Night, Thresh=0.10):

	Same Vehicle		Different Vehicle	
Match	77	75.49%	2787	27.05%
No Match	25	24.51%	7515	72.95%
Total Comparisons	102		10302	

For the mid-day test condition, the sun angle was approximately vertical. Dimensional measurements were generally accurate, and color information was available. Vehicle re-identification (auto-correlation) and vehicle discrimination (cross-correlation) results were generally very good. Figure 10 illustrates a typical correlation error **e** for a white mini-van (vehicle 25). **e** was very small for the vehicle compared with itself (vehicle 25) but was well above the detection threshold, shown as a dashed line, for all other vehicles in the data set. Vehicles which greatly differed from the norm, such as the semi-truck of Figure 11, tended to have very large cross-correlation errors, which clearly distinguished them from conventional automobiles. Cases such as vehicle 33 in Figure 11, for which **e** was small, were similar semi-trucks.

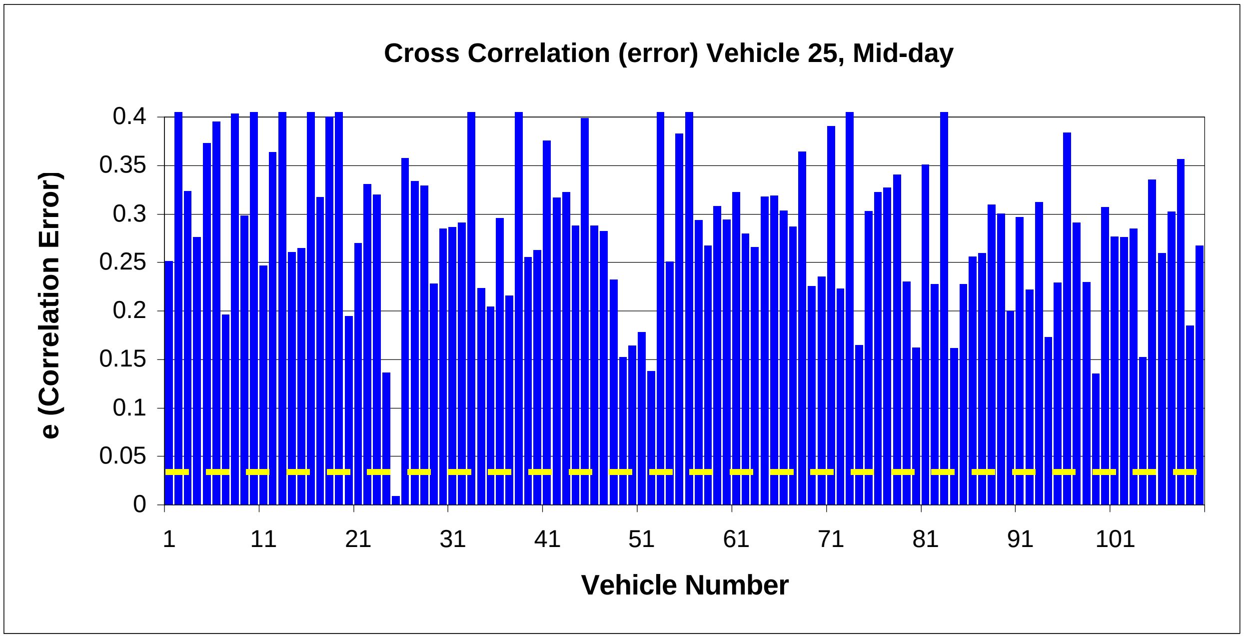

Figure 10. Correlation Error, Vehicle 25 (White Mini-van), Mid-day, Overhead Sun.

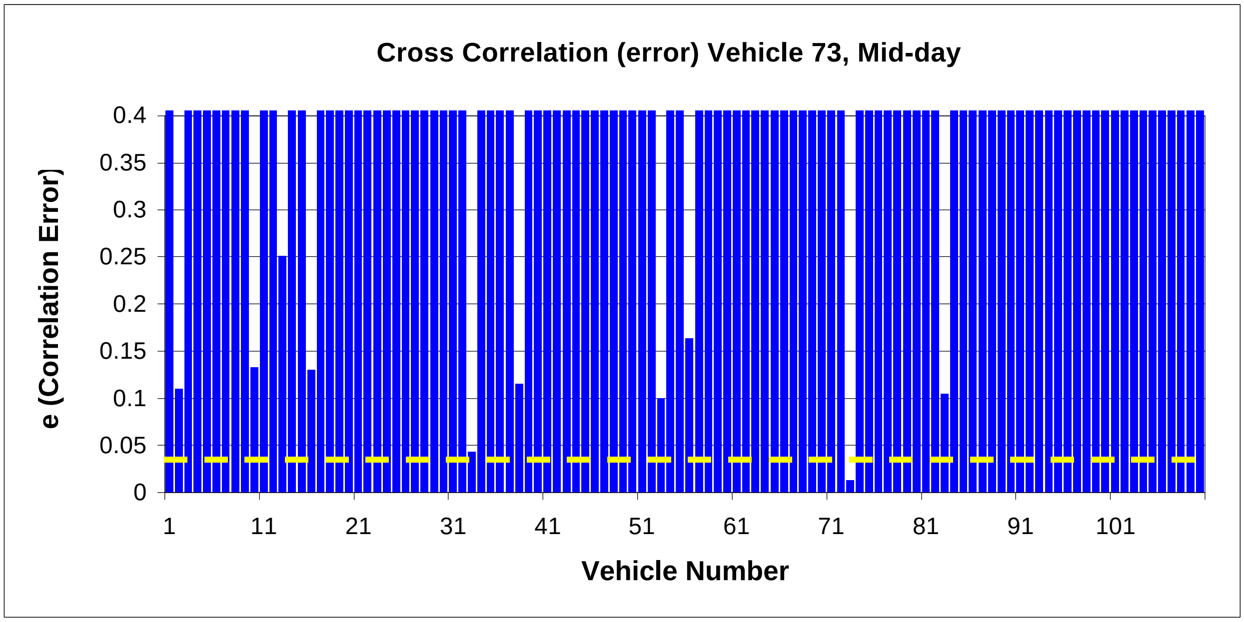

Figure 11. Correlation Error, Vehicle 73 (Semi-truck/trailer), Mid-day, Overhead Sun.

Figures 12 and 13 illustrate afternoon test condition, bright sun at approximately a 45 degree angle. The plots show the correlation error **e** for vehicles 19 and 78 among all vehicles arriving at Site 2. Vehicle 19 was a green sport utility vehicle (SUV). Vehicle 78 was a blue sedan. Both vehicle types were commonly observed. The detection threshold was $\mathbf{e}_T$ = 0.04 for this condition. As indicated in Table 4b, re-identification improved and discrimination degraded compared with the mid-day condition, but neither change was significant. Adjustment of $\mathbf{e}_T$ results in a tradeoff between these factors. The observed difference is consistent with $\mathbf{e}_T$ being slightly greater than that used for the mid-day condition.

