Vehicle Detection Video Through Image Processing: The Autoscope System

Panos G. Michalopoulos

Abstract—**Vehicle detection by video cameras is one of the most promising new technologies for wireless large-scale data collection and implementation of advanced traffic control and management schemes such as vehicle guidance/navigation. In this paper, recent worldwide developments concerning such detection systems are mentioned, and the one developed in the United States, Autoscope, is described. This includes earlier work leading to Autoscope's present state and its advantages over other emerging devices. Recent progress such as preproduction line prototype development, field testing and plans for extensive field validation and verification are also presented. The latter include two large demonstration projects recently initiated in Minneapolis. In the first project, Autoscope will be used for incident detection over a section of Interstate 394. The second project involves implementation of the machine vision system at a signalized intersection.**

I. Introduction

As the problem of urban traffic congestion spreads, there is a pressing need for the introduction of advanced technology and equipment to improve the state-of-the-art of traffic control. Increased research and development funding worldwide resulted in a plethora of new concepts and ideas to meet this objective. However, vehicle detection is the weakest link in implementing the most sophisticated traffic control concepts that have surfaced over the last several years. Detection through video image processing is one of the most attractive alternative new technologies, as it offers opportunities for performing substantially more complex tasks than wireless detection. This concept entails detection of vehicles and extraction of traffic parameters in real time from images generated by video cameras overlooking a traffic scene.

Because of its conceptual appeal, major worldwide efforts have been initiated for developing a practical device. Development of a wide-area multispot video imaging detection system, called Autoscope, was initiated at the University of Minnesota in 1984. Following funding from the Minnesota Department of Transportation (DOT), the Federal Highway Administration (FHWA), and other internal sources, a fieldable preproduction line prototype was only recently completed and demonstrated in live benchmarks in several U.S. and European cities.

In an earlier publication [1] the breadboard system design of Autoscope is described along with preliminary laboratory test results. In the present paper, recent developments concerning Autoscope are presented along with technical details related to the detection approach and field implementation. The new elements include development of the preproduction line prototype, field testing and demonstrations. The latter are being implemented through two projects recently initiated in Minneapolis. In the first project, the Autoscope system is being demonstrated in a large scale and tested extensively for robustness and reliability under continuous operation for six to nine months at three freeway locations and compared with loops. In addition to these tests, software for automatic incident detection is being developed for implementation on Interstate 394, currently under construction in the Minneapolis–St. Paul metropolitan area. A system of approximately 38 coordinated cameras will be used for implementing the incident detection portion of the project. This system will also provide a unique large-scale laboratory facility for studying traffic characteristics. The second project involves implementation of the machine vision system at a signalized intersection and interfacing it with the controller for demonstrating its capability to replace loops.

II. Background

Vehicle detection appears to be the weakest link in traffic surveillance and control. Although detection equipment is available today for sensing vehicle presence on the roadway, it essentially employs technology of the late 1950's, has limited capabilities, presents reliability problems and more often than not requires extensive and expensive installation for truly traffic-responsive control. The latter is particularly true in state-of-the-art surveillance and control systems, which often involve large-scale street or freeway corridor networks. With respect to reliability, it is noted that most cities with mature systems in the U.S. report that at any time 25 to 30% of their detectors are not functional or operating properly at any time.

Perhaps the most important drawback of existing detectors is their limitation in measuring some important traffic parameters and accurately assessing traffic conditions. This is because the technology employed represents a "blind" type of detection, i.e., only the presence or absence of vehicles over the detectors can be assessed with sufficient accuracy. Traffic parameters such as speed, traffic composition, queue length, etc. must be derived from presence or passage and require multiple detection which increases cost and exacerbates the reliability problems mentioned earlier. Furthermore, common detectors (such as loops) do not have visual surveillance capabilities, and their placement is not flexible, i.e., they detect traffic only at fixed points.

Among the most promising new concepts today for effective wireless vehicle detection is through video cameras (machine vision). A machine vision system for vehicle detection consists of an electronic camera overlooking a long section the roadway; from the images received by the camera, a microprocessor determines vehicle presence or passage and derives other traffic parameters preferably in real time. Fig. 1 depicts schematically the preproduction line prototype configuration of the video detection system described in this paper.

The concept of using video image processing for traffic surveillance and control is not new. Because of its conceptual

Manuscript received August 1990.

This work was supported by the Minnesota Department of Transportation, the Federal Highway Administration, and the Center for Transportation of the University of Minnesota.

The author is with the Department of Civil and Mineral Engineering, University of Minnesota, 500 Pillsbury Drive, S.E., Minneapolis, MN 55455.

IEEE Log Number 9040761.

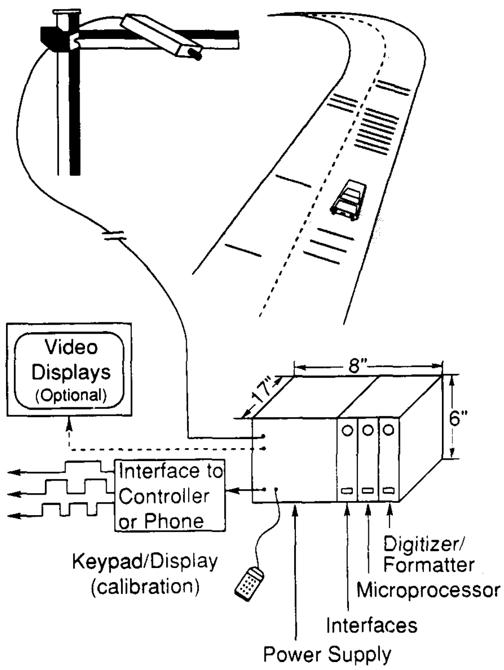


Fig. 1. Real time Autoscope fieldable configuration.

