Abridgment

Evaluation of Video Image Processing Systems for Traffic Detection

CARL A. MACCARLEY, STEPHEN L. M. HOCKADAY, DANIEL NEED, AND SAMUEL TAFF

Recent advances in microprocessor technology have made possible the cost-effective computer processing of video images of highway traffic for measurement of traffic speed, volume, and density. Video image processing systems (VIPS) are now being considered as key components of advanced traffic management systems (ATMS). Eight commercially available or prototype VIPS were recently evaluated for effectiveness at the request of the California Department of Transportation. Test procedures were intended to duplicate conditions typically encountered on California freeway systems. A summary of the test results is reported. Most systems performed well under optimum conditions but degraded significantly under nonoptimum conditions, which varied from system to system. On the basis of the VIPS systems studied, this technology is considered feasible for specific traffic monitoring problems. Limitations and areas for further development are identified.

Using computer vision technology to determine traffic flow data from video images is considered an important enhancement and valuable component of advanced traffic management system (ATMS) strategies. Several commercial or near-commercial systems are now available. Our study examined the current (1990–1991) state of the art in traffic VIPS technologies.

At the time of the study, 10 commercial or prototype VIPS were found to be available in the United States, Europe, and Japan. These are presented in Table 1. All manufacturers listed, except Hitachi Ltd. and Sumitomo Ltd., participated in the study.

These systems were designed to detect some subset of the basic traffic flow parameters: instantaneous and time-average vehicle speed, vehicle density per mile, mean headway, lane occupancy, and accumulated vehicle count. Traffic volume and mean headway may be inferred from the other metrics. These data are usually reported on a per-lane basis, sometimes with full-roadway averages provided. Our study targeted the ability of the systems to count vehicles and determine individual vehicle speeds as the primary metrics of performance.

All systems were software-based. Some required specialized hardware platforms, others ran on IBM PC-compatible platforms requiring only video digitizing cards for the camera interface. The core of the software task involved some algorithm for detecting each vehicle and measuring its velocity (*1–5*).

C. A. MacCarley, D. Need, Electronic and Electrical Engineering Department, California Polytechnic State University, San Luis Obispo, Calif. 93407. S. L. M. Hockaday, S. Taff, Civil and Environmental Engineering Department, California Polytechnic State University, San Luis Obispo, Calif. 93407.

Although the objectives of the project did not include analysis of detection algorithms, setup and operation of each system clearly identified two fundamental algorithmic approaches. We designate these as Types 1 and 2 and segregate the systems on the basis of algorithm type, as indicated in Table 1.

Type 1 algorithms involve detection of the time difference of light-level changes between two virtual gates in the image, spaced a known physical distance apart. A vehicle moving down each lane causes an intensity change at the first gate, then at the second gate. This pair of events is interpreted as the passage of a single vehicle. The vehicle velocity is determined by measurement of the time between the two gate-crossing events.

Type 2 algorithms might be referred to as vehicle tracking algorithms since they first detect the presence of a cohesive object moving in the image and then measure the velocity along its trajectory. Type 2 algorithms are generally more sophisticated and require significantly greater computer processing power. They are similar to military target tracking algorithms.

All algorithms tested were designed to handle oncoming traffic, although most could handle departing traffic also. Detection of departing traffic is possibly a more reliable approach.

All systems used monochrome video images and were designed to operate with standard monochrome surveillance video cameras. Systems manufactured in the United States and Japan used the Electronic Industry Association (EIA) 170 video format. Systems manufactured for use in Europe conformed to the International Radio Consultive Committee (CCIR) video format; some were provided in EIA format for the U.S. market.

TEST PROCEDURES

The use of a real-time video feed of freeway traffic was unfeasible for the nature and scope of the test performed. Therefore, videotaped traffic images were used.

TABLE 1 VIP Systems Evaluated

Company	Status	Algorithm Type	Video Format
ASPEX	prototype	1	EIA
CRS	commercial	1	EIA
Devlonics	commercial	1	EIA
Eliop	prototype	2	EIA
Hitachi	prototype	N/A	EIA
ISS	commercial	1	EIA
INRETS	prototype	2	CCIR
Sense & Vision Systems	prototype	2	EIA
Sumitomo	prototype	N/A	EIA
University of Newcastle	prototype	1	CCIR

Two self-contained mobile video data acquisition units were constructed. Each contained two super-VHS format professional video recorders interfaced with two video cameras, frame number encoders, and monitors, providing concurrent EIA and CCIR format recording and indexing capability. Solid-state metal oxide semiconductor/charge coupled device (MOS/CCD) cameras were used, with variable focal length lenses and mechanical aperture adjustments. Certain night tests substituted specialized MOS cameras, which were less prone to a problem associated with CCD cameras known as vertical smearing, in which vertical white lines appear to extend from vehicle headlights. The two mobile units were operated simultaneously at each data collection site, recording concurrent traffic images from two camera positions.

