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Surveillance at PATH: Part 2

PATH – Partners for Advanced Transit and Highways – is a joint venture of the University of California, Caltrans, private industry, and other public and private academic institutions, with the mission of applying advanced technology to increase highway capacity and safety and to reduce traffic congestion, air pollution, and energy consumption.

CALIFORNIA PATH

The Need for Surveillance in Intelligent Transportation Systems - Part Two

Joe Palen, Caltrans New Technology and Research Program

In part one of this article (Intellimotion 6.1), Joe Palen examined the "what and why" of surveillance, discussing why surveillance is required, and identifying several parameters that need to be detected: travel time and speed, incident verification, volume, safety, emissions, and weight. Here he identifies one additional parameter, class category, and goes on to discuss how some of these traffic related parameters can be measured.

Classification

Vehicles can be classified according to any common criteria; however, the best criteria are based on measurable parameters and lead to unambiguous class category distinctions. Classification criteria should lump vehicles into categories that are useful for some purpose. A vehicle's "function" is a commonly desired classification category (e.g., is it a bus, or a modified RV?), but this is often difficult or impossible to determine from objectively obtainable criteria available exterior to the vehicle. Because the overall purpose of ITS (Intelligent Transportation Systems) is to maximize accessibility while minimizing costs, the effect on system costs would seem to be a useful basis for classification criteria.

For example: the primary parameter affecting pavement design, construction, and maintenance is truck wheel loading – trucks are what tear up the pavement. The primary vehicle parameter affecting structure design and construction is truck total weight. Heavy vehicles also have extended stopping distances, which affects collision risk. They have a difficult time matching the acceleration profiles of congested traffic (reducing throughput), and tend to produce large volumes of pollutants when they try to. Long vehicles consume more lane space and make merging maneuvers difficult (reducing throughput). Large vehicles reduce the sight distance for vehicles behind them (increasing headway, reducing throughput, and increasing collision risk). A vehicle's weight, wheel loading, and overall size therefore have a most significant effect on system costs, and these parameters might most appropriately constitute a valid basis for classification criteria.

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Caltrans prototype mobile video surveillance trailers. See article on page 10.

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However, many vehicle classification schemes (such as those currently used by Caltrans, the federal Department of Transportation, and many toll agencies) are based primarily on axle count and spacing. This appears to be a legacy from the earlier days of loop and treadle based detectors, where axle count and spacing were the only parameters that could easily be measured. As long as axle-count based vehicle classification schemes are still legally mandated for some applications, there will still be a need to survey this parameter.

How can vehicle parameters be measured?

The first thing that must be determined is: "what is, and what is not, a vehicle."

How to optimally survey vehicle parameters – the mechanism of surveillance – is a field in itself. However, PATH has developed some extremely useful mechanisms for traffic detectors deserving mention. Traffic detectors basically measure some parameter which differentiates the vehicle from the roadway. The first thing that must be determined is: "what is, and what is not, a vehicle."

A non-contact detector can only acquire information by analyzing wave energy propagated through the open space between the vehicle and the detector. Generally, detectors measure spatial or temporal variations in the frequency or intensity of sound or electromagnetic waves. As examples: an inductive loop detects vehicles by assessing the change in frequency of a resonant circuit induced by a metal mass moving through the loop's electromagnetic field. Radar, Lidar, and ultrasonic detectors assess vehicles by their reflections of generated waves. Video or infrared focal plane array detectors assess vehicles from the chromatic or intensity contrast of adjacent pixels. Doppler radar assesses vehicle speed from the changing frequency of a reflected signal.

Since wave energy travels in straight lines, traffic detectors should be mounted in line-of-sight to a vehicle, otherwise faraway vehicles could be occluded by nearer ones. Loops and magnetometers are usually mounted in the roadway below the vehicles, which can cause considerable logistical and traffic delay problems for installation. Ultrasonic and laser detectors are usually mounted above the vehicles. Some radar and video detectors are mounted to the side of the vehicles – logistically the simplest method.

Anything that changes the detected background intensity, frequency, or spatial orientation of the measured wave energy can add noise and reduce accuracy. Video image processing is notorious for problems induced by day-night transitions, shadows, and headlight reflections off wet pavement. Fog, smog, dust, snow, rain, and "roadwash" behind trucks can all reduce the transmission of waves of different frequencies, and therefore reduce accuracy. Additionally, detectors that rely on precise timing circuits can be corrupted by temperature extremes.

Most detectors can determine speed as well as volume. For a single loop detector, the vehicle "presence" is converted to speed by simply assuming an average vehicle length. Alternately, a "speed trap" can be used, where two adjacent loop detectors are placed a known distance apart. Speed traps are used with other types of detectors as well. Another method of determining local speed is tracking the vehicle across multiple sensing elements in a single detector, such as the pixels on a CCD camera (e.g. video image processing).

Once the local speed is determined, it is often just assumed to be the same across the entire link in order to get travel time. The problem is that during congestion, by definition, there are spatial and temporal variations in speed, so the speed measured at one point is not necessarily indicative of the entire link's speed. The adverse effects of this assumption are exacerbated if these point-generated speeds are used for such user services as wide-area congestion routing.

New PATH measurement methods

PATH researchers have recently come up with some innovative ways to accurately measure travel time. They began with the observation that point-to-point travel time is, by definition, the time it takes for a vehicle to go from detector site "A" to detector site "B". Therefore, a detector system that can acquire unique or semi-unique features on the vehicle platoon stream at point "A" such that they

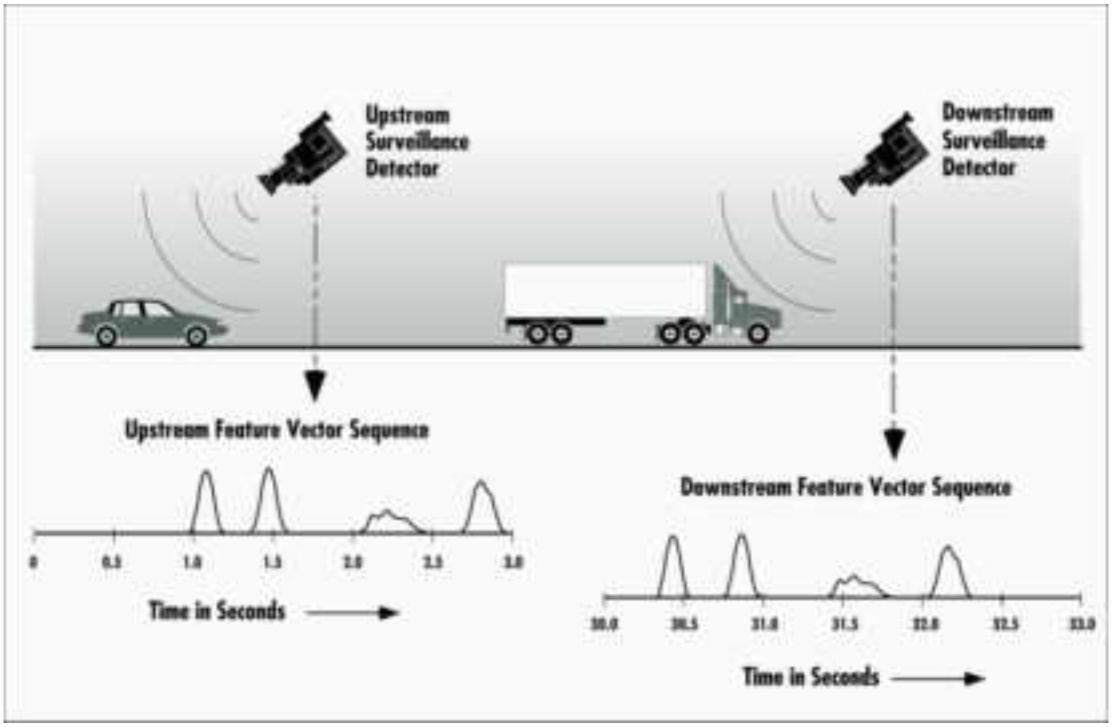

Figure 1 – Vehicle feature vectors are re-recognized downstream to general travel time. Dramatic changes in travel time indicates incidents. In this example, the platoon travel time is sequence offset (e.g. 30 sec.)

can be re-recognized at point "B" can be used to continuously generate the true travel time for an entire vehicle fleet.