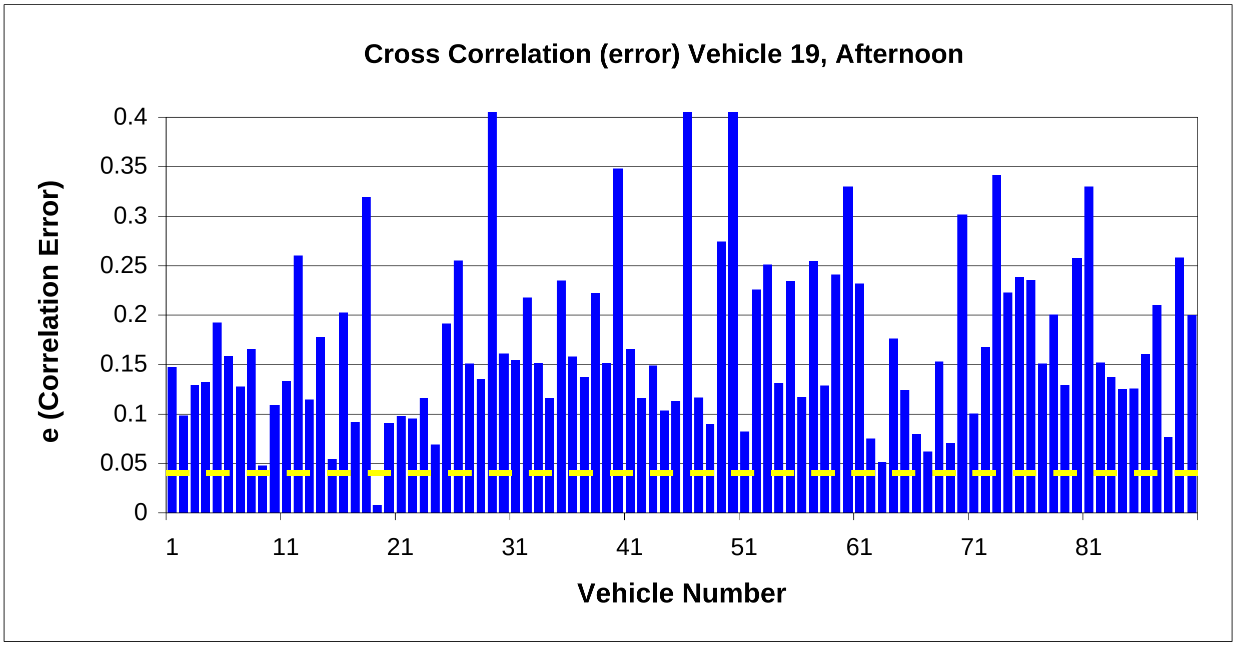

Figure 12. Correlation Error, Vehicle 19 (Green SUV), Afternoon.

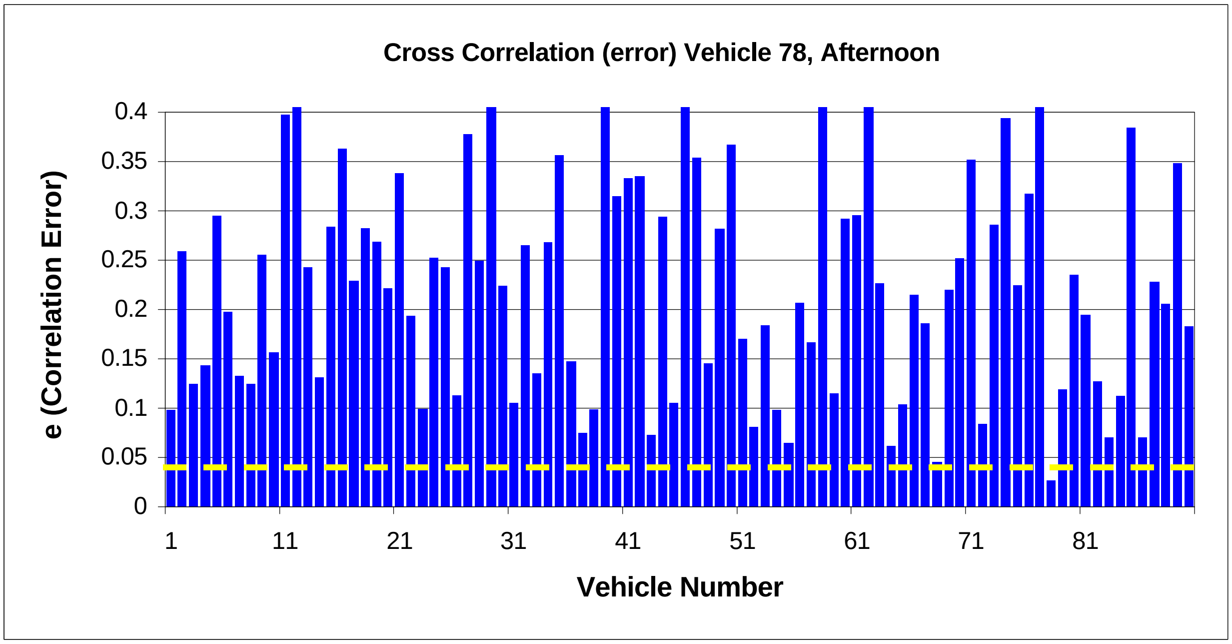

Figure 13. Correlation Error, Vehicle 78 (Blue Sedan), Afternoon.

During late afternoon and sunset, we begin to see long shadows and reduced illumination. For our manual data reduction, the presence of shadows only marginally degraded the dimensional VSV measurements. However, the reduced illumination caused our computer measurements of color to be inaccurate. Average auto-correlation was only trivially reduced compared with the afternoon condition. With $\mathbf{e}_T$ = 0.05, re-identification and discrimination ability both suffered, although not to a degree that would make the detection method unacceptable. Figures 14 and 15 below illustrate the correlation error **e** for a white pickup truck and a white minivan. Vehicle 24 in Figure 14 is falsely matched with vehicle 20.

