Integration of Machine Vision and Adaptive Control in the Fast-Trac Intelligent Vehicle Highway System Program

PANOS G. MICHALOPOULOS, RICHARD D. JACOBSON, CRAIG A. ANDERSON, AND JAMES C. BARBARESSO

Machine vision has been considered one of the most promising technologies for developing and deploying advanced traffic management system and advanced traveler information system applications. Although experimental video detection systems are being developed worldwide, a real-life, practical, and effective application has been elusive. The first and largest application of video detection and its integration with adaptive control in a network of 28 intersections in Oakland County, Michigan, are described. The broader project (called FAST-TRAC), which includes a driver information system, is also summarized. The successful deployment of the state-of-the-art detection/adaptive control system led to the decision to expand it to 93 intersections by June 1993 and ultimately to 800 by 1996.

Advanced traffic management systems (ATMS) is one of the most important areas of the intelligent vehicle highway systems (IVHS) program recently established in the United States. Although many ATMS programs are in the planning stage, the Road Commission for Oakland County (RCOC), Michigan, has successfully deployed the first ATMS in North America that utilizes adaptive, coordinated traffic control of intersections driven exclusively by a new technology, namely video image processing for vehicle detection. The adaptive control system is the Sydney Coordinated Adaptive Control System (SCATS), developed in Sydney, Australia (*1*), and the video vehicle detection system is the AUTOSCOPE (*2*), developed at the University of Minnesota with funding from the Minnesota Department of Transportation, FHWA, and the Center for Transportation Studies at the University of Minnesota. AUTOSCOPE was recently comercialized by Image Sensing Systems and marketed by Econolite Control Products. A third component, an advanced traveler information system (ATIS) called Ali-Scout (*3*), provides an infrared communication link between vehicles and roadside beacons that allows for continuous exchange of traffic and route guidance information, with vehicles also acting as probes to determine travel times. The Ali-Scout was developed by Siemens.

P. G. Michalopoulos, Department of Civil Engineering, University of Minnesota, 500 Pillsbury Dr. S. E., Minneapolis, Minn. 55455. R. D. Jacobson and C. A. Anderson, Image Sensing Systems, Inc., 1350 Energy Lane, Suite 2, St. Paul, Minn. 55108. J. C. Barbaresso, Road Commission for Oakland County, 31001 Lahser Road, Birmingham, Mich. 48010.

The RCOC program responsible for the deployment of these IVHS technologies is called FAST-TRAC (Faster and Safer Travel Through Traffic Routing and Advanced Controls). The program's primary mission is to deploy and evaluate operational ATMS and ATIS technologies that lead to improved mobility and safety on increasingly congested arterial roads and freeways in Oakland County, Michigan. The program has proven to be an excellent example of how public, private, and academic institutions have cooperated in the planning, design, and successful deployment of state-of-the-art traffic technologies. Further background and information on the overall programs basis, objectives, and goals are described elsewhere (*3*).

In this paper the field testing and implementation of the video vehicle detection system in Oakland County and its integration with SCATS are presented. This includes the engineering effort and system performance to meet or exceed the vehicle detection requirements for SCATS intersection control.

FAST-TRAC PROGRAM SUMMARY

The Oakland County IVHS Program, FAST-TRAC, is a large-scale deployment of an integrated ATMS and ATIS. In what follows, the goals of FAST-TRAC are briefly described along with its vision, plans, and status.

The major objective of FAST-TRAC is to demonstrate the effectiveness of an integrated ATMS-ATIS system in improving mobility, reducing energy consumption, enhancing air quality, and reducing traffic accidents. The program also will evaluate and demonstrate requirements for deployment of IVHS throughout North America. Technological constraints and considerations for deploying such systems will be identified and evaluated. Organizational requirements for deploying IVHS at the local, regional, and state levels and across multiple jurisdictions will be defined.

Multiple jurisdictions are becoming involved in FAST-TRAC. Not only will the traffic signal systems of local units of government be integrated, but freeway operations under the control of the Michigan Department of Transportation

(MDOT) will also be incorporated. A link between MDOT's Metropolitan Transportation Center and the Oakland County Traffic Operations Center will be made. Freeway ramp controls, variable message signing, and other freeway operational improvements will be integrated with the surface street ATMS-ATIS to guarantee optimal performance of the overall highway system.

Data requirements and methods of reporting for effective traffic management will be reviewed. The deployment of these technologies will alter staffing requirements and the expertise that staff will be required to have. Finally, the affordability of these systems, especially for local implementation, will be evaluated in a later phase, as maintenance life-cycle costs are accumulated.

The FAST-TRAC partners have developed a program that satisfies many of the operational test objectives spelled out in the IVHS America Strategic Plan. In the ATIS area, commercial, public service, public transit, and private vehicles will be equipped to allow the assessment of human factors, considerations, and productivity gains. These vehicles will also act as traffic probes, providing real-time information for incident management and dynamic route guidance.