PATH is developing some "maximum probability fit" algorithms to allow for detector noise, variations in platoon sequence, and merging or discharging of vehicles between detection sites. This is a truly elegant and robust solution to a major ITS data collection problem!

The PATH research seems to indicate that relatively low resolution fuzzy detectors (such as inductive loops with large apertures) may only be good enough to yield aggregate fleet travel time. Higher resolution, more deterministic crisp detectors may reduce the reidentification "probability fit" variance enough so that it will be possible to uniquely reidentify individual vehicles, producing true origin/destination (O/D) information. This O/D data is needed to calibrate and validate the traffic simulation models, which would be helpful in many aspects of ITS. This vehicle reidentification mechanism is conceptually similar to that currently being proposed for tag-reading Vehicles as Probes (VAP) projects – only with greatly reduced infrastructure costs, no privacy concerns, and applicability to 100% of the fleet immediately upon deployment. If such surveillance systems become reliable enough to sense every passing vehicle, "conservation of flow" could be used to accurately determine queue lengths at ramps and signalized intersections. Flow conservation algorithms should also make it possible to quickly find stranded vehicles on the freeway, saving drivers a potentially dangerous roadside walk to a call box. The benefits could be enormous.

Caltrans is acutely interested in the full life cycle cost of surveillance systems, as well as the benefits. This includes the cost to procure, install, calibrate, maintain, and operate the system. Currently, a large portion of the installation cost goes to trenching and laying conduit for power and communication. A tetherless, photo-voltaic powered system with low enough bandwidth requirements to use a radio-frequency modem would greatly reduce installation costs. Call boxes, which are essentially self-powered, self-communicating, roadside-mounted, crash-tested boxes, are popular simply because they are plug-and-play devices. Such a capability in a reliable high resolution detector would be highly advantageous. PATH is currently examining the full gamut of possibilities in the tradeoff between

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Vehicle Signature Detection Using Standard Loop Detectors

Carlos Sun, Stephen Ritchie, UC Irvine; Reinhart Kåhne, Steierwald Schînharting GmbH; Craig Gardner, Gardner-Rowe Systems; Joe Palen, Caltrans

Our group is conducting innovative research in intelligent surveillance systems that will transform standard Caltrans loop detectors into intelligent sensors capable of keeping track of individual vehicles as they travel from one traffic measurement station to the next. From such data, travel time, speed, section densities, and other useful measures of traffic conditions can easily be derived. Our work is an interdisciplinary effort on the part of PATH, UC Irvine's Department of Civil and Environmental Engineering and Institute of Transportation Studies, Caltrans, Gardner-Rowe Systems, and Dr. Reinhart Kåhne.

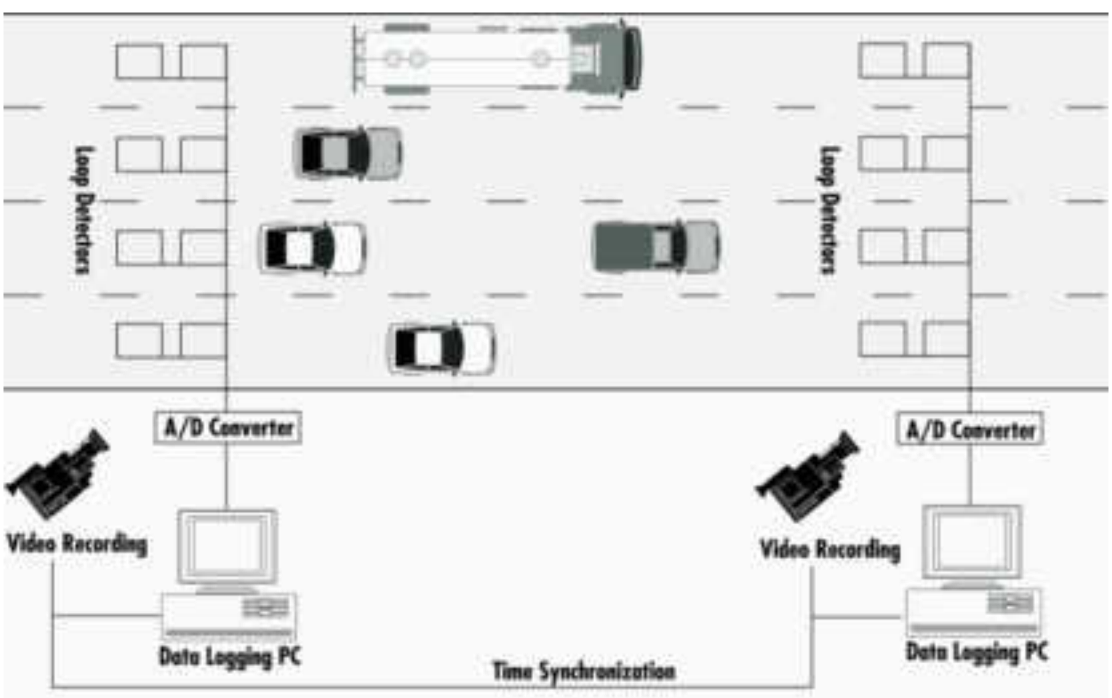
This intelligent surveillance system will be able to derive section-related measures of traffic performance such as section densities and section travel times. Using these parameters, applications for incident detection, dynamic traffic origin/destination estimation, dynamic traffic assignment, and responsive traffic control can be developed.

One of the components that make this system possible is a high-speed scanning detector that scans the loops at millisecond intervals. Another critical component, still under development, is a correlation algorithm capable of matching separate vehicle signatures and determining that a particular vehicle has traversed the network, leaving its "fingerprint" along the various measuring stations.

Field trial data acquisition implementation

To prove the feasibility of such an intelligent surveillance system, a test site consisting of two measuring stations was selected in December 1996. Figure 1 illustrates the data acquisition instrumentation on a sample section of freeway.