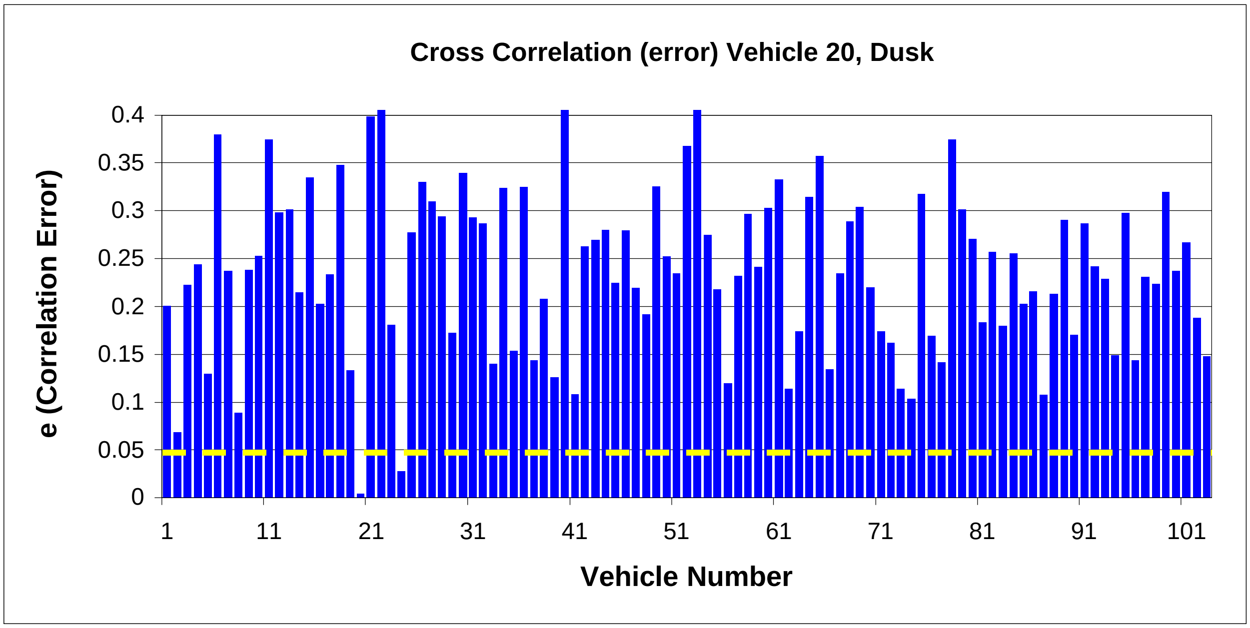

Figure 14. Correlation Error, Vehicle 20 (White PU Truck), Dusk.

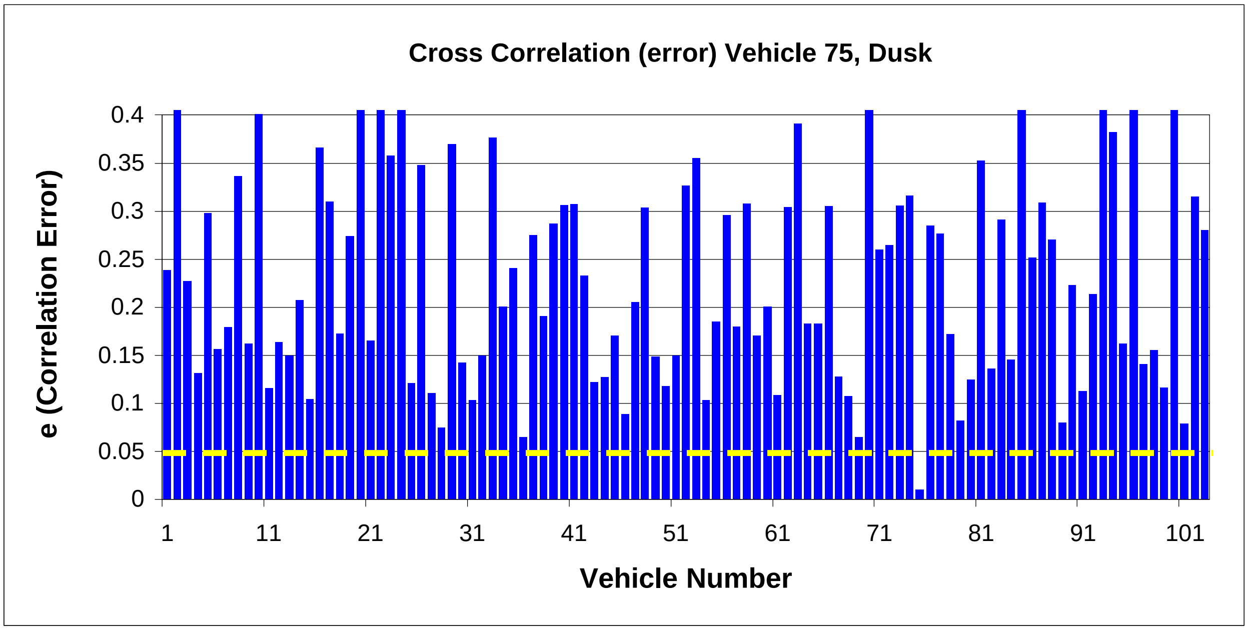

Figure 15. Correlation Error, Vehicle 75 (White Mini-van), Dusk.

Under low-light conditions, auto-correlation decreases and cross-correlation increases, approaching the point at which the uniqueness of detection is unreliable. This condition is illustrated in Figures 16 and 17 below. Color information is absent from most of the VSVs that constitute this data set. $\mathbf{e}_T$ = 0.01 for this condition. In Figure 16, vehicle 22 appears well-differentiated within a "reasonable time of arrival" window, but would be indistinguishable from vehicles 2, 7, 13, 32, 40, 50, 69, 75, 91 and 97 found outside of this time window. At some minimum illumination, the VSV cannot be reliably measured, so that **e** (for both correct and false pairings) dramatically increases, as illustrated in Figure 17 below.