appeal, research in this area was initiated in the mid-1970's in the United States and abroad, most notably in Japan, France, Australia, England, and Belgium [2]–[13]. Despite the major worldwide efforts to develop a machine vision system for traffic surveillance and control, a *real-time* fieldable device having the capabilities and performance required for practical applications has been elusive. Even though claims to the contrary have surfaced in recent years, to the best of the author's knowledge, concrete functionality performance and reliability verification is still lacking. Because of this, no practical installations are currently known; the few that exist appear to be experimental. It should be pointed out, however, that recent advances in image processing, electronic cameras, special purpose computer architectures, and microprocessor technology, have made the machine vision alternative for vehicle detection attractive, economical, and promising. A detailed description and critique concerning the most notable worldwide developments in vehicle detection through video image processing is presented in [1]. Briefly, the major problems with existing systems that have been addressed and resolved by Autoscope are as follows.

1) Automatic adaptation to a wide variety of roadway backgrounds without reference marks: The inability of existing systems to automatically adapt to a wide variety of backgrounds prevents them from running reliably or autonomously. A unique approach to estimating the background at the detection spot was therefore developed; this allows automatic adjustment to any uniform or nonuniform road surface without any operator intervention at startup or while running.

2) Operation in the presence of common artifacts such as shadows, illumination changes, and reflections: Prior approaches have not addressed common artifacts such as shadows, illumination changes, and reflections. This has resulted in these systems having high false alarm rates under these conditions. In the system presented here, these problems were resolved using a vehicle signature based detection approach that can differentiate vehicles from these artifacts.

3) Operation in congested or stopped vehicle conditions: Congested traffic conditions and stopped vehicles have caused the loss of the vehicle and erroneous background estimation in prior approaches. The Autoscope approach only updates the background estimates when the vehicles are not present and allows vehicles to stop for much longer periods of time without "blending" into the background.

4) Arbitrary placement of any type of detector in any configuration anywhere within the camera's field-of-view: Most existing systems only support a small number of fixed position detectors. Autoscope has the ability to place any number, size, and shape detection spots anywhere in the camera's field-of-view and is able to reposition these spots dynamically under software control. This is accomplished without requiring the camera to be placed at a fixed geometry (e.g., height or angle).

5) Cost effectiveness, real-time operation, and programmability: Existing approaches to cost-effective real-time implementations have resulted in oversimplification of the sensor, hardwiring the detection processing, or using cost-prohibitive processors. Cost effectiveness was a major consideration in the development of the Autoscope detection system. The system can operate off standard video cameras; no specialized sensors are needed. The Autoscope system allows operation in real-time while still being fully programmable. This has been accomplished using a single specialized image preprocessor, and then using a single microcomputer for all of the remaining processing. By using an IBM 386 compatible personal computer rather than an expensive image processing platform, it was demonstrated [1] that the final system implementation is cost-effective.

Research concerning the Autoscope's feasibility and breadboard fabrication began at the University of Minnesota in 1984 [14]. Funding was initiated by the Minnesota Department of Transportation through two successive projects: 1) feasibility, and 2) breadboard fabrication. In 1987 the FHWA awarded the same research team a contract for further detection algorithm development especially in the presence of artifacts; such artifacts include rain, snow, nightime conditions, camera motion, fog, shadows and their various combinations. Following the successful completion of these projects, a breadboard Autoscope system was developed, tested, and successfully demonstrated in live benchmarks in several North American and European cities.

III. Autoscope Functions and Operation

The vehicle detection system described here can detect traffic in many locations (i.e., multiple spots) within the camera's field-of-view. These locations are specified by the user in a matter of minutes using interactive graphics and can be changed as often as desired. This flexible detection placement is achieved by placing detection lines along or across the roadway lanes on a TV monitor displaying the traffic scene. Therefore, these detection lines are not physically placed in the pavement but only on the TV monitor. Every time a car crosses these lines, a detection signal (presence or passage) is generated by the device. This signal is similar to that produced by loop detectors. However, the advantage is that, in addition to the wireless detection, a single camera can replace many loops, thus providing true wide-area detection and cost-effectiveness.

Because of this design, the video imaging detection system described here can be installed without disrupting traffic operations. Furthermore, it is not locked to a particular detection

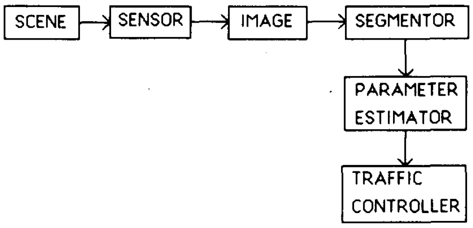


Fig. 2. Basic steps in the imaging process.

configuration. The detection configuration can be changed manually or dynamically (i.e., by software as a function of traffic conditions). Finally, it can extract traffic parameters (such as queue lengths) that cannot easily or economically be derived by conventional devices (if at all). Because of these features, this video detection system leads to the advanced traffic surveillance and control applications as described in the next section.

It is worth noting that in addition to simple detection, the device of Fig. 1 in its present form also performs traffic parameter extraction.