Figure 1 – Layout of measuring stations (1.2 miles apart)



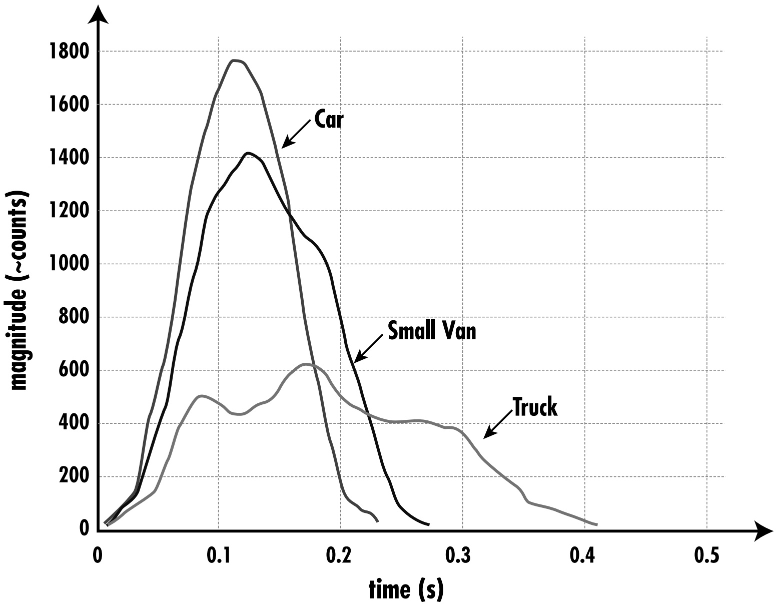


Figure 2 – Vehicle Signatures

The actual freeway segment chosen was westbound SR-24 in Lafayette, California, from a measurement station in Central Lafayette to a station 1.2 miles downstream. Standard 6’x6' loops are used at both stations. Special Peek loop detectors were mounted in the controller cabinet. These detectors performed the analog-to-digital (A/D) conversion to sample the data and feed it in digital form to a data-logging PC for storage. Ground-truthing video data was collected simultaneously, and was time-stamp synchronized with the loop data. Each individual lane was instrumented in order to distinguish lane changes.

Characteristics of vehicle signatures

Loop detectors are electromagnetic resonance circuits. When a metal mass passes through the magnetic field generated by the inductive loop, the net disturbance produces a reduction in the loop inductance or frequency, and the resonance circuit properties are altered. A motorcycle, for example, could produce a frequency shift of up to 0.08%, while an automobile could cause a shift of up to 3%. The metallic component of the vehicle is what disturbs the loop inductance. As a result, double-axle trucks produced a twin-peaked vehicle signature when the resolution of the detector was adequate. As one can see, this method can easily be used for vehicle-type identification purposes. Figure 2 shows some possible variations in the vehicle signatures of different types of vehicles.

Vehicle signature feature extraction and data reduction

Figure 3 shows the many steps involved in taking raw data and modifying it until it is suitable for vehicle signature correlation.

First the raw data is passed through a low-pass filter, removing the high frequency components. (The actual raw data is in discrete form but is plotted continuously for illustration purposes.) This results in a smoothed signature. The signature amplitude is obtained using wavelet power spectrum calculations. The use of wavelet technique can offer added insight and performance compared with traditional Fourier techniques, since wavelets capture time dependency. The time scale is normalized using vehicle speeds, with the result that maximum bandwidth is utilized in the storage of the signature. Since only relevant features are needed for correlation, repetitive data points are eliminated and relatively less memory is needed to store the data set.

Derivation of section-related measures of traffic performance

The overall investigation process starts with data acquisition of the raw data using inductive loops and data-logging PCs. The raw data is modified in the laboratory, and relevant features are extracted into a new data set. This data set is then used for correlation, or for matching vehicles from the

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Advanced Imaging Techniques for Traffic Surveillance and Hazard Detection

C. Arthur MacCarley, California Polytechnic State University, San Luis Obispo

Remote surveillance on highways has traditionally been synonymous with closed circuit television, which relies upon natural or artificial illumination in the visible (0.30 to 0.70 micrometer (µm)) spectral band for the detection and reproduction of a real-time two-dimensional image of a scene. However, real-time image sensing is also possible in areas of the electromagnetic spectrum outside the visible band, and such imaging techniques may be valuable when night or weather dim the camera's eye. Alternative imaging methods generally differ from typical video images both by detecting radiation outside the visible band, and by using more scene information than radiation intensity reflected from object surfaces. The limiting factor is available sensing technology.

Although the atmosphere is opaque over much of the spectrum from the infrared to the microwave band, it has a few distinct windows...

Recent developments in solid state technology have made two-dimensional sensing practicable in the infrared (0.70 µm < λ < 20 µm) and the millimeter-wave (1 mm < λ < 10 mm) spectral bands (λ = wavelength of detected electromagnetic radiation). With PATH support, we are investigating possible applications of imaging in these bands to highway safety and traffic management problems.

Practical imaging sensors are now available that operate in selected bands, as summarized in Table 1.

Although the atmosphere is opaque over much of the spectrum from the infrared to the microwave band, it has a few distinct windows of low attenuation in the infrared and millimeter-wave bands. Alternative sensing technologies utilize these windows for the formation of a scene image. Figures 1 and 2 show atmospheric transmissivity (the inverse of attenuation) as a function of wavelength of detected electromagnetic radiation for two common types of fog with 0.1 km nominal visibility, over the broad spectral range from near ultraviolet to millimeter wave radar. These data were generated using the MODTRAN simulation (MODerate Resolution TRANsmissivity computer simulation, developed by the US Department of Defense for visibility prediction), which predicts relative atmospheric transmission as a function of wavelength and atmospheric composition.

Figure 1 depicts typical radiative (or radiation) fog, such as the "valley fog" common in central California. It generally forms when the temperature drops below the dew point in still air, often as a

Table 1 – Usable Spectral Bands for Electronic Imaging

Wavelength λ	Band Describer	Detector Technology
0.8 – 1.2 µm	Very Near Infrared (VNIR)	Silicon Photodetector, uncooled
3.0 – 5.0 µm	Shortwave Infrared (SWIR)	Platinum Silicide or Indium Antimonide, Sterling cryopump cooled
8.0 – 12.0 µm	Longwave Infrared (LWIR)	Mercury Cadmium Telluride, Sterling cryopump cooled. Pyroelectric or Microbolometer, uncooled.
3200 µm (94 GHz)	Mid-millimeter-wave (MMMW)	Gallium Arsenide
8600 µm (35 GHz)	Long-millimeter-wave (LMMW)	Gallium Arsenide