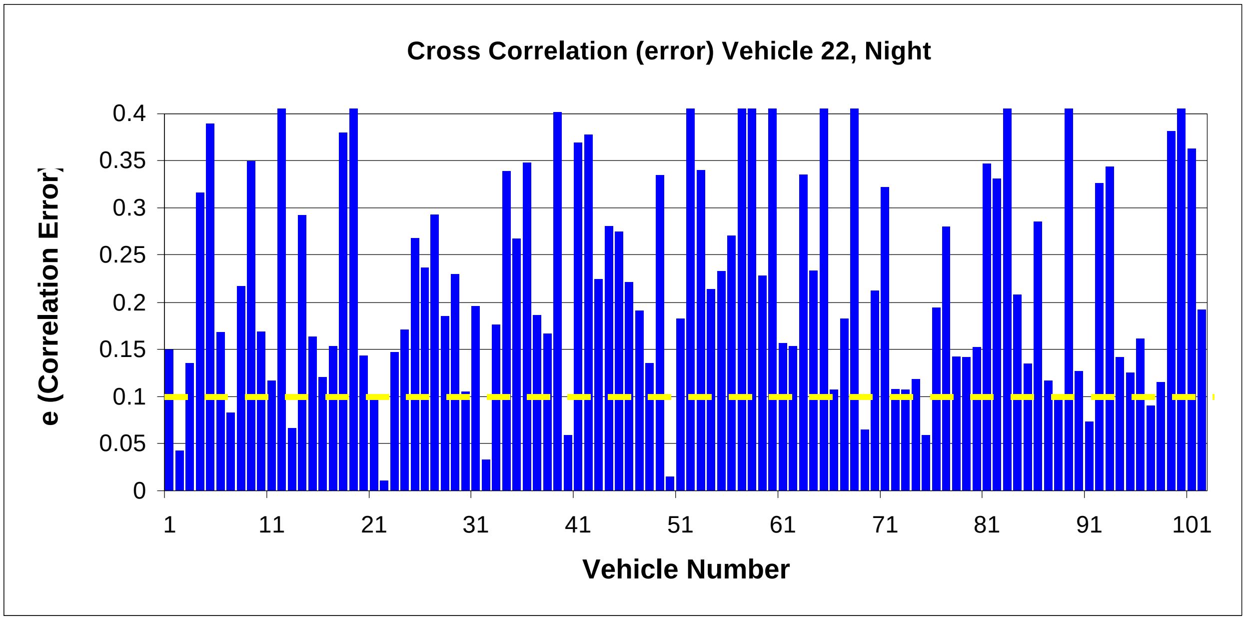

Figure 16. Correlation Error, Vehicle 22 (Red Station Wagon), Night.

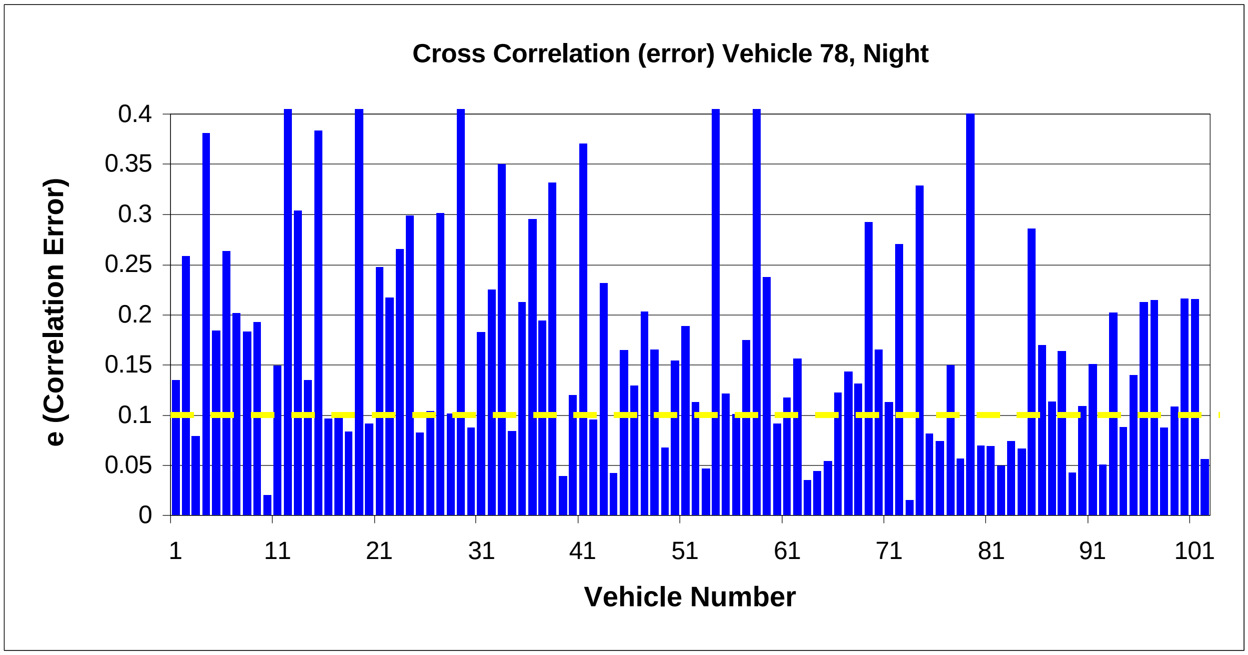

Figure 17. Correlation Error, Vehicle 78 (Station Wagon, Undetectable Color), Night.

Relative Value of Vehicle Color and Reasonable Time of Arrival Window

For the *daylight* conditions only, we studied the relative contribution of the color components of the VSV to the accuracy of site-to-site auto-correlation and cross-correlation. We only examined daylight (mid-day and afternoon) conditions since color information was not available at night, and was not reliable during dusk transition conditions. We were motivated to examine separately this vector component because of the significant incremental cost associated with acquiring and analyzing color images with machine vision. Even during daylight conditions, it was not always possible to obtain a reliable electronic measurement of a vehicle's primary color, especially cases of low color saturation. Color saturation for each vehicle was generated by our computer color analysis program, and is reported on all data spreadsheets (in the Appendix) as "S" in raw binary units (0-255). Low color saturation would roughly correspond to S<64. Saturation was recorded only to allow us to study the "loss-of-color" threshold, and was not itself used as a vector component. Based on the results shown in Table 5 below, we conclude that color information, if it can be obtained, is of significant value in the VSV.

We also examined the data to assess, in a crude sense, the relative additional value of restricting vehicle vector comparisons to within some reasonable time of arrival. The admissible vehicles in each case were determined by allowing comparisons only for vehicles that could have gone from Site 1 to Site 2 between the speeds of 30 and 80 MPH. For a 0.5 mile site separation, this corresponded to a time-or-arrival aperture at site 2 of between 22.5 and 60 seconds. The site pair separations for each of the two daylight condition (mid-day and afternoon) were 0.5 and 0.6 miles, and that traffic conditions were light (typically 3-4 vehicles per minute per lane). Therefore, the use of a "reasonable time of arrival" window typically admitted only between one and four vehicles, one of which was the actual vehicle detected at the first site.

Table 5 reports percent matches among all comparisons, either of the vehicle with itself (correct match) or with a different vehicle (false match). The data trend toward better accuracy when using a restricted arrival window is considered valid, but the exact percentages reported (99% auto-correlation, 0% false correlation) are not considered reliable due to the very small number of vehicles admitted by the time window for our test configurations. With higher density traffic are greater site separation, many more vehicles would be admitted in the time window, so that a non-zero percentage of false matches would be assured.

Table 5. Limited Examination of the Contribution of Color Elements in the VSV, and the Relative Value of a "Reasonable Time of Arrival" Window.