It is a goal of FAST-TRAC to provide a focal point for the collection and dissemination of traveler information on an areawide basis. A traffic operations center (TOC), currently under construction, will provide this focal point and will be linked to the Metropolitan Transportation Center. The ATMS is designed to enhance political and institutional cooperation for effective, areawide traffic management.

FAST-TRAC includes a third-generation traffic management system and uses video image processing for traffic detection. Other IVHS technologies, such as advanced communication technologies, will be used in FAST-TRAC. Alternative communication technologies will be tested to link the TOC to intersection hardware and to make the vehicle-to-roadside communication link.

FAST-TRAC has been made possible through funding from a variety of sources. Initial funding for the first phase of the project was contributed by the Oakland County Road Commission, direct appropriation from Congress, Siemens, and MDOT.

The program is broken down into four phases spanning a period of 5 years. Phase I, which was completed in June 1992, was a pilot phase in which SCATS and AUTOSCOPE were integrated, tested, and deployed at 28 intersections, 23 of which are fully instrumented with AUTOSCOPE and the remainder with loops. Phase II currently consists of 95 intersections in the city of Troy, Michigan, that includes all of southeast Oakland County. The third phase of the program will involve the deployment of another 100 intersections in the burgeoning area surrounding the Oakland Technology Park and the Pontiac Silverdome. Ultimately, all of the urbanized portion of Oakland County will come under SCATS and AUTOSCOPE operations (800 intersections). Some rural applications also will be tested.

A TOC will be established for the combined ATMS-ATIS. The TOC will house the central computers and communications equipment for managing and monitoring the systems. It will also include meeting and training facilities. The TOC is currently being built and is described later in the paper.

AUTOSCOPE VIDEO DETECTION SYSTEM

Only a short description of the system is included here. The interested reader can turn to previous papers (*2*, *4*) for more detailed description of AUTOSCOPE. Briefly, the AUTOSCOPE system can detect traffic in multiple locations of areas within the field of camera's 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 using a mouse. Therefore, these detection lines are not physically placed in the pavement but only on the TV monitor and can be removed after initial placement of the detection lines. 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. Thus, the system emulates loops and can easily replace them in existing installations. However, the advantage is that, in addition to the wireless detection, a single camera can replace many loops, thus providing a true wide-area detection and becoming cost-effective.

SYSTEM OVERVIEW

As mentioned earlier, the current Phase I installation consists of 28 intersections. This small-scale network is the pilot testing of the integrated AUTOSCOPE and SCATS control systems. Of the 28 intersections instrumented, 23 exclusively use AUTOSCOPE for vehicle detection. The remaining five minor intersections require minimal detection coverage and have sufficiently stable pavement to install loops.

SCATS (*1*) is a complete traffic management system that provides adaptive, real-time traffic signal control, coordinated on a network basis. The system has been developed over a period of almost 20 years to control traffic signals in and around Sydney, Australia. Oakland County, Michigan, is the first North American installation of SCATS. The control approach is demand responsive by dynamically adjusting cycle lengths, splits, and offsets for coordination. Cycle lengths are varied (anywhere from 20 to 190 sec) on the basis of overall demand; split adjustments are based on demand between competing directions; and offsets coordinating adjacent intersections are varied with traffic demand to minimize the number of stops within the network. The basis for determining demand is the degree of saturation (DS). The DS is the ratio of effectively used green time to total available green time. The control strategy is designed to minimize "wasted" green time throughout a system to suit the prevailing average traffic conditions.

The DS calculation has some unique vehicle detection requirements. When SCATS is implemented through loops, the vehicle detector size is required to be 4 to 4.5 m long to compute consistent DS results for all vehicle speeds and congestion levels. The detectors must also be placed 1 m back from the stopline for adequate coverage of stopped vehicles. The detectors are almost exclusively placed at the stopline and are used for two purposes: (a) tactical detection to enable a vehicle movement phase such as a left turn and (b) strategic detection to dynamically adjust cycle, split, and offset times. Strategic detector information can be used to control intersections where they are placed as well as intersections downstream of their placement, to measure approaching traffic demand. Detectors can be used for both tactical and strategic purposes, depending on the lane of travel and the complexity of the downstream intersection that the lane feeds.

A typical placement of SCATS/AUTOSCOPE detectors in Oakland County is shown in Figure 1. The figure shows where detectors are placed at intersections upstream of the controlled intersection for strategic inputs for adjusting cycle length, splits, and offset times; it also shows the camera placements for AUTOSCOPE detection.

The size and placement of the SCATS-compatible detectors had serious maintenance and reliability concerns if loop technology were to be used. The road surfaces in Oakland County are typical of those of northern U.S. cities with an assortment of various-sized potholes and combinations of concrete, pavement, and patches. The 4.5-m length implies that loops must typically span mutiple cement pads and survive seasonal shifting of the road surface. Road weight restrictions are few, and it is common to see vehicles with as many as 40 wheels navigating the roads with enormous loads. The average temperature in the region during fall, winter, and spring is near freezing (ice storms are frequent near the Great Lakes). The freezing and thawing cycles destroy the road surfaces very quickly, especially when raw salt is poured from local salt mines onto the road. The survivability of long loops in this environment was in serious doubt; that is, it was questionable whether they would be able to last longer than 1 year at a time.