IV. Vehicle Detection Approach

Vehicle detection is the basic function that must be performed by the Autoscope system before any other parameters can be estimated. The basic approach addresses how it is done in a generic way. This is shown in Fig. 2. Every point in a scene (X, Y, Z) at time t is represented by $S(X, Y, Z, t)$ and describes the energy, intensity, or reflectivity at the scene. A visible camera views the scene and generates an image of the scene described by the function $I(x, y, t)$. This image is generated at 30 frames per second, and each frame has two interlaced fields. Assuming that there are 512 lines per frame, each line is digitized and represented by 512 pixels (picture elements), and each pixel is represented by eight bits, we have an enormous number of bits to process ($512 \times 512 \times 8 \times 30 = 62\,914\,560$ b/s or 7 864 320 bytes where 1 byte = 8 b). A single frame has 262 144 bytes, which means a 256 kbyte RAM is insufficient to store one frame. From the storage point of view, this process is costly, while from the computational point of view, it is time-consuming, i.e., we cannot afford to process every frame and all of it. Thus, selecting windows of every nth frame makes storing and real-time processing feasible. Once the window is selected, the segmentor estimates the background in the absence of vehicles and the detector detects the presence of vehicles. The easiest way to do this is to estimate the statistics of the background from which a threshold is determined. Then the instantaneous image at every pixel is compared with this threshold and if it is greater, it means that a vehicle is present. The performance is measured by the probabilities of detection and false alarm, which are determined through testing and comparison with ground truth. From this, vehicle passage and speed are estimated and traffic parameters determined.

The dominant design parameters for efficient detection employed by Autoscope are sensor configuration, processing algorithms real-time implementation, and artifact treatment. The detector configuration employed includes the equidistant crosslane linear arrays (EDCLA), the isolated crosslane doublet and the downlane linear array. These three configurations have several advantages. The EDCLA affords good single spot detection on each $1 \times n$ linear array and provides more global data for discerning global illumination changes. The isolated crosslane doublet has the least data to process, but requires more sophisticated digital processing to achieve presence detection and velocity estimation. The downlane linear array offers a long longitudinal coverage.

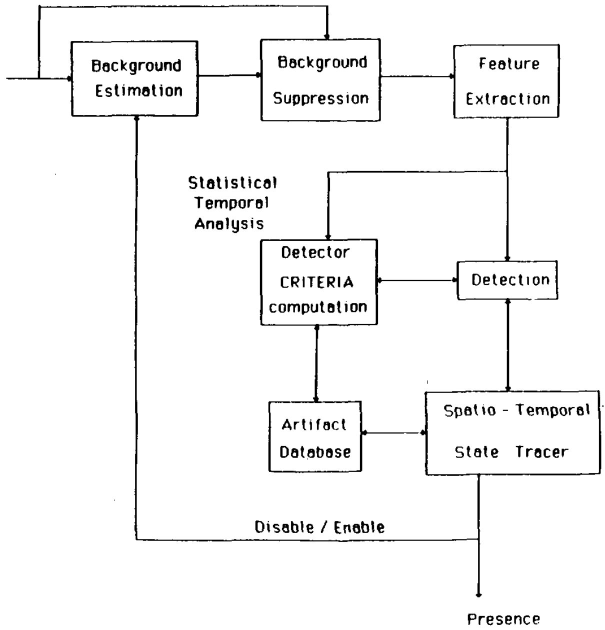


Fig. 3. Vehicle detection algorithm approach.

The algorithm approach for the detection of vehicle presence using Autoscope is depicted by the block diagram in Fig. 3. The first level of processing is responsible for reduction of the data received from the detector to a series of features or measures characterizing the data. The next level of processing processes the extracted features and generates groups of binary decision values. These decision values are subsequently reviewed at the highest processing level, where the current traffic parameter states are determined from the time procession of the generated binary values.

In the first block an estimate of the background detector signature is accrued from a finite impulse response (FIR) filter of the form:

$$BE(j, k) = cl\, I(j, k) + (1 - cl)\, BE(j, k - 1); \quad (1)$$

where j denotes the detector element index ($1 \le j \le$ number of detector elements), while k and $k - 1$ denote the current and previous background update time, respectively. Further, there exists an enable/disable control which comes from a higher level function of the presence detection algorithms, termed the spatio-temporal state tracker, which is responsible for making the final decision as to vehicle presence or absence.

In the background supression block, the current background estimate is subtracted from the incoming detector data. This has the effect of eliminating any characteristics of the background data, which might otherwise pose confusion for the vehicle presence detection algorithms. Typical background characteristics make necessary the background suppression processing; such characteristics include transitions in the road surface between bituminous and concrete, snow packed and bare pavement, and shadowed road surfaces.

Once the detector data have been reduced to a selected set of

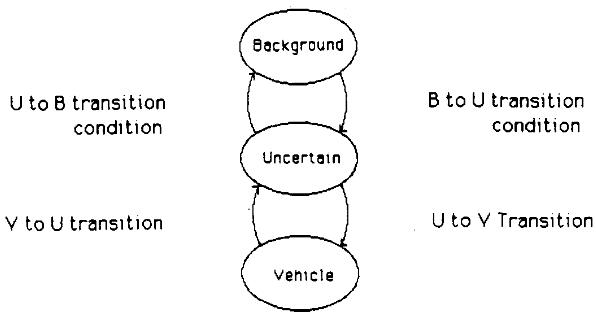


Fig. 4. State tracker concept.

features, the next level of processing transforms the set of feature measurements $(F1, F2, \cdots, Fn)$ to a corresponding set of instantaneous logic states $(S1, S2, \cdots, Sm)$. These logic states indicate the presence or absence of important conditions in the detector footprint.