	VSV w/o Color	***VSV w/ Color***	***w/ Color and Reasonable Time-of-arrival Window***
% Correct Matches	98.3 %	99.0 %	99.0%
% False Matches	5.4%	0.3%	0%

Assessment of the Effectiveness of Ensemble-Averaging for Rejection of Image Artifacts

The image of a vehicle can differ substantially field-to-field in the sequence of video fields containing the passing vehicle. Contributing phenomena include transient reflections off vehicle surfaces, shadows on the vehicle from objects other than the vehicle itself, and image artifacts such as vertical smear and bloom. An example of this is shown in the following five Figures 18 a-e, which are a subset of a sequence of field images of a passing light truck, taken under mid-day overhead sun conditions.

Note from the sequence of images, that the transient image artifacts do not remain fixed with respect to the vehicle, while true optical features of the vehicle maintain a constant dimensional relation ship with respect to each other. Since several fields in a video sequence are available for making the VSV dimensional and chromatic measurements, true optical features can be distinguished from false features caused by image artifacts. This observation has been made over all conditions tested, which gives us an increased degree of confidence in the ensemble average extraction method we have proposed for robust measurement of VSV components.

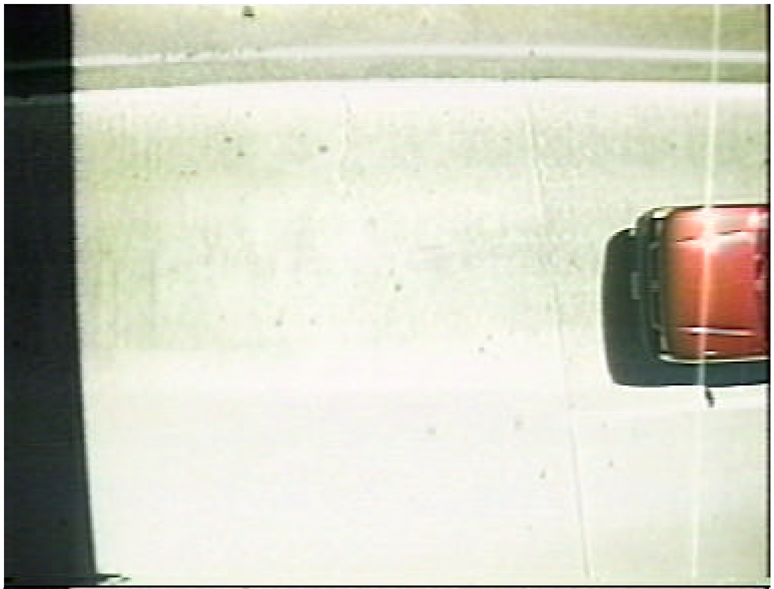

Figure 18a.

Vertical smear due to sunlight reflection on hood of vehicle.

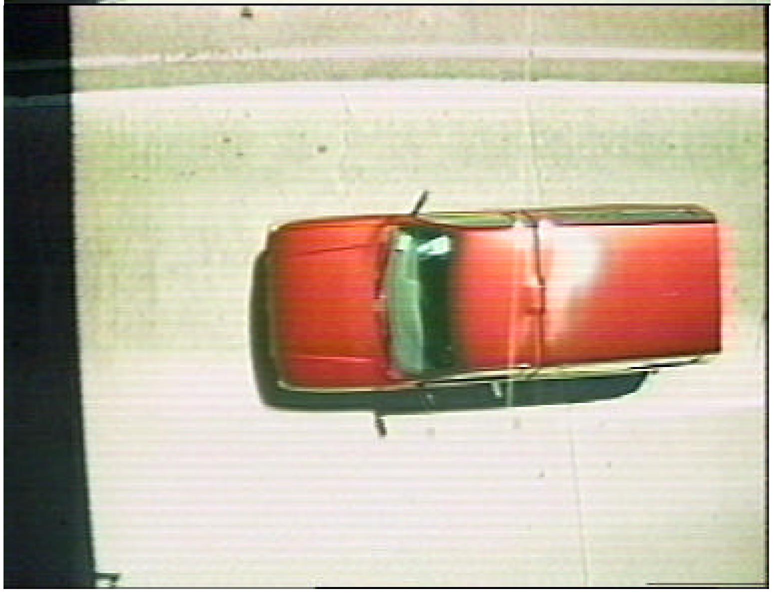

Figure 18b.

Bright area front of shell, and vertical smear from sun reflection off right side door trim.

Figure 18c.

Vertical smear gone, but bright area on roof shifted back; could be interpreted as an optical feature.

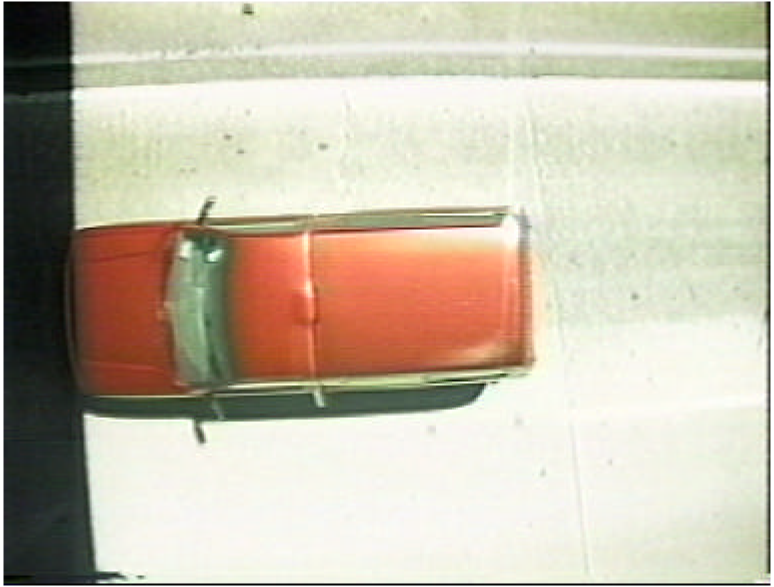

Figure 18d.

Bright area gone, but vertical smear from sun reflection off rear corner of roof.

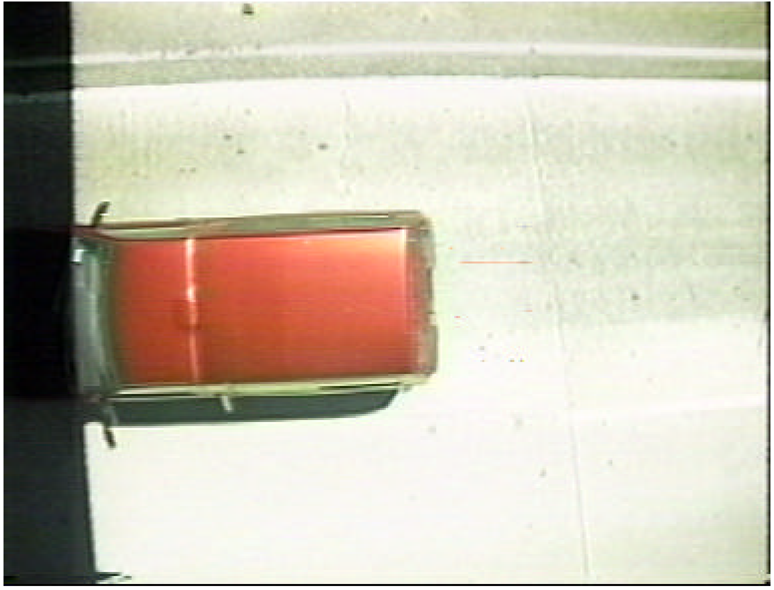

Figure 18e.