The aforementioned problems, along with the following considerations, led to the decision to use AUTOSCOPE in the FAST-TRAC project:

1. The detectors are nondestructive to the road surface, with no lane closures to install or maintain equipment.
2. The multiple detection capability offered by AUTOSCOPE can be used for queue length detection that will be used to develop the next generation of SCATS; when this occurs, no new detector installation will be required.
3. The AUTOSCOPE and peripheral equipment can be installed any time of the year. Most of the AUTOSCOPE installation for this initial project occurred from February through May.
4. AUTOSCOPE can be used in the future for deriving stops, delays, energy consumption, and pollution levels for continuous monitoring of SCATS performance.
5. The detectors can meet the size and placement requirements for SCATS. A study was conducted to define and test AUTOSCOPE detectors that emulate the area coverage of a 4.5-m loop placed 1 m behind the stopline; the performance results are presented later.
6. The detectors can be positioned over any road surface or combinations of road surfaces with no loss of performance or consistency.

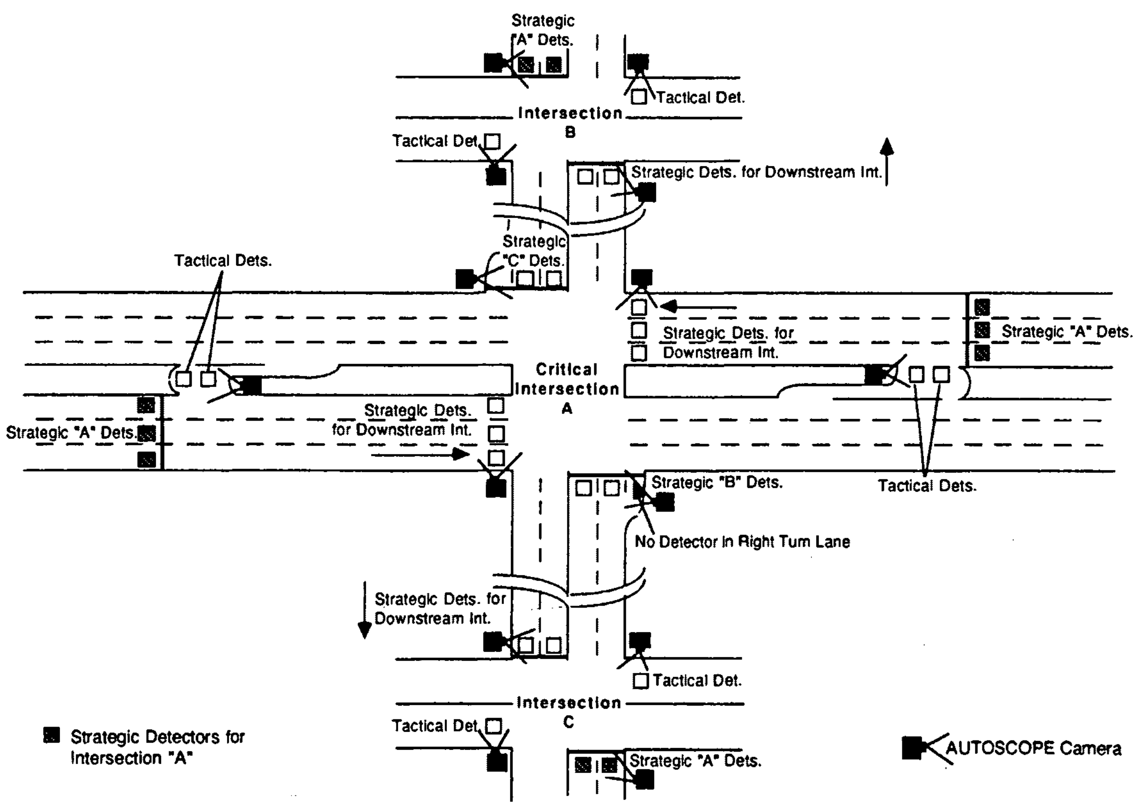

FIGURE 1 Typical SCATS-controlled intersection configuration.

7. The detection performance of AUTOSCOPE has been documented to perform under all weather, lighting, and range conditions that do not obscure the camera's field of view.