A suite of 28 test conditions was defined for evaluation of the systems, described in Table 2. This collection of images was intended to emulate actual field conditions that would be encountered during 24-hr, year-round service on California urban freeways. Parameters included day and night illumination levels, variable numbers of lanes (2 to 6), various camera elevations and angles to the roadway, rain and fog conditions, camera vibration and sway, traffic conditions ranging from free flow through heavy congestion, shadows from vehicles or stationary objects, and the effects of simulated ignition noise and 60 Hz electromagnetic noise combined with the video signal. Tests were performed on approaching and departing traffic. As a practical matter, included in the test suite were only those combinations of variables most representative of standard deployment scenarios. Table 2 indicates the parameter or combination of parameters emphasized in each of the 28 standard tests.

The test suite was created by editing several hundred hours of raw video collected over the course of a year. Each test segment is 20 min long. This includes a 10-min initial period to permit the system under test to cancel the background and adapt to the ambient light level. Actual traffic counts and vehicle velocities on a per-lane basis were determined by inspection of the videotaped images over the duration of each segment. Frame-by-frame inspection was employed for accurate velocity measurements and vehicle counts.

Most systems were designed for camera placement directly above the roadway centerline at a height of 10 to 15 m. A high camera position minimizes vehicle occlusion but is more prone to sway and vibration. A centered camera minimizes perspective distortion. A roadside placement is easier to install and maintain and provides a greater field of view.

All test images were acquired from freeway overpasses, with cameras placed on both the roadway centerline and off to the side. This duplicates the placement of surveillance cameras anticipated by the California Department of Transportation (Caltrans) in the Los Angeles area. Camera heights for the 28 test conditions varied from 8.3 to 14.2 m above the roadway surface, measured with an ultrasonic range finder.

Lenses for both camera placements were selected to permit all traffic lanes (in one direction) to be contained in the field of view.

All systems were set up and calibrated to the manufacturer's specifications; manufacturer representatives were present in most cases.

A qualitative evaluation of system human factors was also performed, considering issues of ease-of-setup and use, quality of graphical interface, and sensibility of data display. System reliability was not specifically evaluated, but observations relating to it were recorded and reported.

TABLE 2 Summary of Test Suite

Test #	Parameter Tested
1	Large # of Lanes
2	Small # of Lanes
3	Day to Night Transition
4	Shallow Camera Angle
5	Steep Camera Angle, Departing Traffic
6	Shallow Camera Angle, Departing Traffic
7	Night, Steep Camera Angle, Approaching Traffic
8	Night, Shallow Camera Angle, Approaching Traffic
9	Night, Steep Camera Angle, Departing Traffic
10	Night, Shallow Camera Angle, Departing Traffic
11-18	Same as 3-10(above), Side Camera Mounting
19	Weather - Fog
20	Weather - Rain, Daytime
21	Weather - Rain, Night time
22	Unstable Camera Mount - Sway
23	Heavy Traffic - Capacity Operation
24	Congested traffic
25	Heavy Shadows from Vehicles
26	Heavy Shadows from Environment
27-28	Ignition and Electromagnetic Noise

EVALUATION RESULTS

Figure 1 summarizes the average performance of the systems, classified by algorithm type. Shown are group average detection accuracies relative to each test condition and in performance categories. For all systems, we observed error rates usually less than 20 percent for vehicle count and speed measurements over a mix of low, moderate, and high traffic densities, with optimum camera placement and clear, daylight, nonshadow conditions. Complete numerical results of all tests are included in the project final report (*6*).

Systems designed for very high camera placement were usually intolerant of partial occlusion of vehicles, yielding high error rates for tests with lower camera heights.

Tests with slow-moving high traffic densities usually yielded reduced accuracy and occasionally complete detection failure, probably because of the action of the particular background subtraction algorithm employed. These situations were emphasized in Tests 23 and 24 (Table 2).

Light-level changes at sunrise and sunset caused reduced accuracy. During these periods, most systems make a transition from daytime algorithms, which detect entire vehicles, to nighttime algorithms, which detect headlight groups. To some degree, this was a notable area of weakness for all systems tested as this area is suggested for further study, because peak traffic periods usually coincide with sunrise and sunset.

Tests 21, 25, and 26 (Table 2) emphasized two aberrant conditions that caused particularly high error rates for most systems: rain at night and long vehicular and stationary shadows. Long shadows are a particular problem at sunrise and sunset, adding to the transition difficulties just mentioned. Headlight reflections from a wet roadway, especially in low-light conditions, cause similar detection errors. These problems are related in the sense that they challenge the ability of the systems to discriminate actual vehicles from other moving areas of high contrast (either light or dark) in the camera image.