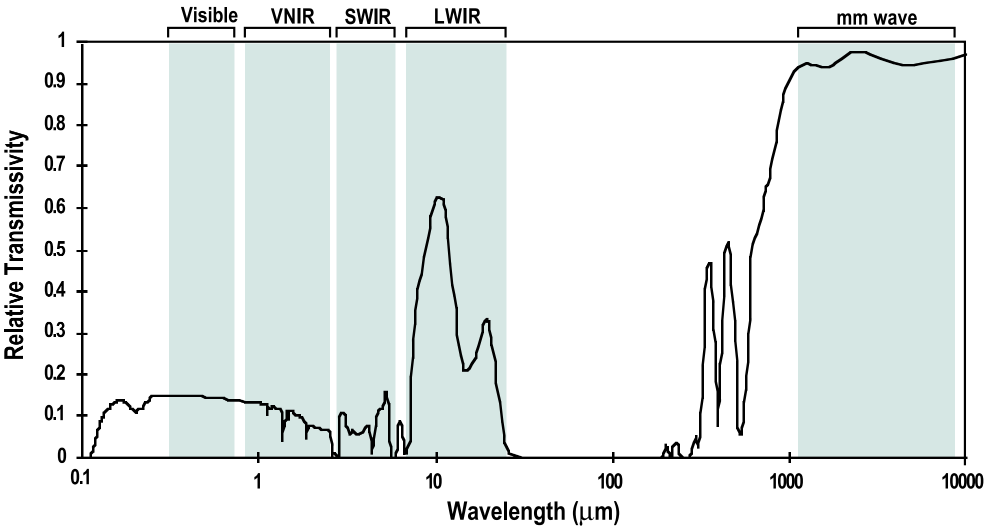

Figure 1 – Atmospheric Transmission, Medium Density Radiative Fog

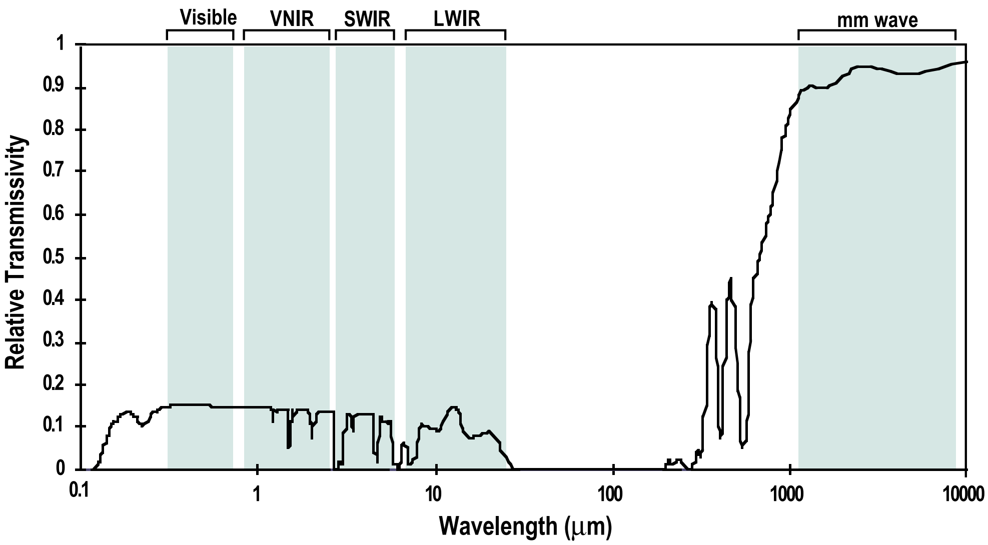

Figure 2 – Atmospheric Transmission, Medium Density Advective Fog

result of heat loss from ground radiation to open sky. Radiative fog is unpredictable and transient, and is a significant causative factor in visibility-related traffic incidents.

Figure 2 depicts advective (or advection) fog, common in the coastal or mountainous areas of California. It is distinguished by wind transport of moist air and subsequent temperature drop, due to a number of possible factors including mixing with colder air and altitude change. Advective fog, while equally transient, seems to be less often associated with major traffic incidents.

Figures 1 and 2 show relative transmission over a 0.05 km path length. The bands of low atmospheric attenuation are each associated with a detector technology. In the infrared bands, water droplets and vapor, as well as carbon dioxide, are primarily responsible for attenuation by absorption and scattering mechanisms. For both fog models, transmission in the VNIR and SWIR bands is similar to the visible band. Transmission in the LWIR band is predicted to be superior, although substantial differences are seen between the two fog models. Radiation in the MMMW and LMMW bands is virtually unattenuated for almost any common atmospheric obscurants. While transmission alone is not the only factor affecting human perception of an image, these model predictions suggest a superior ability to “see” though fog in selected bands compared with the visible band.

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Accurate definition of visibility in fog appears to be application-specific, and a topic of current research. Correlation of fog density with traffic safety remains inexact, however, and little quantitative data has been found, despite several deployments and tests of highway fog monitoring systems. There appears to be no clear relationship between a particular observed visibility and the threshold of unacceptable hazard, although Caltrans District 10 (Stockton) uses 300 feet of visibility as the threshold of activation for an automated fog warning system.

Visibility in a particular band is a function not just of signal attenuation, but of many other factors, among them human perception, detector performance (e.g., resolution, sensitivity, dynamic range), and inherent information-signal to background-noise ratio. We felt, therefore, that only actual hardware field tests would make it possible to compare and assess the potential of alternative imaging technologies.

Field and laboratory tests

Procedures were developed to compare test results with our transmission simulation model predictions, and to evaluate the various alternative technologies. Nine infrared cameras and one 94 GHz (3.2 μm) “multi-spectral scanner” were field-tested under a wide range of atmospheric, illumination and scene conditions. A list of the imaging systems tested appears in Table 2.

A test apparatus was constructed comprising an integrated video data acquisition system with five LTC-synchronized SVHS video recorders, a PC-based computer control system, and a 10 meter high mobile surveillance tower (MST) to provide elevated camera positions in situations when existing platforms such as freeway overcrossings are not available. Video data was recorded simultaneously from four IR cameras, plus a fifth visible-spectrum color reference camera.

Table 2 – Imaging Systems Tested

Company Name and Product	Radiation Wavelength (μm)	Operating Temperature	Detector Type	Array Size (Pixels)
AGEMA Thermovision	8-12	77K Sterling	HgCdTe	Mech X–Y scanned 5-element detector array
Cincinnati Electric IRIS-256ST	3-5	77K Sterling	InSb	256x256, 160x120
FSI Prism	3-5	77K Sterling	PtSi	320x244
GEC/Marconi Sentry IR20	8-15	77K Sterling	Micro-bolometer	256x256
Inframetrics 600	3-5 & 8-12	77K Cryogenic	PtSi and HgCdTe	Mech X-Y scanned 1-element detector
Inframetrics 760	8-12	77K Sterling	HgCdTe	Mech X-Y scanned 1-element detector
Inframetrics InfraCam	3-5	77K Sterling	PtSi	256x256 Focal Plane Array
Insight/Starsight	8-14	Ambient	Pyroelectric	256x256
Mitsubishi IR-M300	3-5	77K Sterling	PtSi	256x256
TI NightSite	8-14	Ambient	Pyroelectric	320x200
TRW multispectral scanner	94 GHz mm wave	Ambient	HEMT-heterodyne	Mech X-Y scanned 1-element detector

Field tests were conducted during the period December 1, 1994 through January 15, 1995. Additional tests followed in March and May, 1995, with the most dense fog encountered in the last tests at Morro Bay, California. Approximately 160 hours of video tape and 100 digitized image files (from the millimeter wave imager) were created at nine field sites in the Los Angeles, Fresno, Central California Valley, Sierra Nevada Mountains, and San Luis Obispo county coastal areas. A typical field site setup, located on an unopened new overcrossing over Highway 99 in Fresno, is shown in Figure 3.

Figure 3 – Field Test Site, California Highway 99, Fresno

Due to limited availability of the rented or loaned imaging systems, it was not possible to test all cameras and sensors under all conditions. Although tests were conducted under a range of conditions judged to be typical of light advection and radiation fog, it was not possible to quantitatively correlate these conditions with those simulated in our MODTRAN atmospheric models. Only two cameras (one 3-5 µm and one 8-12 µm) were tested in visibility less than 0.1 km, advection (coastal) fog.

Visibility comparisons were based on human observation of recorded images, viewed on a reference monitor, that had been recorded as each camera viewed an identical scene. When possible, stationary visibility targets (orange traffic cones) were placed in the scene at known distances. However, these were of limited value since the improved imaging capability of IR cameras (especially for LWIR) is related to such factors as the surface temperature of the targets of interest, in this case automobiles. Subject to the experimental limitations, our field observations supported the trends predicted by MODTRAN for the visible, SWIR, LWIR and 94 Ghz mm wave bands.