Figure 2 shows how the FAST-TRAC system is configured. AUTOSCOPE cameras are placed at designated locations to acquire the desired road coverage for SCATS tactical and strategic detectors. The AUTOSCOPE detectors are tied into the SCATS local controller using a NEMA TS/1 contact closure interface. Several Ali-Scout roadside beacons are at several intersection approaches to exchange information with Ali-Scout–equipped vehicles that pass through the intersection and passed on to the Ali-Scout central system. The SCATS local controllers are tied directly to the SCATS regional computer via dedicated phone lines (and modem). The local SCATS controllers execute timing plans defined by the regional computer, thus allowing synchronization and coordination of local controllers in a region. The SCATS central management system provides coordination between regions and a common data base for the network. AUTOSCOPE vehicle detections, traffic parameters, and statistics are managed by the SCATS. The SCATS regional computer also has a user interface to monitor and manage the SCATS controlled intersections. It currently acts as the primary input for any command and control activities. Phases III and IV of the FAST-TRAC program will integrate the SCATS hardware with the Ali-Scout and video surveillance for a unified command and control display console. All command, control, and response functions will be activated via a geographical information system user interface. The command and control system will be interfaced with other traffic information centers, highway patrol, and MDOT to exchange information, manage incidents, and coordinate the management of freeways and arterials via ramp control, changeable message signs, and vehicle communication.

PRELIMINARY ENGINEERING

Because the SCATS and AUTOSCOPE technologies were new to the engineers and technicians of Oakland County, RCOC decided to expand the funding for the preliminary engineering so that the systems could be properly deployed. Preliminary engineering for the SCATS controller was relatively straightforward because it is a very stable product that has been in service for many years. The majority of engineering effort for the SCATS was user training and defining control designs for the various intersection test sites.

The major engineering issue to resolve was using AUTOSCOPE as the vehicle detection sensor. The AUTOSCOPE was a proven prototype (*2*) but was not field ready when the project began in August 1991. The AUTOSCOPE needed to be environmentally hardened to meet industrial (NEMA) specifications for temperature, shock, radio frequency, form factor, and so forth. Cost-effectiveness would also be gained by providing up to four cameras of video input into a single AUTOSCOPE. The AUTOSCOPE product development was not funded directly by RCOC but offered an excellent set of system requirements that the AUTOSCOPE had to satisfy. In view of this, development was funded privately by Image Sensing Systems and Econolite Control Products. In this manner, the private sector was brought in to complete a product for which the basic research and development were performed in a university environment with government funding.

There were several preliminary engineering tasks that had to be performed to weatherize and develop AUTOSCOPE. The first was to plan and coordinate the trade-off and analysis studies, hardware selection and procurement, hardware installation, site detector layout programming, detector data file management, and so on. The second was to define, test, and evaluate the performance of the AUTOSCOPE to successfully emulate the detection requirements of the loop-based

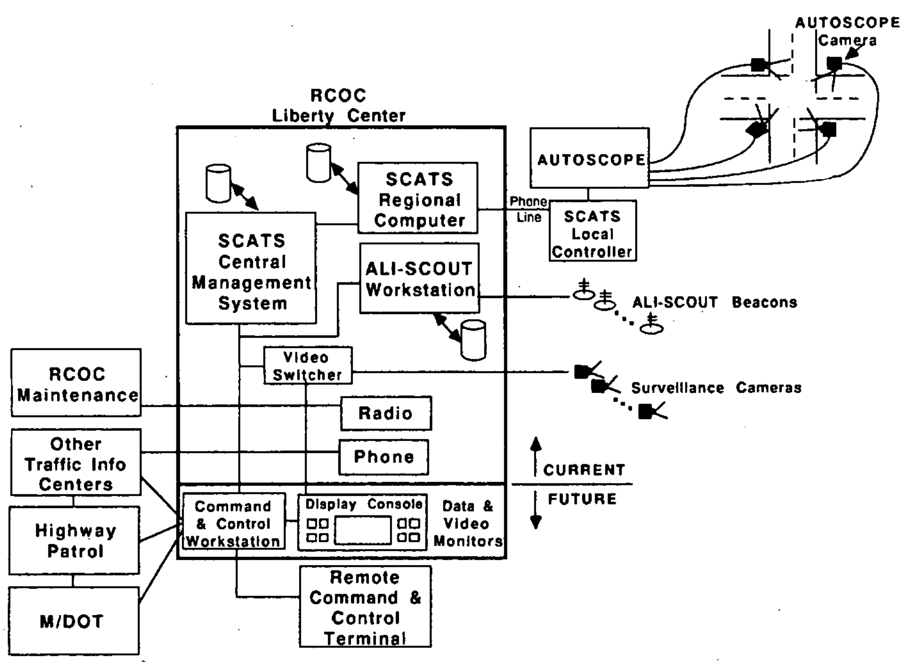

FIGURE 2 RCOC command and control center.

systems deployed in Sydney, Australia. There were two requirements for meeting this objective. The first was that the detector size and placement provide consistent performance so that the SCATS degree of saturation control signal is reliable. The second requirement was that the absolute detection of vehicles at stoplines be robust to safely and efficiently control turning and through movements.

The third task in the preliminary engineering was to perform site engineering of detector placement for each intersection approach. This included definition of the infrastructure to support the AUTOSCOPE and peripherals (poles, camera, optics, cabinets, cables, power, etc.) for the desired detector placements. Details are presented later.