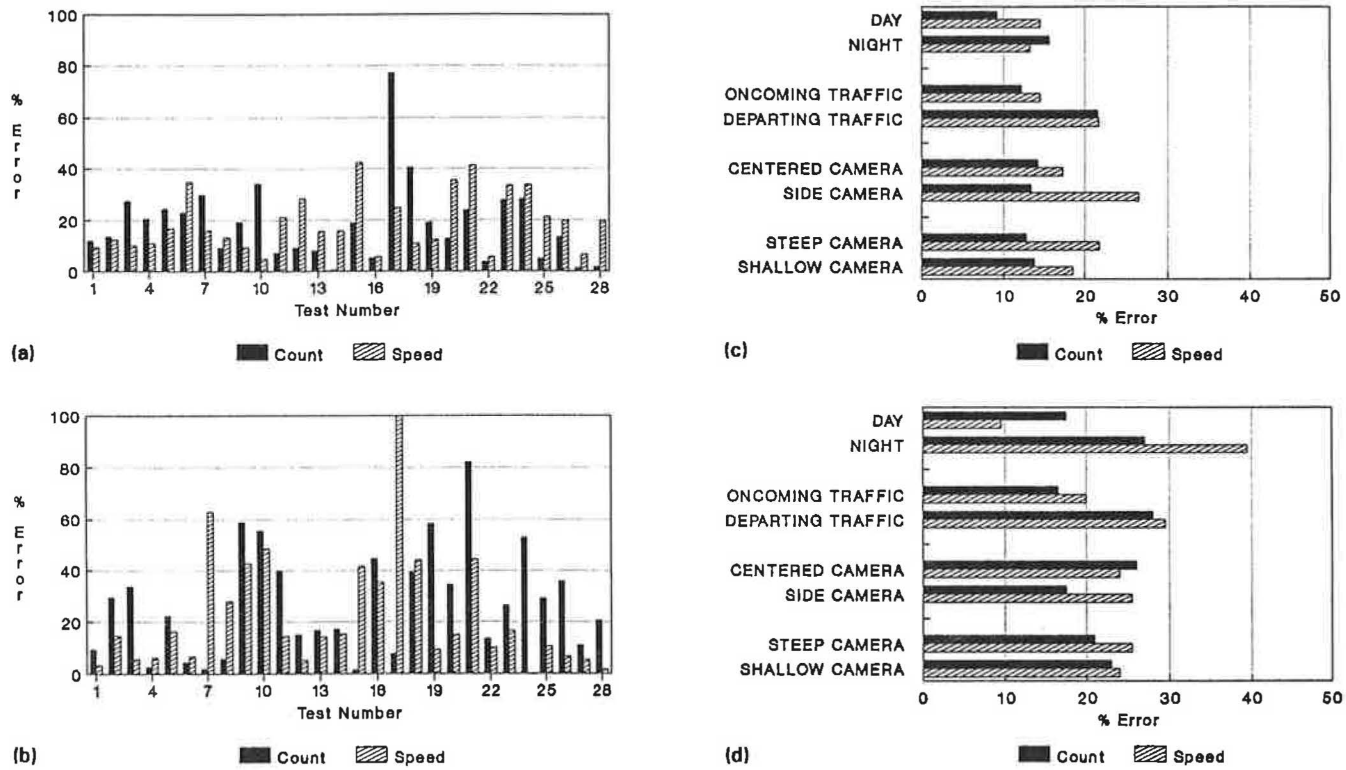

FIGURE 1 Summary of test results: average absolute error by test for (*a*) Type 1 systems and (*b*) Type 2 systems; average absolute error by grouping for (*c*) Type 1 systems and (*d*) Type 2 systems.

Type 1 algorithms attempt to cancel headlight reflections and vehicle shadows by rejecting detection events that occur in too brief a time interval. Type 2 systems attempt to correlate a shadow or reflection with an associated vehicle. However, the source of the shadow or light may be outside the field of view, for example, a car off the detected area of roadway, aircraft overhead, or the shadow of a tall object or tree. In these situations, both algorithm classes usually fail.

The effects of added electronic (ignition) noise were also studied in Tests 27 and 28. Generally, low noise levels had little effect on count or speed accuracy up to a threshold at which detection failed completely. A similar observation for atmospheric fog was made in Test 19.

At the time of the study, only three of the systems were available commercially for "immediate installation." All used Type 1 algorithms.

CONCLUSIONS AND RECOMMENDATIONS

Under optimum daytime conditions, the Type 1 systems generated more accurate vehicle counts and the Type 2 systems generated more accurate speed measurements. Under optimum conditions, no system was clearly superior to the others. Aberrant conditions yielded high error rates for both algorithm classes. Overall, Type 1 systems showed somewhat lower error rates in both vehicle count and speed measurements. However, it should be noted that the Type 2 systems studied were prototype versions at the time.

Conditions that degraded the performance included the following:

1. Nonoptimum camera placement,
2. Transition from day to night,
3. Headlight reflections on wet pavement,
4. Shadows from vehicles or objects outside the detection area, and
5. Obscured atmospheric conditions (fog or heavy rain).

System costs have fallen significantly from 1989 to 1992; quantity prices for commercial systems are now projected at under $5,000 (U.S.). As more commercial products become available, costs should approach that of the processing hardware.

Specifications should be developed for field installations to simplify deployment and maintenance activities. Links to traffic operation center (TOC) technologies should also be designed into systems to avoid telecommunications problems. Compatibility with video data compression algorithms is also recommended as an area for development, because signals from field-deployed cameras may be transmitted to a TOC in compressed format.

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