All image artifacts gone.

Image Sensor Performance and Selection Considerations

The cameras we utilized in this study were not identical, but were generally matched in performance. Camera 1 was a Minitron GM470C ½ inch CCD color camera specified as having a 450 line resolution and "high" sensitivity. Its purchase price without lens was $495 USD. Camera 2 was a Burle TC9388-1 1/3 inch CCD color camera, specified as having a 380 line resolution and "high" sensitivity. Its purchase price (1995) was $625 USD.

In general, the exceptionally low cost and high signal information content of solid state (chip) video cameras make them hard to beat as primary detectors for this application. Solid state cameras are compact, and low in power consumption. However, certain limitations of current-technology solid-state cameras preclude certain classes of cameras from consideration [4,6,7]. State-of-the-art monochrome CCD (charge coupled device) surveillance cameras are characterized by exceptional sensitivity, but are plagued by the problem of vertical or horizontal smear when a bright light source appears in the field of view. This image artifact occurs when vehicle headlights are on during periods of darkness. The resulting long white streaks in the video image confound all vision-based traffic detection algorithms that we are aware of. Both of our test cameras exhibited problems with vertical smear. The Minitron camera (higher resolution but lower cost) also exhibited this problem during bright daylight conditions, due to sunlight reflection off of chrome or polished surfaces of some vehicles (see Figure 18).

Since the detectors are required to be fully operational under both daylight and darkness conditions, this limitation is a significant obstacle. This is a fundamental characteristic of the technology which cannot be corrected by signal post-processing or optical filtering. This problem is not encountered with older lower resolution and less sensitive MOS (metal oxide semiconductor) technology cameras. The problem is also less pronounced, but not eliminated, with the newest enhanced dynamic range interline-transfer cameras. The problem is not observed in infrared cameras, both pyroelectric (room temperature) or cooled technologies (MeCdTe, InSb, or PtSi) which detect black-body infrared radiation from the object rather than reflected visible light.

Figure 19. Digitized Video Image of Night Highway Traffic, Burle TC9388-1 Camera, Auto-shutter mode.

In Figure 19, a typical night (low light) highway image acquired using the Burle camera (Camera 2) is shown. This image was acquired in color, but almost no color can be seen in the digitized video frame. Intensity-based detail in the image remains very clear, but most color information is lost at low light levels. The additional chromatic information provided by a CCD color video camera is considered to be of significant value for vehicle delineation, not only as a vector component, but as a potential mechanism for discrimination of a vehicle from its shadow. Rejection of shadow effects by the computer vision system is critical for accurate measurements of vehicle dimensions such as length or width. Color may be useful in this respect because a shadowed area in a scene usually is represented in video as having reduced intensity (I) but no change in color hue (H) and only a small change in color saturation (S). The transformation of native NTSC composite or RGB encoded information generated by a color frame grabber into HSI components facilitates this improved ability to distinguish a vehicle edge from its own shadow or the shadow of another object in the scene. While color is advantageous for both shadow-discrimination and as a characterizing component of the VSV, color cameras are typically at least 10dB lower in sensitivity compared with monochrome cameras, and are typically twice as costly. We have observed that even low-cost color cameras possess adequate sensitivity to provide an intensity (I) image of a vehicle in reduced light. However, chromatic (H and S) information is lost at low light levels. Color is not detectable below some minimum illumination level, which is inversely proportional to the product of the aperture and integration time of the camera.

We are aware of recently available high-dynamic-range color cameras from Hitachi, Sony, Cohu, Pulnix, and Burle, which are designed to have an extremely wide dynamic range. Improved dynamic range assures that the CCD array remains out of saturation, even for points of high intensity. This eliminates or reduces vertical or horizontal smear. Cameras in this class could be expected to detect color under lower light conditions. This would reduce or eliminate what we estimate to be the greatest source of potential errors in the generation of an accurate and repeatable VSV using computer vision. We are in the process of obtaining the Hitachi KP-DP581 (retail cost $3,100 USD) for evaluation. The substantially greater cost of this class of video cameras make for a difficult trade-off in the design of a possible production V2SAT detector. The ultimate question will be a cost-performance issue – is the increased cost justified if the system is *accurate enough* using an inexpensive ($500 USD) camera.

Conclusions and Future Direction

Tests were conducted to generate Vehicle Signature Vectors (VSVs) using manual graphical measurement and computer-based color measurements, from field-acquired video image sequences of vehicles observed at three pairs of sites on US Highway 101. A correlation error factor (**e**) was developed for comparison of VSVs for each vehicle traveling from one observation site to another. A "match" is reported if the correlation error is below some fixed threshold. If successful, the method may permit the tracking of individual vehicles through an instrumented roadway network. On the basis of the acquired and reduced data, we conclude that:

1. Under daylight conditions (mid-day and afternoon), an average of 98.00% of all vehicles were re-identified at the second site, for a sequence of 200 vehicles.

2. For this data set and conditions, the method incorrectly matched the vehicle with different vehicles at the second site 0.87% of the time.

3. Under daylight conditions, when a "reasonable time of arrival" window was used to admit only vehicles that could have traveled between sites at speeds between 30 and 80 mph, the incorrect match percentage falls significantly, approaching 0% under the restricted conditions of this test.

4. Under dusk illumination, but otherwise identical test conditions, correct matches occurred for 95.15% of all vehicles, while false matches occurred for 2.02% of all vehicles in a sequence of 103 vehicles.

5. Under conditions of inadequate illumination (night) but otherwise identical test conditions, correct self-correlation occurred for 75.49% of all vehicles, while false correlation occurred for 27.05% of all vehicles in a sequence of 102 vehicles.

6. All correlation results were based upon a fixed detection thresholds, set to be approximately inversely proportional to the average illumination level for each condition. It appears that the use of an adaptive threshold, dependent upon average correlation levels, has the potential to improve both auto-correlation and cross-correlation results.

7. On the basis of these observations, we conclude that the V2SAT method has the potential to serve as a reliable basis for non-intrusively tracking the progress of individual vehicles along an appropriately detectorized freeway network under daylight conditions.