The last major task during the preliminary engineering was to develop the interfaces between the SCATS and AUTOSCOPE so that they are electrically compatible, provide the correct contact closer characteristics during system operation (and nonoperation), and are reliable. A loop-compatible output module for the AUTOSCOPE that meets NEMA TS/1 specifications was developed, tested, and deployed to meet this requirement.

SITE ENGINEERING

Site engineering for the AUTOSCOPE is very different from what traffic engineers have experienced before. However, the engineering concepts are easy to understand and practice. One of the most powerful impacts of the technology is the human visualization and verification (instant feedback) that this video detection system provides. The order of engineering tasks to perform for implementation generally follows the steps of the FAST-TRAC deployment. The first is to get a thorough understanding of the detection requirements of the application to be performed, that is, where detectors are needed and what type (volume, occupancy, speed, gap times). For the SCATS installation, it was necessary for the SCATS engineers and RCOC to define their desired control strategies before any AUTOSCOPE site engineering could begin. Next, one should define a detector placement configuration strategy that determines the camera's expected field of view. Some detectors and detector information are typically more important than others in the configuration. It is important to understand which detector functionality may have to suffer because of geometric road considerations, such as safe placement and easy access to poles for maintenance, absolute stopline detection to enable safe turning movements, and so on. Knowing the priority of detection needs makes it easier to choose optimal camera locations. The third step is to take advantage of existing infrastructure where and whenever possible; that is, use existing poles, span wires, underground conduit, cabinets, and so on. When new equipment must be installed, providing for public safety and easy maintenance access is necessary.

The engineer should also update site drawings of existing sites to reflect "as-built" dimensions. The following dimensions are of most interest: the accurate placement of stoplines from the nearest corner, existing poles in the vicinity and dimensions to the road, and height on the poles where cameras can be safely mounted without interfering with power or phone lines. There were basically four types of intersection configurations that existed in Oakland County. The first is a boulevard intersection with three to four lanes on the boulevard and two to three lanes on the crossroad with no left turns on any approach. The second is a five-lane intersection with two through lanes per approach on the major road with a fifth lane used for protected left turns. The minor road typically would have one to two through lanes per approach with protected or permissive left-turn lanes. The third intersection configuration is a minor intersection with two through lanes per approach on the major road with permissive left turns and one to two lanes on the minor road. The phase for the minor road was typically enabled by nonlocking detectors. Finally, the last configuration involves boulevard crossovers to eliminate protected left turns on boulevards. The crossover phases are enabled by nonlocking detection. The area coverage was typically very large. The stopline was 9 to 12 m wide to accommodate turning trucks. Vehicles could approach the stopline anywhere along the stopline. An example of these four intersection types is shown in Figure 1, which shows where SCATS detectors are typically placed and where the detector information is used.

RCOC was willing to route video and power lines across span wires (above ground) at the majority of intersections so it was not necessary to install underground conduit or to check if there was existing capacity for the video and power cables.

Another step during the site engineering is to define a camera location and height that minimize the field of view obstructions (occlusions) on the basis of the camera's location and perspective. Increasing the camera height reduces the occlusion effects. Drawing some simple diagrams of camera height, number of lanes of coverage, pole distance from the road, and expected vehicle heights from occluding lanes typically is used to define a required camera height. The camera placement should also minimize reflections from leading headlights and adjacent roads at night. Leading headlight reflections can be eliminated by observing vehicles moving away; this, however, results in unrealistic and expensive "extra" pole placements at intersections. As an alternative, headlight reflections can be minimized by placing detectors in closer downlane proximity to the pole, thus reducing the amount of reflected light that enters the camera. In addition to this, enabling processing algorithms in the AUTOSCOPE were developed that significantly reduced the effects of leading headlights. Finally, the majority of poles and cameras placed in Oakland County were chosen to be adjacent to the stopline at the same approach. This location optimizes the field of view for high-accuracy stopline detections (volume and occupancy) and minimizes leading headlight reflections that can result in false detections. Luminaires at the intersections also provide excellent occupancy results at night.

AUTOSCOPE PERFORMANCE EVALUATION

The performance of the AUTOSCOPE has been evaluated previously on freeways (*2,4,5*) and most recently at an intersection (*5*). Each evaluation included long-term data comparisons of AUTOSCOPE detection versus loops and manual ground truthing. Comparisons of the loops and AUTOSCOPE with manual ground truth show comparable performance and accuracy levels in excess of 95 percent for volume, speed, and occupancy. Although AUTOSCOPE can be used in conjunction with any control strategy, the special requirements of the SCATS detectors necessitated additional testing and calibrations to ensure full compatibility. The results of this testing are presented here.

To verify that it could meet or exceed the unique vehicle detection requirements of the SCATS and intersection control applications for the Oakland County installation, AUTOSCOPE was further tested and modified to determine its detection performance and adapt it to the following problem and artifact conditions.