The final stage, and highest level, of vehicle presence processing consists of a tracker module which coalesces the time series of decision states into a high confidence presence signal. To achieve a high confidence decision based on the series of individual decision states for the spatial and temporal features, the tracker module utilizes sequential decision-making processes based on a finite state diagram; hence its name spatio-temporal state tracker. The concept of the state tracker is depicted in Fig. 4.

The tracker assigns the current state of the traffic monitoring system's observations to fall into one of three states; namely, background, undecided and vehicle. These three states are used to partition the decision space into three regions as shown in Fig. 4.

Before concluding this section, it is worth mentioning the general approach for treating some of the major artifacts such as shadows, vehicle reflections in the pavement, and transition periods. For fixed objects the effect of shadows was compensated for by the background suppression. For moving shadows, the compensation is based on detection of normal background signature modified by gain and/or bias phenomena.

The periods during which there is a transition in the background illumination were handled by the continuous adaptation within several stages of the presence detection processing. First, the background estimation continually updates the reference background signature against which vehicles must be discerned. Secondly, the feature detection criteria are automatically adapted to compensate for the decrease or increase in the various signature strengths, as measured through the extracted features. Finally, the operating condition database and the features extracted are used to adjust the vehicle presence detection system's global operating point by the selection of particular algorithms or merely parameter values, so that algorithm performance is optimized. The effects of corrupt visibility caused by rain, sleet, snow or fog are handled by the same adaptation processes.

V. Traffic Parameter Extraction

As one might expect, derivation of traffic parameters depends on the placement of the detection lines in the image received by the camera. Multiple detection is required for extracting all parameters.

From the presence and passage signals and individual vehicle speed measurement which are directly measured by Autoscope, it is possible to derive all the necessary traffic parameters required for traffic surveillance and control. This is of crucial importance since it reduces the need for additional algorithmic development and promotes a more flexible design, including the possibility of multiple processors.

The following discussion presents the formulas associated with either a single detection line or a segment in the Autoscope area; these are presented to illustrate how the required traffic measurements can be derived from presence and speed data. Extension for the entire detection area can easily follow. Referring to Fig. 5 define:

- s station (detection line) number;
- S total number of stations;
- n vehicle number passing over a station;
- l lane number;
- L number of lanes;
- Δx_s spacing between station s and $s+1$;
- T number of scanning intervals having duration Δt;
- t_{sln} time at which the nth car in lane l arrives at station s;
- v_{sln} speed of the nth car at station s line l;
- Q_{sl} volume at station s line l over period $T\Delta t$;
- Q_s total volume over all lanes at station s.

From the preceding notation the time mean speed at station s line l is

$$V_T = \frac{\sum_{n=1}^{Q_{sl}} v_{sln}}{Q_{sl}} \tag{2}$$

and over all lanes at s:

$$v_T = \left[\sum_{l=1}^{L} \sum_{n=1}^{Q_{sl}} v_{sln}\right] / Q_s. \tag{3}$$

The space mean speed is

$$\bar{V} = \frac{\Delta x_s}{\text{average travel time}} = \frac{Q_s \Delta x_s}{\sum_{l=1}^{L} \sum_{n=1}^{Q_{sl}} \left(t_{(s+1)ln} - t_{sln}\right)} \tag{4}$$

or alternatively

$$\bar{V} = \frac{\text{total travel}}{\text{total travel time}} = \frac{Q_s \Delta x_s}{\int_0^{T\Delta t} N_{st}\, dt} \tag{5}$$

where N_{st} represents the number of cars in Δx_s at time t, which can be obtained from longitudinal detection.

The value Q_{sl} during a time period $T\Delta t$ is easily obtained from the number of presence signals at station s line l. Thus P_{slt} represents presence on station s line l at time t; then $P_{slt} = 0$ when there is no car over station s line l and $P_{slt} = 1$ otherwise. The volume Q_{sl} will be incremented whenever the Boolean condition

$$P_{slt} \cdot \left[P_{slT} \oplus P_{sl(T-1)}\right] \tag{6}$$

is met. Stated otherwise, the total volume over the sampling period will be the accumulation of individual vehicle actuations (counts). Flow rate (in vehicles/unit time) is easily derived by dividing volume over the sampling period. Naturally, the volume entering and leaving the detection area is the volume measured over all lanes at the first and last station, respectively.