In terms of overall visual detectability of vehicles, we observed that under both daylight and night illumination, and light to medium density fog conditions, the LWIR cameras provided more usable traffic images than conventional monochrome and color video cameras. SWIR performance seemed to be only marginally inferior to LWIR in light to medium density fog, although, as mentioned above, we could not clearly test the distinction between advection and radiation fog, which showed significant difference in the MODTRAN results.

The 94 GHz Multispectral Scanner was capable of producing only still images, of such poor resolution as to be of no surveillance value, despite the exceptional fog-penetrating characteristics of this spectral band. This poor performance is a function of antenna-theoretic considerations as well as the experimental nature of the mechanically-scanned apparatus. The resolutions of MiMIC focal plane arrays (Microwave Monolithic Integrated Circuits-gallium arsenide detector arrays operating at 94 GHz) presently under development are expected to be greatly improved over this single-detector heterodyne system.

Many additional factors were found to influence the quality and information content of the IR, mm-wave and visible video images. These factors are related to the fact that the information content of images in the IR and mm-wave bands differs significantly from familiar visible perception. Figure 4 shows the different characteristics of images "seen" in the various bands.

Observations

In daylight, atmospheric transmissivity seems to correlate well with practical visibility. The combination of darkness and fog presents a unique set of visibility problems, not necessarily predicted by

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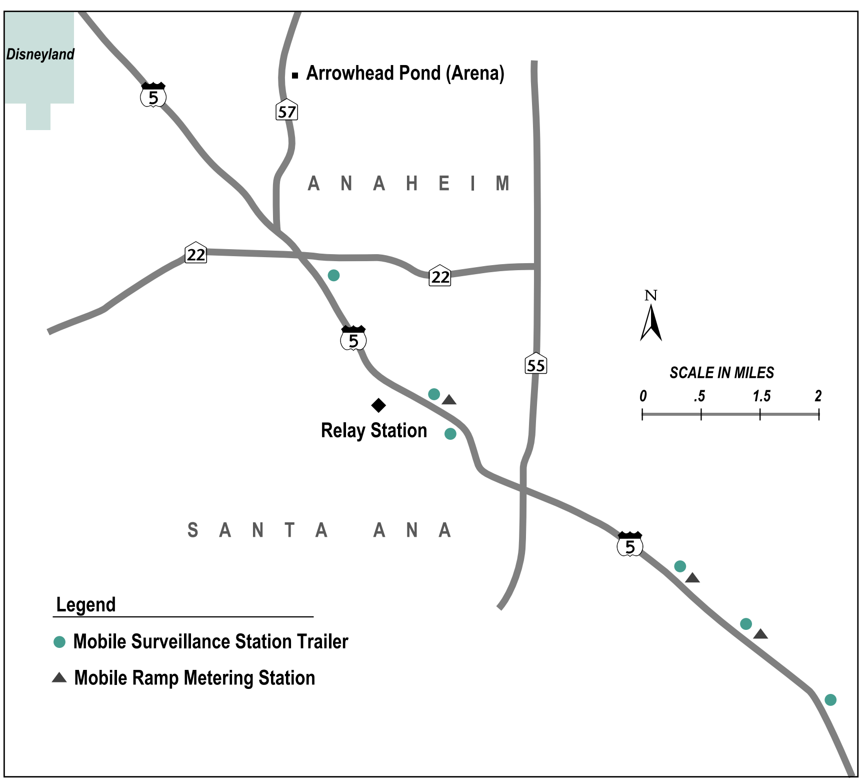
Mobile Video Surveillance and Ramp-Metering S

Lawrence Emerson, Caltrans New Technology and Research Program

Anaheim, California, home of Disneyland and the Mighty Ducks hockey team, has recently been the scene of special-event traffic congestion during the Ducks' playoff race. Here Caltrans, in partnership with the UC Irvine Institute of Transportation Studies, the Federal Highway Administration, and Hughes Aircraft Company, is testing a prototype mobile video surveillance and ramp-metering system for freeway ramp metering and city arterial applications. The two-part Field Operational Test will assess the system's effectiveness as a temporary replacement for inductive loop detectors out of service due to freeway reconstruction, as well as its utility for flexible placement of traffic monitoring cameras during special events. Pacific Polytechnic Institute of San Luis Obispo is evaluator of the FOT, under contract to PATH.

Field operational test trailer locations



The mobile video surveillance and ramp metering system combines video image processing, video compression/decompression, spread-spectrum wireless communications, and distributed data processing and control. It consists of six surveillance trailers with telescoping masts, three ramp-metering trailers (with two portable traffic signal light heads and a metering on/off sign), three fixed data collection and analysis sites, and one relay site, all communicating over a spread-spectrum radio microwave communications network. Each trailer has four cameras, three mounted on the telescoping mast. One mast-mounted camera, for color surveillance, incorporates pan, tilt, and zoom control. The other two are pan-and-tilt black-and-white cameras that supply imagery to a video image processor. The fourth camera is mounted on the trailer's roof to provide a security view of the trailer entrance. The trailers and cameras can be controlled and the images viewed from the data collection and analysis sites at Caltrans District 12 Transportation Management Center in the City of Santa Ana, the UC Irvine Institute of Transportation Studies, and the City of Anaheim Traffic Management Center. The city of Anaheim is also supporting this FOT by providing trailer site locations within its boundaries, and by installing a data collection and control system in its TMC.

Surveillance trailers can be used to provide real-time compressed video of major intersections or special-event traffic conditions in municipal arterial applications. They can also be used to monitor mainline freeway traffic flow. Surveillance trailers and ramp-meter trailers can be placed in pairs at selected onramps to provide automatic ramp-meter timing and control. Because the trailers are self-powered and able to transmit images and data via spread-spectrum radio, they can be set up in locations that are without power or land-line communications (though line-of sight to the relay station is a factor).

ystem

Each surveillance trailer contains a Type 170 Traffic Controller (170 controller) and a video image processor (VIP). The VIP simulates vehicle presence loops on the freeway mainline and transmits lane occupancy to the 170 controller. Mainline volume and occupancy data are generated from the video imagery supplied by one of the black and white cameras on the telescoping mast. The 170 controller can either use preset time-of-day timing or the mainline volume and occupancy data to set the metering rate. The second black-and-white camera can be aimed at the onramp, and its video fed to another input on the VIP. This imagery provides ramp queue, demand, and passage loop inputs to the 170 controller. The 170 controls the ramp-metering trailer's traffic signal lights via a dedicated spread-spectrum digital radio link (19.2 kbps). When signal lights must be placed on both sides of the onramp, they are synchronized using another spread-spectrum radio link that transmits timing information between the signal heads.