1. Intersections impose stiffer safety requirements to absolutely detect vehicles at stoplines and to not remain stuck on when no vehicles are present (which leads to overall system inefficiency).
2. SCATS has requirements of high-accuracy volume and occupancy to compute reliably the SCATS degree of saturation control parameter.
3. Detection must be robust to work under all weather and lighting conditions (day or night). Shadows from vehicles in adjacent lanes pose the biggest problems here. Almost every video sequence analyzed had some form of weather artifact, such as snow, rain, sleet, ice, fog, high winds, and so on. There were some concerns of obtaining accurate occupancy at night. In all but two approaches at one intersection, there was sufficient illumination from street lights, commercial or retail business lights, and closely following vehicles to obtain very good occupancy at the stopline for the 23 intersections in Oakland County.
4. Downlane and crosslane geometric occlusion effects were minimized by detector placement at the stopline. Only five poles were added or moved on the entire project of the 62 cameras that currently are in operation. The existing pole infrastructure was used cost-effectively to retrofit existing intersections.

Several improvements were made to the detection algorithms to meet the above detection requirements. A new presence detector was defined that is very effective at holding and maintaining a vehicle detection whenever a vehicle passes through or stops under the detector for long periods of time, thus providing true presence. The presence detector is typically placed downlane at the stopline to obtain good coverage of the roadway for vehicles that stop short of the stopline. A further improvement to the AUTOSCOPE presence detector that was instrumental in fulfilling deployment detection requirements was the ability to distinguish which direction the vehicle enters the detector or is stopped under the detector. This capability immediately eliminated all false actuations due to "wrong-way" detections. Such detections were caused by strong shadows entering the detector from adjacent lanes, turning vehicles from other approaches taking shortcuts across empty left-turn lanes, and any light reflections (day or night) that enter the detector from the wrong way (such as an exit of a convenience store across the road from the detectors that shines light across the detectors).

The AUTOSCOPE has another type of presence detector called a count detector that is used for counting closely following vehicles at range. The detector is typically oriented across the road (crosslane) to separate closely following vehicles at range. The count detector is better suited for freeway applications where there is typically some vehicle motion, even in the heaviest of congestion. The count detector has not been required by SCATS so far.

The performance of AUTOSCOPE was analyzed with the directional presence detectors in through and left-turn lanes. Some of the video sequences analyzed were taken from nonoptimal camera positions so that performance degradation could be determined. The AUTOSCOPE detector presence was compared with ground truth presence as determined by visual observation of vehicles within the detection zone on a frame-by-frame basis. Frame rates are on 33-msec boundaries, and it was estimated that the human observer could distinguish the entry and exit time of the vehicles to within one to two frame times. This was accomplished by slow-motion videotape replay methods.

The performance of the AUTOSCOPE directional presence detectors placed in through lanes at several intersections using the SCATS size and placement specification of 4.5 m long and 1 m behind the stopline is shown in Table 1. All performance measures are given in percentages compared with the manually determined ground truth data. The detection accuracy is the percentage of ground truth vehicles that were detected. The false detection rate is the sum of the number of double detections of the same vehicle plus the number of false detections with no vehicle present, given as a percentage of the number of actual vehicles. The volume

TABLE 1 AUTOSCOPE Direction Detector Through Lane Performance Compared with Manual Ground Truth

TEST ARTIFACTS	DET. ACCURACY %	FALSE DET. RATE %	VOLUME ERROR %	OCCU-PANCY ERROR %	NUMBER GROUND TRUTH VEHICLES
1. High Winds, Shadows	98.1	3.0	1.1	-2.5	264
2. Overcast, Snow, Windy	99.6	4.2	3.8	-2.7	262
3. Overcast, Wet Rd, Windy*	96.1	2.0	-2.0	-6.1	51
4. Day/Night Transition	97.1	7.4	3.5	4.0	312
5. Night	98.1	6.1	4.2	7.5	407
6. Partly Cloudy, Lt Wind	96.2	4.1	0.3	-3.7	290

*Not an actual camera location; viewed head-on at an exit ramp from across the intersection road.

error is the difference between the total number of detections and the number of vehicles, given as a percentage of the number of vehicles. Finally, the occupancy error is the difference between the number of frames where the detector was on and the number of ground truth frames where a vehicle was judged to occupy the detection zone, given as a percentage of the number of ground truth frames on which the detection zone was occupied. A negative sign of volume and occupancy error implies that the AUTOSCOPE value is lower than manual ground truth.

The performance of the AUTOSCOPE directional presence detectors placed in left-turn lanes was also evaluated. The number of cars missed while the detector was on and off was counted. A miss while on means that the detector was already on when the vehicle entered the detection zone, as it would be, for example, for a closely following vehicle; therefore, the number of separate actuations was not incremented for that vehicle. A miss while off means that the detector did not detect the vehicle while it was present. A miss while off is of crucial importance for left-turning lanes because errors cannot be tolerated for safety reasons. The tests consisted of several 30- to 45-min videotape sequences for each artifact. Each intersection tested was running at approximately 90-sec cycle lengths. The seemingly large number of misses with the detector on is a desired behavior of the detector for SCATS. The detector was sized at 3.5 to 4.5 m to bridge the gap between two closely following vehicles traveling at less than 13 km/hr (8 mph). It should be evident that, with detectors that long, it is practically impossible to separate cars when they are closely spaced. Thus, the number of misses with the detector on was a desirable feature for SCATS.