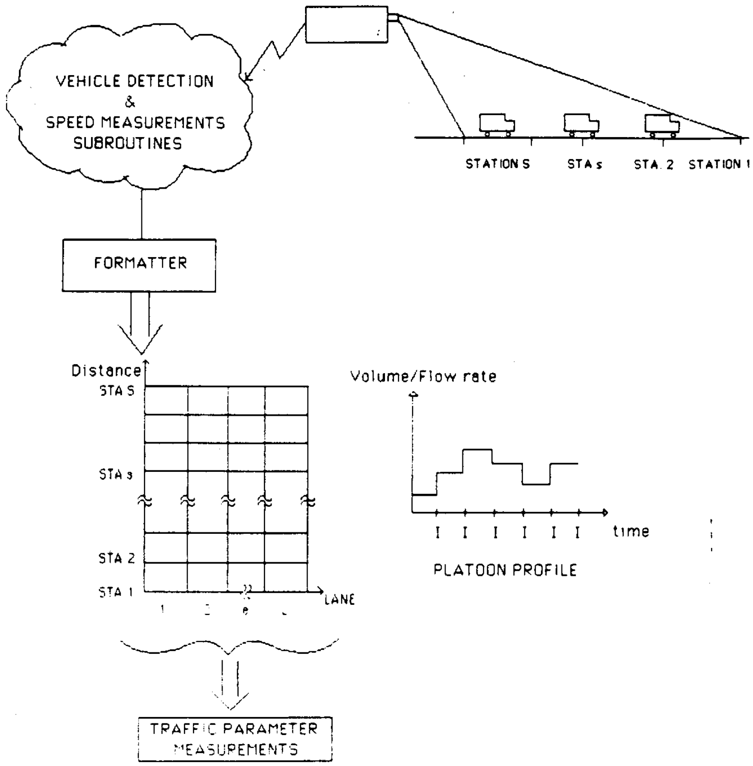


Fig. 5. Derivation of traffic parameters from Autoscope detection.

Lane distribution is also simple to obtain from volumes by calculating the ratio of the lane volume over the total volume. For instance, the lane distribution at station 1 lane 1 is

$$D_{11} = \frac{Q_{11}}{Q_1} = \frac{Q_{11}}{\sum_{l=1}^{L} Q_{1l}}. \tag{7}$$

Measurement of stops can be obtained from speed by setting a lane stop flag whenever it is determined that the speed at a detection station in the lane has fallen below a threshold value. The number of stops is incremented whenever a vehicle enters the Autoscope detection area in a lane in which the stop flag is set. The lane stop flag is reset whenever no stop is detected at any station in the lane.

The time headway H_{sln} is determined directly from the start of successive presence signals from

$$H_{sln} = t_{sl(n+1)} - t_{sln} \tag{8}$$

where t_{sln} is the time of arrival of the nth vehicle in line l at station s. Although it may not be necessary, space headway H_{sln} can also be measured from

$$H_{sln} = H_{sln} v_{sln}. \tag{9}$$

Headways may be accumulated over the sampling period to determine average values or they may be accumulated by class interval (integer multiple of Δt) to generate a histogram.

For generating platoon profiles an interval I must be defined as an integer multiple of Δt. The cycle length must be an integer multiple of I. Then the total volume (or flow rate) at any station and lane may be subdivided into a histogram as shown in Fig. 5. In short, platoon profiles are really a graphical representation of volumes or flow rates in time and space (stations) and do not require any special algorithm development.

Finally, occupancy is determined from the presence signals generated at each station. If P_{slt} is the binary representation of presence as defined earlier, then the area occupancy accumulated over T scanning intervals of Δt seconds is

$$0 = \text{area occupancy} = \left\{ \sum_{s=1}^{S} \sum_{l=1}^{L} \sum_{t=1}^{T} P_{slt} \right\} / (SLT). \tag{10}$$

It should be evident that occupancy over a lane or a single station is a special case of the preceding equation. For instance, occupancy in lane 1 station 1 is

$$0_{11} = \sum_{t=1}^{T} P_{11t} / T \tag{11}$$

and for the entire station 1

$$0_1 = \left[\sum_{l=1}^{L} \sum_{t=1}^{T} P_{1lt} \right] / LT. \tag{12}$$

VI. Field Testing and Validation

The performance of the Autoscope system is continuously evaluated as improvements are being made. Laboratory and field tests as of summer 1988 were presented in an earlier publication [1]. These were performed on almost 36 hours of videotaped data, and in two live cameras: one monitoring a freeway section and the other an intersection. In the live tests, all-day evaluations were performed. The 36 hours of videotaped data were selected from a video tape library of traffic sequences collected throughout the United States covering a large combination of artifact conditions (shadow, rain, snow, nighttime, reflection on cars or pavement, dusk, down, etc.) as well as congestion.

The on-line evaluations using live data were performed from cameras at the Mn/DOT Traffic Management Center (TMC). The results of the first all-day live evaluation, which was conducted in July 1988, are included in [1]. The present paper contains the results of the second all-day evaluation which was performed in January 1989. Between these two evaluations, improvements to the detection algorithms were made and tested in the laboratory using both video tapes and traffic sequences recorded on the optical video discs. The live evaluations required installation of the Autoscope system in the TMC which monitors freeway traffic in the Twin Cities at Minneapolis and St. Paul through 38 camera installations. The Autoscope system was connected with most of these cameras to allow visual inspection of the detection outputs.

The second all-day evaluation of the Autoscope system was conducted on Friday, January 27, 1989 at Mn/DOT's Traffic Management Center. System performance was sampled for 10 minutes out of each half-hour, starting prior to sunrise (6:30 AM) and proceeding until after sunset (6:00 PM). The goal of this evaluation was to measure improvements to system performance since July 1988 (the last all-day evaluation), and, at the same time, assess performance during the dawn and dusk rush-hours that occur during late fall and early winter. Due to the Mn/DOT camera placements, it was decided to concentrate this evaluation on freeway data. None of the camera placements are placed ideally for intersection detection nor close to heavily traveled intersections. Two video-based detectors were placed on the second and third lane of southbound I-35W just north of the 42nd street overpass in Minneapolis. Performance of the system was tabulated with a manual count of the correct, missed, and erroneous detections in the same manner as the July 1988 on-line evaluation, except no intersection evaluation was performed in January 1989.

The evaluation took into account passage (volume) detection to determine how well the system counts vehicles. Performance was measured by counting three variables, i.e., the number of correct detections (number of errors).