8. Conventional CCD color video cameras are subject to the loss of chromatic information under low-light conditions and at very high shutter speeds. The VSV cannot be reliably detected under low-light conditions. The V2SAT method is not usable at night without provision for supplemental illumination of the detection area or the use of specialized high-dynamic-range cameras.

We feel that the generally positive results obtained under Phase I sufficiently justify Phase II work directed toward the development of an automated machine vision mechanization of V2SAT, and the deployment of the system for evaluation under actual field conditions over a large sample of vehicles.

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Appendix

Data Reduction Procedure

These notes cover the procedure for the lab processing of raw video data from field work to generate a VSV for each vehicle at each detector site.

Required Equipment:

1. Sony Trinitron PVM1351Q reference monitor.
2. Two Panasonic AG 3150 VTR's, for video tape-based correlation of vehicle images from two sites.
3. Calibrated 0.1" grid overlay transparency.
4. ISA-bus PC with Data Translation DT 2871 video IP card installed.
5. Extron NTSC to RGB converter.
6. Hotronic Time Base Corrector (Optional).
7. 9" Auxiliary color monitor.

Equipment Connection and Setup Procedure:

1. Connect the first VTR (video out) to the input of the Extron converter (video input connector).

2. Connect the RGB (RBG,H+V) outputs of the Extron converter to the respective inputs of the DT 2871 card (RGB, external sync).

3. Connect the RGB, external sync outputs of the DT 2871 card to the respective inputs on the back of the Sony monitor.

4. On the front of the Sony monitor, set the EXT SYNC button "in" and press the ANALOG RGB COMPONENT button.

5. Connect the second VTR (video output) to the 9" color monitor.

6. Turn on the 9" monitor and press the TV/VIDEO button so that it displays the word VIDEO on the screen.

7. Turn on all of the power on all of the equipment.

8. Boot the computer

9. Make sure that the files ADRV71.SYS and the ANSI.SYS files are listed in the CONFIG.SYS file. If they are not, enter them as follows:

   ```
   device=c:\dos\ansi.sys
   device=c:\adrv71.sys
   ```

10. Note that the file location may vary with your computer.

11. To measure vehicle color at a particular location in the image, run the COL.EXE program. It will prompt you for the desired screen location in pixel coordinates, e.g., (255,255) is the center of the screen. Then enter the desired color for the background text (0 – Black letters, 1 – White letters). Select white text unless you are viewing against a very light road surface image such as concrete on a bright day. After completion of setup, the image processing card operates in display / overlay

mode, showing a digitized image of it's input on the computer screen at it's maximum frame rate (approx 2 fields per second).

12. Start the tape rolling (PLAY) in the VTR connected to the computer, for the selected data sequence.

13. Depending upon the settings on the Extron converter, the computer screen image will either come up out of sync or it will jitter.

14. Cycle the SYNC toggle switch on the back of the Extron converter from H to HV and back to the H position. This will correct the sync problem. Also note, if the video signal from the VTR is routed through the Hotronic Time Base Corrector and then to the Extron converter, this will help stabilize the sync when the VTR is paused while taking a screen measurement.

15. A second cable can be run from the VTR to the Sony monitor (Channel A) so that the user can switch between dimensional measurement and color measurement.

16. Connect a second cable from the second VTR to the Channel B on the Sony monitor. The user can switch between Channel A and B on the monitor front panel to select the corresponding vehicle from the alternate detection site from the other VTR and measure it. Note that the EXT SYNC button on the Sony monitor should be in the "out" position for correct viewing of Channels A & B.

Tape Data Processing Procedure:

Dimensional Measurement

1. Tape the measurement grid transparency to the Sony monitor screen

2. Using the Channel A & B switch on the Sony monitor, select Channel A (connected to the VTR that is connected to the image processing PC).

3. Using the jog/shuttle editing wheel on each VTR, locate two cars to be compared on both video data tapes.

4. Starting with the car on Channel A, graphically measure the vector length elements along the centerline of each vehicle, starting with L1 and working toward the back of the vehicle, ending with the overall length L0. Then measure the width W of the extremal width of the vehicle.

5. Switch to Channel B and repeat the procedure for the corresponding car measurement.

6. Note the time code on the front display of both VTR's.

7. Locate the next pair of cars and repeat the procedure.

Color Measurement

1. Perform the dimensional measurement for all vehicles first. Then go back over the tape using the time code index to relocate each vehicle.

2. Boot the computer, run Col.exe, enter the screen coordinates, choice for the text color, and sync the video with the computer as previously described in SETUP.

3. Use the Hotronic time base corrector / proc-amp to match the white balance of the cameras at each site. Select a test vehicle from the first tape and then adjust the chroma and saturation using the TBC/proc-amp until a close computer-interpreted color match is obtained for the same car on the second tape.

4. Using the edit wheel on the VTR that is connected to the computer, move the vehicle of interest into the frame, with the color-target area under the square window that is displayed on the Sony Monitor. Hit the Enter key on the computer twice. (Note: The first key stroke freezes the frame and does the measurement and the second keystroke unfreezes the screen). The average R, G and B values for the target area are reported on the computer monitor. Record these onto the data sheet.

5. Use the edit wheel on the VTR to advance the frames until the next vehicle of interest appears. Try to take all of the measurements in a consistent manner, i.e. use the hood of the vehicle or some other convenient location. (All Phase 1 data used the hood of the car.)

6. Take all measurements from one tape, before you move to the next tape.

Record all data in corresponding Excel spread sheet.

