

RECENT ADVANCES IN IMPLEMENTATION OF MACHINE VISION TECHNOLOGY IN FREEWAYS

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Abstract

Although successful deployment of new technology in Advanced Traffic Management Systems is constantly sought in ITS projects, it is often not realized. One of the limited number of new technologies that is proving successful is wide area video detection. In this paper, successful deployment of this technology in freeway traffic management projects is presented. Even though the technology can be used in any traffic management application requiring vehicle detection, incident management appears to be its most popular application on freeways so far. This may be because incident detection, response, and management is still one of the major challenges in urban freeway operations, requiring constant attention and considerable investment in manpower and equipment. However, despite efforts worldwide, fast and reliable automated incident detection has been elusive. In this paper, a new automated incident detection and management system based on wide area video detection (machine vision) is briefly reviewed.

Following many years of development and field implementation at several beta sites, the system has been substantially improved and a more sophisticated version was recently deployed on the Gowanus Expressway in Brooklyn, New York. This paper describes the fieldable version of the system along with results observed up to the time of the writing of this paper. So far the system successfully detected 81% of the incidents, had no false alarms, and reduced incident response time substantially. Deployment of the technology in various forms at several other sites for freeway management is also summarized.

Introduction

Successful deployment of state-of-the-art technology in the field is essential to support the ITS movement. One of the new technologies which is gaining acceptance among practicing traffic engineers is wide area video detection (machine vision). This paper presents the successful deployment of this technology in recently completed and operational projects for freeway traffic management. Even though the technology can and is employed in any traffic management application requiring vehicle detection and wide area data extraction, incident management appears to be the most popular application of this technology on freeways at this early stage. However, despite continuous efforts worldwide, fast and reliable automated incident detection and management has been elusive. Conventional, automated techniques based on computerized algorithms have been less effective than desired for operational use as they generate a high level of false alarms or missed incidents. Manual, operator-assisted methods, on the other hand, minimize the false alarm risk but also suffer from missed or delayed detections, are labor intensive, and restrict the potential benefits of advanced integrated traffic management as they require human attention for detecting incidents rather than confirming, responding, and managing them through computer-aided means.

Video detection is receiving much attention for incident detection applications because of its ability to detect over a wide area. Video detection has now been available commercially for several years and is gaining acceptance as a more effective tool than conventional inductive loop detectors. The additional benefits of using video are many. Key is the ability to cover many lanes with one camera and extract wide area measurements, such as density, queue length, speed profiles and others. Additionally, lane closures are typically not needed during installation which results in increased driver and traffic personnel safety and minimal traffic disruption. In fact, once installed, they are typically used during subsequent road construction or resurfacing by repositioning cameras, as needed, as the road geometry varies.

Finally, if desired, the video can be used to provide or supplement existing video surveillance. For these and other practical and theoretical reasons, video detection systems have generated much interest for those involved in advanced traffic management systems. Unfortunately, most video-based incident detection systems proposed or implemented so far are rather simplistic. In effect, they have degenerated to simply detecting the onset of congestion while they are unable to detect incidents beyond the effective field of the camera's view (only a few hundred feet for effective image processing), as they lack sophisticated algorithms or incident detection logic capable of capitalizing on the real advantages of machine vision.

The incident detection system discussed here is an outgrowth of an earlier system described in the next section. Following many years of development and experimentation in Minnesota, the system was enhanced and incident management features were added. In addition, the system was installed experimentally in Montgomery County, Maryland prior to large-scale deployment on the Gowanus

Expressway, on the Olympic Road Freeway in Korea, and in several other projects. The machine vision technology was also deployed on I-75 in Atlanta for the 1996 Olympic Games and is currently being expanded. The I-75 (Atlanta) and Korean deployments are described in referenced articles (Culver, 1997) and (Vinger, 1997). The Gowanus deployment is presented here. Despite of the fact that the enabling technology used in all projects is the same, there are significant differences in the specific system deployments at each site. For instance, GDOT is using the machine vision technology in connection with a different incident detection/management scheme of its own design, while Gowanus expanded on the basic system described here. Other deployments, briefly presented as well, have their own custom tailored features.

Background

The initial development of the machine vision-based Automated Incident Detection Algorithm (AIDA) was completed using an 80386-based PC, interfaced to a video detection system. The video detection system used was the Autoscope, first developed by the University of Minnesota (Michalopoulos, 1991). Because only single, isolated, video detection stations were available, the detection algorithm was required to use a single station rather than multiple stations. There are several advantages to a single station algorithm. To begin with, no sensor data from an adjacent detector station is required, thus reducing algorithm complexity. Several algorithms were developed and compared and are discussed in the referenced article (Michalopoulos, 1993).