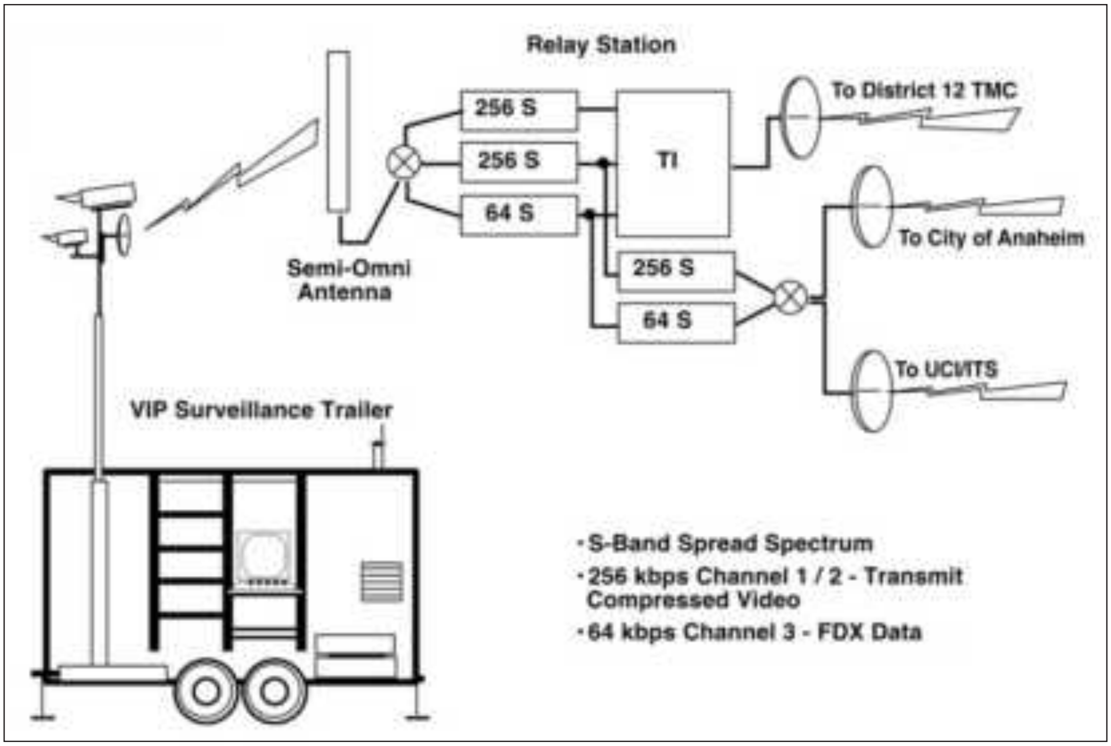
Communication between the surveillance trailers and the data collection and analysis site is provided by the relay site through the use of two spread-spectrum radio channels (64 kbps data channel and a 256 kbps digitally compressed video channel). Management of the entire communications network is provided by a Wide Area Communications Control subsystem (WACC) that has nodes in each trailer type and each data collection and analysis site. Each node comprises an array of ruggedized single-board computers running application-specific software developed by Iron Mountain Systems, Inc.

The WACC subsystem is responsible for efficient delivery of control commands and data to their intended destinations, as well as keeping track of equipment status. It also manages the two radio channels available for transmission of digitized video from any two of the surveillance trailers. The selection of the two video sources is controlled by the operator at the data collection and analysis site. The WACC system's management of Caltrans District 12 TMC Front End Processor (FEP) poll commands and polled 170 controller response is transparent, i.e., no difference is discernible by the FEP and 170 controllers between the spread-spectrum channel and corresponding VIP data and existing land-line channels.

An omnidirectional antenna located at the relay site provides for reception and transmission of signals between the surveillance trailers and the relay site. This antenna supplies flexibility in trailer location within the FOT area of operations. The mainlobe of this 18.1 dBi gain antenna is 240 degrees (horizontal) by 2 degrees (vertical). Data from all the trailers (transmitted over the 64 kbps data channel), and digital video from the two remotely selected trailers (via the 256 kbps video channel) are multiplexed and transmitted to the Caltrans District 12 TMC from the relay site over a T1

Ramp-metering trailers with signal heads (front) and mobile surveillence trailers (rear)

Trailer and relay site communications schematic



Mobile surveillance trailer at onramp on I-5

spread-spectrum radio link. The aggregated trailer data and one channel of video are also combined for simultaneous transmission to the Anaheim TMC and the UC Irvine Institute of Transportation Studies fixed sites

The FOT consists of two tests, both aimed at assessing the technology, transportability, cost, and institutional issues associated with use of the system. Test 1, in a freeway setting, involves six surveillance and three ramp-metering trailers, and is being conducted along the Santa Ana Freeway (Interstate 5). Test 2, assessing video surveillance for special-event traffic management, involves three surveillance trailers and is being conducted by the City of Anaheim during Mighty Ducks games at the Arrowhead Pond hockey arena. (Test #2 has not involved the VIP simulation of loop detection.)

In addition to all immediate benefits from the test to Caltrans District 12 and the City of Anaheim, we anticipate that UC Irvine Institute of Transportation Studies and other New Technology partners will use the capabilities of our trailers for operational activities of the Advanced Transportation Management System Testbed, including research implementations of traffic management algorithms and control strategies.

Vehicle Signature Detection Using Standard Loop Detectors

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upstream station to the downstream station. Different statistical methods in system identification are employed to minimize errors in classification. Section-related measures result straightforwardly from the result of correlating vehicles. Once the identification and reidentification are done reliably, individual travel time becomes simply the difference between the time the vehicle appears at the downstream station from the time it appeared at the upstream station. Speeds are obtained from the known section length and the travel time. Section densities are calculated on the basis of comparison of consecutive numbers, which are known because the ingress/egress points of the system are fully instrumented. Platoon and average conditions are also easily derived.

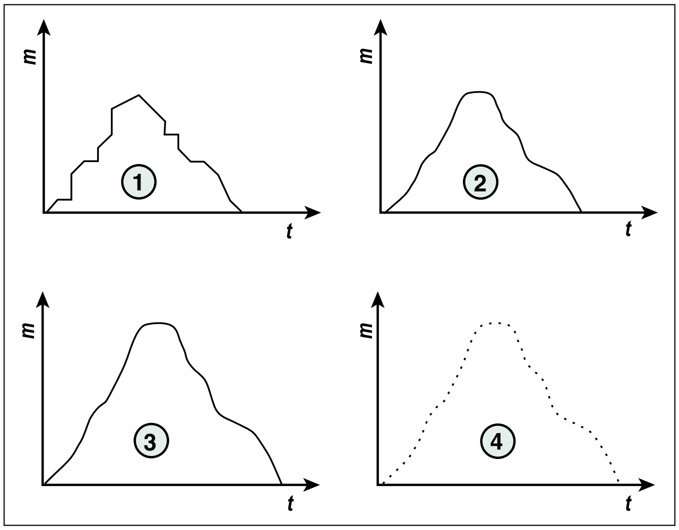

Figure 3 – Steps in vehicle signature feature extraction and data reduction process: 1. Full sample (actual data is discrete) 2. Low pass filtering and data smoothing 3. Amplitude normalization using wavelet transformation power spectrum and speed normalization 4. Data reduction

In addition to section-related measures of traffic system performance, there are also auxiliary benefits to using the signature detection approach. With conventional “hardwired” loop cards, the change in inductance that indicates the presence of a vehicle — the threshold — must be set correctly. If the threshold is set too low, some trucks can be double counted. If set too high, some vehicles can be missed. Vehicles traversing lanes are often double counted or missed. Moreover, weather-induced corrosion may change a loop’s inductance below the set hardwired threshold.

High-speed scanning detectors, however, output some type of change in inductance for every vehicle passage. This allows the development of software to interpret and handle any irregularities. (For example, two small simultaneous inductance changes in detectors for adjacent lanes may indicate a vehicle traversing both lanes.) It may now be possible to accurately measure all vehicles, which would be extremely useful for free-flow incident detection. Weather-induced changes can be easily handled in software, enhancing robustness and tolerance to faults. With this type of signature card, it is now possible to quickly traverse the loop with a vehicle of known signature to periodically access the “health” of the loops.