A correct passage detection was defined as a single turn-on of the detection signal that corresponded to a single vehicle. A missed passage detection was a vehicle that passed under the detector without the detector turning on. Finally, a false passage detection was a detector that turned on with no vehicle passing under it.

From these three counts, the detection and error rates were derived. First the total number of vehicles was determined, the sum of the total number of detected vehicles and the total number of vehicles missed. Then detection rate was computed as the total number of detections over the total number of vehicles, and error rate was the total number of errors over the total number of vehicles.

Table I compares the results from this all-day evaluation to the results of the July 1988 evaluation. In this evaluation, detection performance improved 1.4% and the error rate dropped by half a percent. Most importantly, performance was far more consistent across the course of the entire day than during the July 1988 evaluation, especially with respect to error rate.

However, once again the on-line evaluation was able to highlight problems with system performance that had been previously overlooked. The detection percentage (93.2%) was not optimal during this recent all-day evaluation for two different reasons. First, the placement of detectors was not ideal, causing vehicles to overlap one end of the detector. This presented a problem on vehicles of low contrast, causing the system to not count them. Thermal expansion of the camera mounting aggravated the problem over the course of the day, as the detectors drifted farther and farther from an ideal location. Up to one out of ten vehicles was missed in any half-hour period due to this problem, which can most likely be corrected by better detector placement.

TABLE I
IMPROVEMENT IN RESULTS OF ON-LINE EVALUATION

	Detection (%)	Errors (%)
January 1989	93.2	1.8
July 1988	91.8	2.3

A second reason was responsible for the detection percentage falling far below 90%, around 3:30 PM. At this time of day the detectors fell within the mottled shadow of a nearby tree. The strength of signals collected from vehicles in the shadow was judged *insignificant* by the algorithms, when in fact it would have been a simple matter to separate these vehicles from the background if the significance level were better adjusted. However, in other imaging condititions we have encountered, the strength of the signal from the shadowed vehicles would have been in the noise, and a lower setting of the significance level would result in a much higher error rate. We have recently improved the technique employed for the setting of the significance level, in order to improve the adaptation to different imaging conditions. Finally, it should be mentioned that the system ran continuously for 24 hours. In this manner the algorithms, software, and hardware were demonstrated in around-the-clock operation.

During the second on-line evaluation, the video detectors had been placed in close proximity to an existing detector station on southbound I-35W. After the on-line evaluation, the actual 5-min loop volumes and occupancies for this detector station were dumped from the TMC computer. In the laboratory the following week, the system was rerun on video tapes that had been collected simultaneously during the on-line evaluation, and the volume and occupancy (5-min averages) generated by the Autoscope system were compared with those collected from the detector station. This was done for a 2-h period from 16:00 to 18:00. This period was chosen because of the relative difficulty of conditions: congestion, vehicle shadows, tree shadows, and transition to dusk. The measurements by both devices were very close although Autoscope-generated volumes were consistently slightly lower than loops. Overall results at six different testing locations showing the range of accuracies found are summarized in Table II. Over 8 h of video data was processed. Evaluations were done under light, medium, and heavy traffic flow conditions, with some occurrence of stationary and moving shadows.

The speed, total travel, and total travel time at these sites were evaluated by comparison to speeds collected by a radar detector temporarily set up in the field. For example, at test site 2, shown in Fig. 6, two speed traps were constructed in lane 1, each trap 50 ft (15 m) in length, separated by 200 ft (61 m). A radar detector was mounted upstream from each speed trap. The results for test site 2 are summarized in Table III.

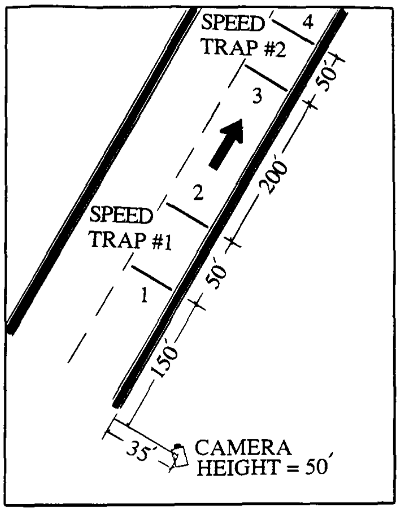


Fig. 6. Test site 2: comparison of Autoscope speed detection to radar detection.

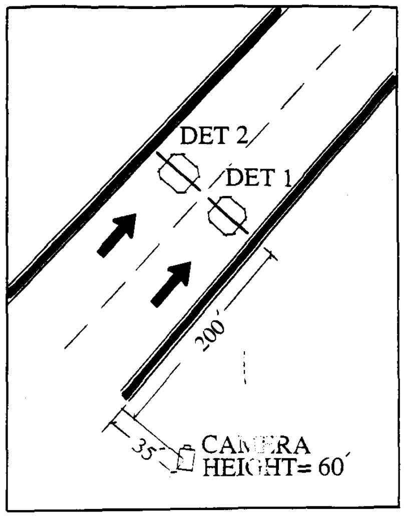


Fig. 7. Test site 6: colocated Autoscope and loop detectors.

TABLE II
OVERALL EVALUATION OF AUTOSCOPE PERFORMANCE AT SIX DIFFERENT SITES

Traffic Measure	Accuracy (%)
Volume	92.19–98.32
Speed*	94.57–97.66
Total Travel	90.76–96.06
Total Travel Time	92.08–97.21

* The speeds measured were in the range 40 to 65 mi/h (64 to 105 km/h).