Color Discrimination Program Source Code, PCOL.C

For Use with Data Translation DT 2781 Image Processing Card.

```
/*  For V2SAT Video-based Vehicle Signature Analysis and Tracking lab data reduction */
/*  Color hue and saturation determination using DT 2781 color frame grabber/image processing card  */
/*  By:  Matt Cotton                              */
/*  Last Build: 7/31/97                           */

/*  Note:  You must load ansi.sys and adrv71.sys in your config.sys file     */
/*        inorder for this program to work correctly.                       */

void main()
{

#include <conio.h>    /* Header files required to run this portion of the program           */
#include <string.h>
#include "vglobal.h"  /* Global header file used by the main program and the subroutine      */

        /*  VARIABLE DEFINITION */

        int status;   /*  Variable used by the DT Card for returning error codes            */
        int line;     /*  Variable used to define starting column location [Line=80 or Line=380]*/
        int i,j,x;    /*  Generic loop counter variables                               */
        int direction;/*  Defines the direction of the cars [dirtection=1 or 2]            */
        int col;      /*  Color of the text overlay color [Black=0, White=1]              */
        int color[4] = {0,0,0,0};/* Array used to set overlay color in each buffer.  It uses the*/
                                                          /* same convention as the col variable.        */
        int overlay[4] = {0,0,0,1}; /* Array that turns on the text overlay buffer (buffer #3)  */
        int shift;    /*  Shift defines the distance (in pixels) from the detection zone column */
                                  /*  defined by the variable Line,to the width measurement column.      */
        int hold;     /*  Is a temporary variable that stores the current background measurement*/
        int h;        /*  Is the measured Hue value [0 - 255]                          */
        int ht;       /*  Is the running total of Hue [0 - 255]                        */
        int ha;       /*  Is the average value of Hue generated by the background [0 - 255]  */
        int hd;       /*  Is the average Hue value used by the detection loop [0 - 255]      */

        char text[23] = {'V','V','S','A','T',' ','V','e','c','t','o','r',' ','G','e','n','e','r','a','t','o','r','\0'};
                /*  This is the string of letters used to generate the title across the*/
                /*  top of the screen.                                    */

        /*  VARIABLE INITIALIZATION */
        hold=0;

        /*  SETTING UP THE DT 2871 CARD                                          */
        au_err_msgs(1);         /*  Turn on the Error Message [1=on, 0=off]               */
        status = au_init();     /*  Initialize the DT 2871 card                        */
        if (status !=0)         /*  If there is as error, reset the card               */
                {
                status = au_reset();  /* Reset the card and check the status again          */
                printf("\n",status);
                }

        /*  USER MENU */
        printf("\033[2J");      /*  Used by ANSI.SYS file to clear the terminal screen     */
```

```
    printf("\n\n\n\n    User Menu\n");
    /*  Determine the direction of cars so that the car detection area can be defined    */
    printf("\n\nEnter the Direction for vehicle travel (1-2):");
    printf("\n      1)  Left to right ( ----> )");
    printf("\n      2)  Right to Left ( <---- )\n");
    printf("\n Enter your selection:");
    while(direction !=1 && direction !=2 )
        {
        scanf("%d", &direction);
        }
    if (direction ==2)
        {
        line=80;
        shift=80;
        }
    else
        {
        line=380;
        shift=-80;
        }

    /*  Determine the color of the text for the text overlay on the measurement screen   */
    printf("\n\nEnter background lettering color 0 - black or 1 - white? ");
    scanf("%d",&col);
    if(col == 1)
        {
        color[3] = 1;  /* Changes the letter color to white else the default letter  */
                       /* color is black                                           */
        }
    au_set_mode(0);  /* Set to HSI Mode                                       */
    au_set_sync(1);  /* Set Sync to External reference                          */
    au_passthru();   /* Set to Passthru Mode                                  */
    au_display(1);   /* Truns on the video monitor [1 - on , 0 - off]              */
    au_set_ovl_plns(overlay);   /* Sets up text overlay planes using the array "overaly" */
    au_clear_pln(3);            /* Clears the text overlay plane {buffer #3}            */
    au_set_ovl_clrs(color);     /* Sets text colors based upon values in the array "color*/
    au_set_grfx_pos(150,line,3); /* Sets the graphics start position (row,column,buffer) */
                                                         /*         perparing it to draw an shape (box)
*/
    au_draw_box(200,6,1);      /* Draws a box in the overlay buffer, defining the detection */
                                                  /* zone (length=200pixels, width=6 pixels, draw=1)
*/
    au_set_text_pos(20,200,3);  /* Sets up the starting position for the text string     */
                                                         /* (row=20, cloumn=200, buffer=3)
*/
    au_write_text(strlen(text),text,3); /* Write the text string to the screen in the text  */
                                                                         /* overlay buffer
*/

    /*  ++++++++++++++++++++++++++++++++   MAIN LOOP ++++++++++++++++++++++++++++*/
    top: /*  Top of main loop              */

    /*  Does this loop 300 times before updating the background value                  */
    for (x=0;x<300;x++)
        {
```

```
/* BACKGROUND HUE VALUE */
if(x==0)   /*  Makes sure that this is the first time thru the loop          */
        {
        redo:
        au_acquire(0,1); /* Acquire one frame to picture buffer 0           */
                        /* Note:  Picture buffer 0 is the frame memory housed */
                        /*       on the Data Translation card.            */

        ht=0; /*  Set the Hue accumulator value to zero.                  */

        /* Loop that gathers a 2x200 group of pixels and then takes the average*/
        /* hue value and stores it in the variable ha (average hue)         */
        for (j=0;j<1;j++)              /* Column */
                {
                for (i=0;i<200;i++)    /* Row    */
                        {
                        /* Grabs the pixel value from pixel buffer 2 (HUE)   */
                        /* (buffer=2, row=i+150, column=j+line, 1, hue value)*/
                        au_get_pixel(2,i+150,j+line,1,&h);
                        ht=ht+h;  /*  Running total for Hue value           */
                        }
                }
        ha=ht/400;  /*  Finding the average value of Hue                   */

        /*  Conditional statement that looks to see if there was a car in the*/
        /*  detection region when a measurement was taken. (i.e. The background*/
        /*  Hue value must not change between two consecutive measurements   */
        if(hold > ha+2 || hold < ha-2)
                {
                hold=ha;
                goto redo; /*  If fail then redo the measurement            */
                }
        printf("\n\nUpdating Background Values\n");
        hold=ha;
        }


/*  VEHICLE DETECTION ALGORITHM */
ht=0;  /*  Set total Hue accumulator to zero                              */
au_acquire(0,1);  /*  Acquire a picture and put it in frame buffer 0        */

/*  Similar loop to the background detection algorithm.  This loop is used to*/
/*  get a new average value for Hue.  It then compares the average background*/
/*  value of Hue (ha) to the new average value of Hue (hd).  If there has been*/
/*  a change within +/-3 then there is a car in the detection zone.  It then */
/*  calls the width measurement subroutine.                               */
for (j=0;j<1;j++)              /* Column */
        {
        for (i=0;i<200;i++)    /* Row    */
                {
                au_get_pixel(2,i+150,j+line,1,&h);
                ht=ht+h;
                }
        }
hd=ht/400;
```

```
                /* Conditional statement that determines wheather or not a car is in the     */
                /* detection zone
                                                                          */
                if (hd > ha+3 || hd < ha-3)
                        {
                        do_width(line,shift);
                        }
                }
        goto top;  /* Once the loop has executed 300 times, this statement resets the loop so*/
                     /* that the system will update the background Hue value.           */
/* ++++++++++++++++++++++++ END OF MAIN LOOP ++++++++++++++++++++++++++++++++*/
}
```

Field Data and Correlation Results – MS Excel Spreadsheets

MS Excel data spreadsheets for each test condition:

1. Mid-day, Field Trip 3
2. Afternoon, Field Trip 2
3. Dusk, Field Trip 1a
4. Night, Field Trip 1b