The results of our research show that implementation of such a system will be both feasible and cost-effective. By using the current infrastructure, consisting of standard loops and controllers, costly customization is avoided. Traffic conditions can be improved through the use of such a system, and the travelers will reap the ultimate benefits.

Ground-truthing: video data is time-stamp synchronized to loop data

Advanced Imaging Techniques for Traffic Surveillance and Hazard Detection

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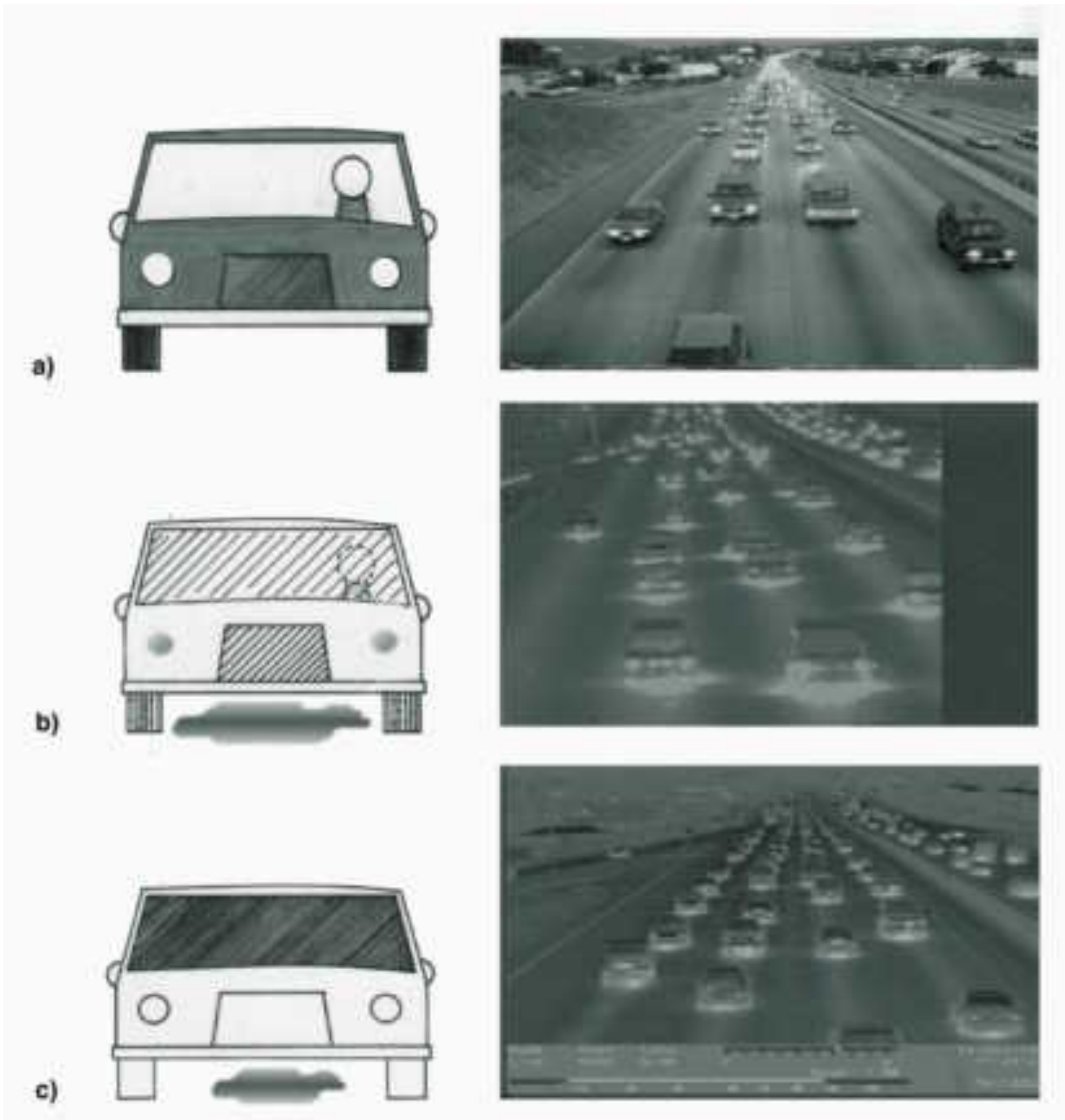
atmospheric transmissivity or camera performance metrics. Backscatter from sunlight, streetlight, or headlight illumination appears to be the dominant visibility-reducing factor as fog density increases. Backscatter tends to follow forward diffusion (a transmissivity-reducing factor), so that useful information content in the image declines approximately as the inverse square of fog density. In view of this, it is not surprising that many of the most serious fog-related traffic accidents have occurred in conditions of darkness or twilight.

The LWIR (8-12 µm infrared) and millimeter wave (94 GHz) bands offer a significant advantage under combined conditions of darkness and fog. Images formed in these bands are based almost exclusively upon the product of the black-body temperatures and surface emissivities of objects in the field of view: backscatter is not a factor. LWIR images appear to be virtually immune to headlight or streetlight backscatter effects. With shorter wavelengths, specular (reflective) effects begin to dominate, and this advantage is lost. For example, SWIR

Figure 4 – Characteristics of images "seen" in various bands: a) Visible or Very Near Infrared (VNIR) , b) 3–5 µm Short Wave Infrared (SWIR), c) 8–12 µm Long Wave Infrared (LWIR)



daylight images often contain infrared shadows, similar to visible spectrum shadows.

The characteristics of VNIR images are so close to those of monochromatic visible spectrum images that there appears to be no discernible advantage for traffic monitoring, except perhaps covert surveillance with artificial VNIR illumination. Chromatic (frequency-specific) information is available only in the visible band, made possible by the highly developed human eye. In earlier studies, we found that color surveillance information is of significant value in traffic management operations.

During the course of our field studies, the performance, operating characteristics and features of each imaging device were also tested. Evaluation criteria included: imaging performance based upon standard video performance metrics, technical limitations, reliability, serviceability, and total system costs. A comprehensive database has been assembled for a videotape library (SVHS) of field imagery acquired using each system.

Some Preliminary Conclusions

Our work to date has confirmed superior imaging ability under obscured atmospheric conditions for some advanced technologies. Uncooled LWIR cameras seem to hold the greatest promise for highway applications, due to improved transmissivity and reduced backscatter in this band, and the lowest (present) cost among the available technologies. The high cost and limited lifetime of the mechanical cooling engine required for cooled detector technologies is expected to make these impractical for unattended roadway surveillance use. State-of-the-art advanced imagers offer the potential for improved surveillance capability and enhanced information content, but their inferior resolution, loss of chromatic information, inferior reliability (for cooled detectors), and exorbitant cost remain significant obstacles to practical implementation.

We tentatively conclude that these factors will limit the justification for deployment of these technologies to situations involving recurrent obscured atmosphere or adverse illumination (e.g., glare). Exceptions may be found for machine-vision applications, where immunity to shadows and consistent day/night images permit more robust image processing algorithms.

It is important to note the immature state of these technologies. Present high costs of uncooled LWIR focal plane arrays are primarily related to engineering and process considerations, and large reductions in cost and improvements in performance could reasonably be expected if manufacturers perceive adequate market potential. Since the highway surveillance market is potentially significant for these technologies, market volume and cost/performance are interrelated.

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PATH Presentations

Recent and Upcoming PATH Sponsored Presentations

IASTED International Conference on Artificial Intelligence and Soft Computing, Banff, Canada, July 27-August 1, 1997.
•Susan Y. Chao and Alice M. Agogino "Hazard Diagnosis in Intelligent Vehicle Highway Systems."