The only two misses confirmed so far with the detector off are considered critical failures of the detector. Close examination of the two cases indicated that the vehicles partially passed through the detector by shortcutting the left turn. As a result of this analysis, two AUTOSCOPE directional presence detectors were placed side-by-side in every left-turn lane approach. So far the two-detector configuration has not failed to enable the left-turn movement. The only reported cases of failure to enable the left turn were because drivers were not pulling up under the 4.5-m detectors placed 1 m behind the stopline. Additional detectors have since been added further behind the stopline to eliminate this problem.

The true test metric for AUTOSCOPE to meet is an accurate extraction of the SCATS DS. The DS (ignoring premature-phase termination by gap time out) is defined as

$$\mathrm{DS} = \frac{Gt - \{T - [h * (N + 1)]\}}{Gt}$$

where

Gt = signal phase green time (sec),
T = total off time of the detector during Gt (sec),
h = minimum time headway, and
N = number of vehicles during the signal green time.

The minimum time headway is the one at which two closely following vehicles would travel at peak saturation. This parameter is recomputed every day on the basis of the largest demand for the day. This value is very sensitive to road geometrics and driver behavior. A typical value is 0.8 sec. Finally, this vehicle count is incremented by 1 to account for the detector size, which is designed to bridge the gap between the first two vehicles when the queue discharges.

The video sequences of Table 1 were analyzed by computing the DS control parameter. Figures 3 through 5 show the magnitude and difference between the manual ground truth and AUTOSCOPE in computing the SCATS DS under only a few adverse conditions. Similar figures for other artifacts, such as night, occlusion, partially cloudy weather, lightning, heavy rain, and so on, are not shown because of space limitations. The magnitude of DS in the figures indicates the congestion levels the detectors were tested under and how closely they track the manual ground truth. The major deviations of the AUTOSCOPE from ground truth were because of incorrect vehicle counts (mostly extra false detections and double counts). However, these deviations are negligible, and even with potentially high false detection rates the difference between the AUTOSCOPE DS and the ground truth DS does not have a significant effect on the intersection efficiency.

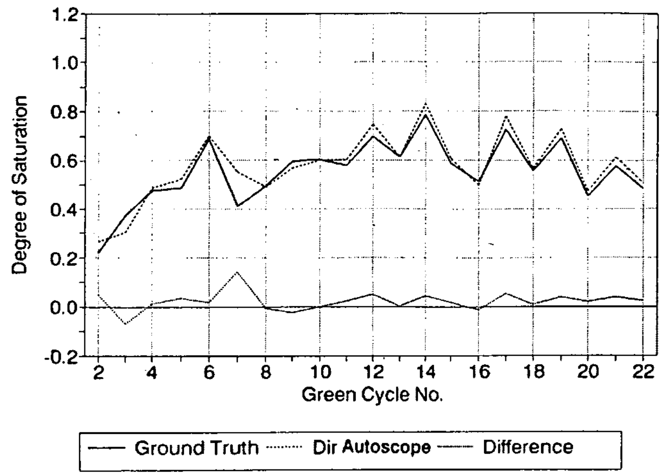

FIGURE 3 Comparison between measured and AUTOSCOPE-derived DS under high wind, strong shadows, and congestion.

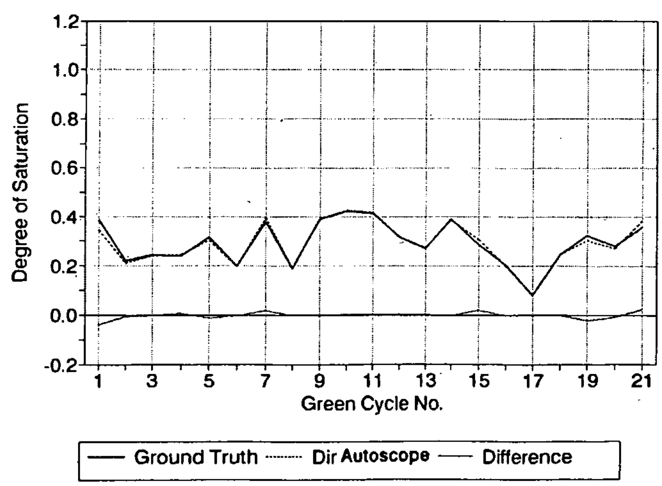

FIGURE 4 Comparison between measured and AUTOSCOPE-derived DS under overcast, snow, wet road, and windy conditions.