TABLE III
COMPARISON OF AUTOSCOPE TRAFFIC PARAMETER ESTIMATION TO RADAR-BASED MEASURES

Traffic Measure	Accuracy (%) 5-Minute Interval	Overall
Volume		
Detector 1	93.24–99.92	95.73
Detector 2	94.59–99.06	96.77
Detector 3	89.38–98.20	94.87
Detector 4	88.87–97.14	93.72
Speed*		
Trap 1	93.47–99.87	96.90
Trap 2	92.83–99.93	97.14
Total Travel	92.42–99.27	95.39
Total Travel Time	88.21–98.65	95.02

*The speeds measured were in the range 40 to 65 mi/h (64 to 105 km/h)

At test site 6, shown in Fig. 7, the output of the Autoscope system was compared to the output of two collocated loop detectors, at two different times of day. Both were contrasted to manually entered volumes. Results are shown in Table IV. It is worth noting that in this test case the Autoscope system actually outperformed loops.

TABLE IV
COMPARISON OF AUTOSCOPE PERFORMANCE TO LOOPS

	Accuracy (%) VIDS	Loops
I. (7:45–8:45)		
Detector 1	97.12	97.72
Detector 2	98.38	97.16
II. (15:25–16:55)		
Detector 1	98.57	97.16
Detector 2	96.99	95.46

VII. FIELD IMPLEMENTATION

To further demonstrate robustness and reliability, the system was recently installed at three locations where it is continuously tested and compared with loops on a 24-hour basis using a sophisticated automatic comparison apparatus specifically developed for this purpose. This apparatus, called the result recorder, saves the traffic scene on videotape for further manual comparison if differences between the loops and the Autoscope system are detected. Due to the short time from the writing of this paper since the commencement of the experiments, complete results from all test sites are not available. In what follows, preliminary results from the first test site are presented.

The first test site is at Interstate 35W and Lyndale Avenue in Minneapolis. This site has been fully operational for a month prior to the writing of this paper. There are three loops (one per lane) across the freeway and a camera placed at a 45-ft pole, 30 ft off the roadway is used for providing input to the Autoscope. Three detection lines were placed over the loops for direct comparisons. The output from the loops is sensed by an M-170 controller where one minute volume speed and occupancy counts are collected and transferred via phone line to a central location where the Autoscope system is installed. The one minute volume speed and occupancy data are received by a 80286 PC/AT and also stored to disk for later analysis. The video output of the camera is also sent back to the central location, the Minneapolis Traffic Management Center, through cable. The video output is

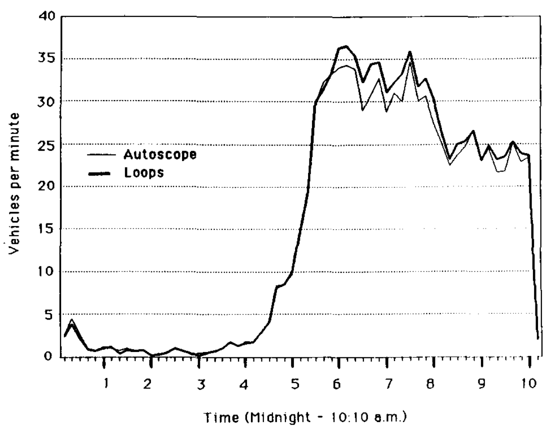


Fig. 8. Autoscope versus loop volume comparison at 35 W and Lyndale: lane 3.

looped through a video recorder to selectively capture video sequences and then into the Autoscope that has been fitted with a floppy disk drive to compute, collect, and capture corresponding one minute volume, speed, and occupancy counts. The M170-PC/AT combination has been correctly time synchronized to the Autoscope to capture synchronized vehicle data.

Two weeks of data were collected and analyzed with this last setup as of April 1990. A data analysis program has been written that filters, displays, and computes errors between the loops and Autoscope, utilizing the one-minute detection data. In what follows a typical day of volume data comparison is presented. Specifically the data presented here were collected on a very windy day (winds gusting to 50 mi/h) on April 2, 1990, from midnight to noon.

The volume comparison is for lane 3, which is the lane farthest from the camera. The results in the remaining two lanes are even more favorable. The comparison between loops and Autoscope is shown in Fig. 8. The figure suggests extremely close correspondence at night (in spite of the strong winds), dawn, the start of the rush hour and during late morning normal flow. The results are also very close even during the morning peak hour. Autoscope volume count is only 6% lower than loops during the rush hour. To answer the question of which system is closer to data, a one-hour video sequence was also collected during the peak period and manually analyzed. The traffic flow across all three lanes was scrupulously counted. It was found that loops, at least on this location, over-count traffic by an average of 3%, compared to the manual ground truth. Thus, at this time period, both Autoscope and loops are equally at error at this location by about 3% each. Given the very large distance of the detection lines from the camera, this performance can be considered very satisfactory and beyond expectations. To be sure, a 100% accuracy should not be expected by any device.

VIII. Concluding Remarks

From the results presented here, it should be evident that the Autoscope technology has advanced significantly over the last year or so. Synergy between the various research projects ensured that a robust real time video detection system with true wide area multispot detection capabilities is now available, albeit in a preproduction prototype stage. Even so, Autoscope is suitable for demonstration projects such as the ones underway (Incident Detection and Intersection Control). Unlike video detection systems being developed elsewhere, Autoscope can be demonstrated with live video input and allows instant visual verification. Most importantly, the system capabilities described here can be confirmed either at the Minneapolis Traffic Management Center where the system is installed, or at any location receiving live video input from traffic surveillance cameras. Finally, the flexible detection placement through interactive graphics, the ability of Autoscope to work with any camera, and its capability to work under congested flow and other artifact conditions while still being able to use the camera for surveillance should be reassuring to practicing engineers.