8th IFAC / IFIP / IFORS Symposium on Transportation Systems 97, Chania, Greece, June 16-18, 1997.
•Youngbin Yim "A Focus Group Study on AHS and Related Technologies."

American Control Conference, Albuquerque, New Mexico, June 1997.
• John Haddon "Evaluation of AHS Throughput using SmartCAP."
• Datta N. Godbole and John Lygeros "Tools for Safety-Throughput Analysis of Automated Highway Systems."
• Jason Carbaugh, Datta N. Godbole and Raja Sengupta "Tools for Safety Analysis of Vehicle Automation Systems."
• Randolph W. Hall and H.-S. Jacob Tsao "Capacity of Automated Highway Systems: Merging Efficiency."
• Alexander Kanaris, Petros A. Ioannou and Fu-Sheng Ho "Spacing and Capacity Evaluation for Different AHS Concepts."

7th Annual Meeting Intelligent Transportation Society of America, Washington, D.C., June 2-5, 1997.
• Ching-Yao Chan "Simulation of Vehicle Trajectories and Maneuvers in Vehicle-Following Collisions."
• Randolph Hall, Youngbin Yim, Stein Weissenberger "TravInfo Field Operational Test: Public-Private Partnership."
• Youngbin Yim, Jean-Luc Ygnace, Randolph Hall "Trends and Prospects of the Traffic Information Market."
• Youngbin Yim "Consumer Attitudes Toward Automated Highway Systems."
• Stein Weissenberger "TravInfo Field Operational Test: A Survey of Information Service Providers."
• James B. Michael "A Modeling Framework for Reasoning About Automated Highway System Development Paths."
• Raja Sengupta "Advanced Software Architecture for ATMS Applications."
• Andrew Segal, Ching-Yao Chan, James B. Michael "Fault Tree Analysis of Advanced Vehicle Control Systems."
• Mark Miller "TravInfo's Traveler Information Center: A Bridge Between the Transportation and Communications Worlds."
• Mark Miller "Analysis of Throughput Achievable with Automated and Manual Vehicles Sharing a Lane."
• Raghu R. Kowshik, Paul P. Jovanis, Ryuichi Kitamura "Real-Time Ridesharing: Does it Work? Results and Recommendations from Sacramento Area Field Operation Test."

Panel "Commuter Response to Real-time Traffic Information."
• Stein Weissenberger, panelist.
• Paul Jovanis, panelist.

Panel "Surveillance Data for Planning, Development and Operation."
• Stein Weissenberger, Organizer and chair
• Joy Dahlgren, panelist.

Panel "Evaluating AHS Concepts."
• James Misener, Moderator.
• Aleks Göllü, panelist.
• Mark Miller, panelist.
• Bin Ran, panelist.
• Randolph Hall, panelist.
• Matthew Barth, panelist.

INFORMS, Spring 97 Meeting, San Diego, California May 4-7, 1997.
• Baher Abdulhai "Universality of Freeway Incident Detection Systems, Beyond the Neural Network."
• Jacob Tsao "Entropy Optimization and Mathematical Programming."

The Society for Disability Studies, Minneapolis, Minnesota, May, 1997.
•James Marston, Reginald G. Golledge "Transit Use by the Blind and Vision Impaired."

Association of American Geographers 93rd Annual Meetings, Fort Worth, Texas, April 1-5, 1997.
•James Marston "Travel Behavior and Transit Use by the Blind and Vision Impaired."

11th Annual International Symposium on Aerospace / Defense Sensing, Simulation, and Controls (AeroSense '97) sponsored by SPIE, Orlando, Florida, April 22, 1997.
•Jim Misener, Raja Sengupta and Datta Godbole "Preliminary Study of the Application of Synthetic Vision for Obstacle Avoidance on Highways."

3rd International Conference of ITS Australia, Brisbane, Australia, March 11-14, 1997.
•Jean-Luc Ygnace and Youngbin Yim "Business Opportunities for Traveler Information Services in Europe and the U.S."

FHWA Model Deployment Initiative Workshop, San Antonio, Texas, March 20, 1997
•Stein Weissenberger "The Evaluation of the TravInfo Field Operational Test."

Office of Naval Research, Workshop on Intelligent Control, Monterey, California, March 17-18, 1997.
•Raja Sengupta "Fault Detection and Compensation, PATH Fault Management Research."

Western Regional Science Association 36th Annual Meeting, Big Island, Hawaii, February 23-27, 1997.
•Youngbin Yim "The Effects of Traffic Information on Travel Behavior."

The Second Asian Pacific Rim Transportation Development Conference, San Francisco, California, February 14-16, 1997.
• Ching-Yao Chan "Evolution and Trends in Vehicular Occupant Restraint Systems"
• Wei-Hua Lin "A Practical Method for Dynamic Traffic Assignment – Compromise Between User-Equilibrium and System Optimization."

Transportation Research Board's 76th Annual Meeting, Washington, D.C., January 12-16, 1997.
• David Lovell "Determining the Technical and Economic Viability of Automated Highways Systems."
• Tim W. Lawson "Using the Input-Output Diagram to Determine the Spatial and Temporal Extents of a Queue Upstream of a Bottleneck."

International Mechanical Engineering Conference and Exposition, Atlanta, Georgia, November 18-20, 1996.
•Seibum B. Choi "The Design of a Control Coupled Observer for the Longitudinal Control of Autonomous Vehicles."

The Need for Surveillance in Intelligent Transportation Systems

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detection-system cost and benefits. Some projects are attempting to extract more useful information from the existing detection infrastructure, and some are examining the development of new low power detectors capable of generating the maximum reproducible vehicle delineation features at the lowest deployment cost.

Karl Petty has demonstrated how travel time can be generated from the existing single loop infrastructure, as long as the individual conventional loop bivalent state "vehicle presence" data is reported with sufficient resolution (see Intellimotion 6.1). Other PATH researchers are developing an even more robust method of generating travel time based on vehicle length generated by dual loops – still using existing loop detector cards. Carlos Sun and Steven Ritchie are taking this a few steps further by assessing the vast array of additional information made possible by analyzing the change in inductance amplitude through the use of high resolution A/D cards (see p. 4). Jitendra Malik is seeing if he can mitigate the technical and computational expense of using existing side-mounted incident verification surveillance cameras to determine travel time through advanced image processing techniques (Intellimotion 6.1). As an offshoot of his work on alternative imaging systems, Art MacCarley is assessing the feasibility of using very inexpensive low power, fixed field of view, overhead-mount CCD cameras for vehicle re-recognition (see p. 6). In Anaheim, a partnership between Caltrans, UC Irvine, the FHWA, and Hughes has developed a prototype mobile video surveillance and ramp metering system. (see article by Lawrence Emerson, p. 10). At UC Davis, Harry Cheng and Ben Shaw are examining the use of a low power active laser and photodiode array to mitigate the effects of changing sunlight and vehicle-detector orientation on re-recognition. Some of these detection systems may be patented and eventually be brought out on the commercial market.

These surveillance systems can be used to directly generate both the volume and travel time parameters that appear to be key in ITS Measures of Performance calculations. Caltrans is closely following PATH's efforts in this field.

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Smart Call Box Field Operation Test Evaluation: Summary Report, James H. Banks, Patrick A.D. Powell, January 1997, $10.00
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