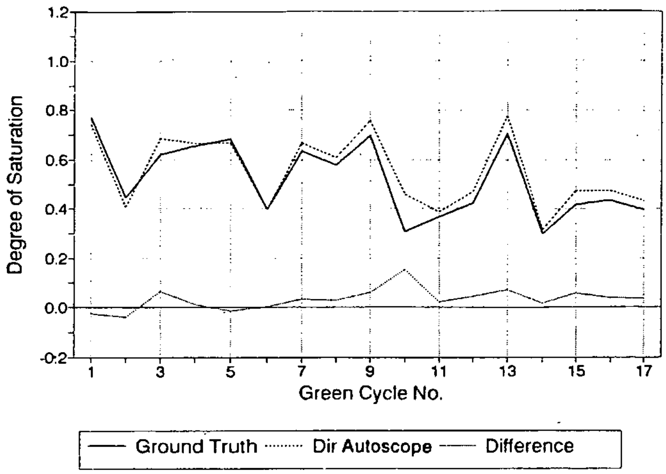

FIGURE 5 Comparison between measured and AUTOSCOPE-derived DS during day-to-night transition.

The results presented here along with the detailed tests were presented to the SCATS developers, who, following additional manual observations of their own, were satisfied that AUTOSCOPE was performing well. Following this verification AUTOSCOPE and SCATS were fully integrated and deployed.

FIELD DEPLOYMENT ISSUES

The installation of the AUTOSCOPE equipment went very smoothly. The biggest problem was in obtaining video connectors to work correctly with the video cable; this problem led to delays in cable installation and replacement of low-quality connectors with the correct connectors for the cable. The cable selected was a new product line because connector manufacturers did not have any connectors that fit the cable properly. RCOC retained the AUTOSCOPE developer under a continuing engineering contract to train installation technicians and engineers, quickly resolve installation problems and issues, define optimal detector placements for the best road coverage for each intersection, assist in programming the AUTOSCOPE detectors, and troubleshoot interface problems with the SCATS controller. Some other minor problems with installing the first AUTOSCOPE production units were quickly overcome. The installation was started in February 1992 and finished in May 1992. The official commencement of the entire system was June 1992.

CONCLUSIONS

The first and largest worldwide installation of video-based vehicle detection for adaptive intersection control was successfully deployed and is operational today. The system has been running continuously since May 1992. Because the integration and field deployment of AUTOSCOPE with adaptive control appears to be an early winner in the area of IVHS, the system is being expanded to 94 intersections and will eventually grow to 800.

Considerable logistical and technical problems had to be overcome. These were resolved through close cooperation of the participants and competent project management. RCOC took considerable, but calculated, risks in attempting to deploy machine vision on such a large scale for the first time rather than seeking the safety of proven systems. The risk seems to be paying off since development of the next generation of adaptive control is now feasible, and plans are currently under way to achieve this control on the basis of the AUTOSCOPE capabilities that have not yet been fully used. RCOC was also prudent to receive thorough training and expert assistance to correctly engineer the system components and installation sites for the deployment of the new integrated technology. The project clearly benefited by having enthusiastic and high quality human resources, including managers, engineers, and technicians to quickly and efficiently make changes and modifications as needed. The entire program is an excellent example of public, private, and academic cooperation to meet the primary program objective of improving urban traffic mobility and safety.

A word of caution on the AUTOSCOPE implementation and field deployment is in order. Specifically, the device is not simply a replacement of loops that will continue to serve their intended purpose for some time; instead AUTOSCOPE should be viewed as a wide-area detection device that can obtain valuable information and extract traffic parameters and measures of effectiveness (delays, stops, queue lengths, energy consumption, etc.) that are hard, labor intensive, time-consuming, and expensive to obtain. Such capabilities should lead to more effective ATMS and ATIS applications and deployment.

REFERENCES

1. P. R. Lowrie, SCATS Sydney Coordinated Adaptive Traffic System: A Traffic Responsive Method for Controlling Urban Traffic. *Road and Traffic Authority of N.S.W.*, Sydney, Australia, 1990.
2. P. G. Michalopoulos. Vehicle Detection Through Video Image Processing: The AUTOSCOPE System. *IEEE Transactions on Vehicular Technology*, Vol. 40, No. 1, 1991, pp. 21–29.
3. J. Grubba, J. Haugan, and R. Knockeart. Implementing the FAST-TRAC ATMS/ATIS Demonstration Program. *Proc., 2nd International Conference on Vehicle Navigation and Information Systems (VNIS)*, Detroit, Mich. 1991.
4. P. Michalopoulos, B. Wolf, and R. Benke. Testing and Field Implementation of the Minnesota Video Detection System. In *Transportation Research Record 1287*, TRB, National Research Council, Washington, D.C., 1990, pp. 176–184.
5. P. G. Michalopoulos and R. Jacobson. Implementation of Image Processing in Traffic Detection, Surveillance and Control. *Proc., International Conference on AI Application Transportation Engineering*. San Bonaventura, Calif., 1992, pp. 311–325.

Publication of this paper sponsored by Committee on Traffic Signal Systems.