Although more work is underway to establish reliability as well as performance on a long-term continuous operation, by all indications the elusive goal of wide-area video detection research and development is now extremely close to fulfillment; the cost-effective ability to detect vehicles via video cameras with satisfactory accuracy for traffic surveillance and control. The live benchmark demonstrations of Autoscope in the United States and abroad clearly confirmed its capabilities. In these benchmarks, the system was connected to several live cameras, and the detection results were visually verified. Based on these results and benchmarks, it was decided to start commercial production of Autoscope by the end of 1990.

Prior to implementation of the Autoscope technology, a word of caution is appropriate. The device should not be viewed as a simple replacement of loops, which will continue to serve their intended purpose for some time. Instead, Autoscope should be considered as a wide-area detection system. As such, it leads to potential applications that have not been seriously attempted before. Therefore, initial application of the technology should be selected with caution to capitalize on the Autoscope capabilities.

References

[1] P. G. Michalopoulos, R. Fitch, and B. Wolf, "Development and evaluation of a breadboard video imaging system for wide area vehicle detection," presented at 1989 Annu. Meet. Transport. Res. Board, 1989.

[2] R. C. Waterfall and K. W. Dickinson, "Image processing applied to traffic: 2. Practical experience," *Traffic Eng. Contr.*, pp. 60-67, 1984.

[3] K. W. Dickinson and C. L. Wan, "Road traffic monitoring using the TRIP II system," in *Inst. Elec. Eng. 2nd Int. Conf. Road Traffic Monitoring*, Pub. no. 299, 1989, pp. 56-60.

[4] A. D. Houghton, G. S. Hobson, N. L. Seed, and R. C. Tozer, "Automatic vehicle recognition," in *Inst. Elec. Eng. 2nd Int. Conf. Road Traffic Monitoring*, Pub. no. 299, 1989, pp. 71-78.

[5] N. Hoose, "Queue detection using computer image processing," in *Inst. Elec. Eng. 2nd Int. Conf. Road Traffic Monitoring*, pub. no. 299, 1989, pp. 71-78.

[6] S. Beucher, J. M. Blosseville, and F. Lenoir, "Traffic spatial measurements using video image processing," *SPIE Proc. Intelligent Robots and Comp. Vision*, vol. 848, 1987.

[7] J. M. Blosseville, C. Krafft, F. Lenoir, V. Motyka, and S. Beucher, "TITAN: A traffic measurement system using image processing techniques," in *Inst. Elec. Eng. 2nd Int. Conf. Road Traffic Monitoring*, Pub. no. 299, 1989, pp. 84-88.

[8] J. Versavel, F. Lemaire, and D. Van der Stede, "Camera and computer-aided traffic sensor," in *Inst. Elec. Eng. 2nd Int. Conf. Road Traffic Monitoring*, pub. no. 299, 1989, pp. 66-70.

[9] S. Takaba *et al.*, "Measurement of traffic flow using real-time processing of moving pictures," in *Proc. IEEE Veh. Technol. Soc. 32nd Annu. Conf.*, San Diego, CA, 1982, pp. 488-494.

[10] S. Takaba, "Measurement of flow of vehicles and pedestrians

using real time processing of moving pictures," in *Proc. Int. Symp. Image Proc. and Appl.*, Inst. Indust. Sci., Univ. Tokyo, Tokyo, Japan, 1984.

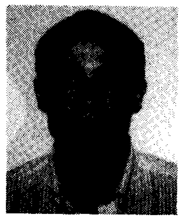
[11] N. Ooyama and K Shigeta, "Area measurement of traffic flow using photoelectric elements," in *Proc. 4th IFAC/IFIP/IFORS Conf.*, Baden-Baden, FRG, 1983, pp. 281-287.

[12] K. Shimizu and N. Shigehara, "Image processing system used cameras for vehicle surveillance," in *Inst. Elec. Eng. 2nd Int. Conf. Road Traffic Monitoring*, Pub. no. 299, 1989, pp. 61-65.

[13] J. S. Dods, "The Australian Road Research Board video based vehicle presence detector," in *Int. Conf. Road Traffic Data Collection.*, London, England, 1984, pp. 96-100.

[14] P. Michalopoulos, R. C. Fitch, and M. Geokezas, "Development of a visible infrared vehicle detection system: Feasibility study," Dept. Civil and Mineral Eng., Univ. Minnesota, Final Rep., project 0632-5063, 1986.

[15] P. Michalopoulos and B. Wolf, "Automatic incident detection through video image processing preliminary engineering," Center for Transport. Studies, Dept. Civil and Mineral Eng., Univ. Minnesota, Proposal to Minnesota DOT, 1989.



Panos G. Michalopoulos received the B.S. degree in civil engineering from the College of Engineering of Athens, Athens, Greece, in 1969, and the M.S. and Ph.D. degrees in transportation engineering, both from the University of Florida, Gainesville, in 1972 and 1975, respectively.

From 1975 to 1977 he served as an Assistant Professor of Civil Engineering at Rennselaer Polytechnic Institute, Troy, NY. He has since joined the University of Minnesota, Minneapolis, where is a Professor of Civil Engineering. His areas of specialization are traffic engineering, flow theory simulation, and control. He is currently involved in high technology applications to transportation through microelectronics, image processing (machine vision), and expert systems.