However, since the AIDA algorithm was believed to be the most promising, it was selected for continued development and evaluation. The algorithm initially used speed, occupancy, and volume data as provided by the video detection system. These were averaged into 30-second intervals, and thresholds were applied to look for rapid changes indicative of a capacity reducing event. Later AIDA was improved to include ancillary information provided by video detection such as stopped vehicles and shock wave signature recognition. Since its initial deployment in 1992, numerous improvements to the machine vision-based incident detection system were made. The 80X86 PC platform video detection server has been streamlined and improved. It has been designed to talk to many detection devices either directly, or on multidrop communication lines, or any combination of the two.

The communications bandwidth requirements were greatly reduced by using the distributed processing afforded by the new video detection system. Interval statistics, no longer calculated on the server, are obtained by simply polling each video detection system. A new level of service (LOS) congestion grade is displayed using user-selected thresholds either from the Highway Capacity Manual or from custom-defined thresholds. An application programming interface was developed to enable end users to write their own applications (such as their own incident detection logic, ramp control schemes, speed alarms, congestion level indicators, etc.) using data collected by the server. The new AIDA algorithm now runs as an application itself on the server. In fact, several different incident detection algorithms can be run concurrently if desired. Finally, to provide quick verification of incident alarms, integrated camera management

capabilities have been added to automatically call the appropriate video camera output to the operator's computer screen or a user-selected monitor.

In addition, a number of changes have been made to improve the AIDA algorithm by adjusting the turn-off logic, streamlining the turn-on logic, and adding logic to create an alarm when stopped vehicles on the shoulders or in the traveled lanes are detected. In order to achieve this latter feature, a new type of detector was developed. This is called the stopped vehicle detector. It simply detects stopped vehicles within the field of the camera's view. This feature cannot be duplicated by loop detectors. The user can place many virtual stopped vehicle detectors interactively on the video monitor and set location and lane-specific thresholds which, if exceeded, will generate an alarm.

It should be noted that in 1995, the incident detection logic was moved from the centrally located PC-based system server to the Autoscope unit in the field. This ensured that at large-scale installations a software failure would contain the problem to only a few cameras rather than the entire system. Of equal importance was the development of a more compact and reliable as well as considerably less expensive fourth generation Autoscope unit in 1995 (the 2004). This unit has also been substantially improved since then through several software releases to achieve substantially more effective shadow treatment, image stabilization, video frame compression, and numerous other performance and functional features. The incident detection system was also incorporated into the 2004. The 2004 processes the traffic data (speed, volume, occupancy, etc.) in ten-second increments enabling incident alarms within 30 seconds, a 66% improvement. Along with this, as large-scale deployment of the video-based technology began to take hold, it became necessary to communicate with many machine vision units and manage the processed data in real time. For this purpose the ScopeServer Interface Developer's Kit (IDK) was developed. This IDK is a Microsoft Windows(r) application that provides communication between a central computer and over 100 Autoscope units (processing over 400 cameras). In this manner the integrated data can be used for developing other applications, such as ramp control, signal optimization, adaptive control, variable message signs, incident management, and others. The data (in up to ten-second increments) can also be stored or graphically presented on demand and passed to multiple users. This allows many applications to run in parallel. For instance, ramp control, variable message signs, incident detection, and tunnel control can all run in parallel.

Gowanus Expressway Deployment

The Gowanus Expressway rehabilitation project in Brooklyn, NY is the first site at which the complete incident detection system described earlier was employed on a non-experimental basis and has been working flawlessly since May 1997. Installation began in the second half of 1996. It is one of the most advanced incident detection systems presently deployed in the United States. The system consists of 20 CCTV surveillance cameras with pan/tilt/zoom capabilities, the automated incident detection/management system, highway advisory radio, variable message signs, and a construction information hotline.

When the New York State Department of Transportation (NYSDOT) made the decision to revamp the Gowanus Expressway, it was determined that an incident detection system had to be employed to minimize the effects of road construction on traffic flow. The construction on the roadway included resurfacing and major structural work, such as expanding the width of the road and relocating a two-lane exit ramp. Activities of this nature and magnitude tend to cause major traffic flow disruption. As a result of the automated management system installation, traffic moves freely with minimal disruption related to the clearing of incidents. Initial system installation took about three months. The construction consisted of both field work (installing the cameras, camera equipment, and fiber optic equipment), as well as the construction of the TCC itself. System integration was completed in April 1997. At that time the system became fully operational. The detection system was initially put into place to monitor and manage the traffic on the roadway during the reconstruction of the Expressway. However, given the resulting effective performance, it was decided to keep it in place after the completion of the rehabilitation project.

In addition to the 20 surveillance cameras, 43 Imaging Sensors (cameras meeting machine vision specifications) were mounted on existing luminaire poles, throughout the construction area. Even though the construction area is 8km (five miles) long, a total of 16km (ten miles) of roadway is covered by the 43 Imaging Sensors (IS). The live video is fed to fiber optic transmitters via single-mode fiber optic cable to the TCC. The video signals for each of the 43 IS are fed to their respective input on one of eleven Autoscope processors, called Machine Vision Processors (MVP). At that point the video image is digitized and the processing of the video occurs. Each MVP provides up to four video inputs for detection processing and a fifth input for surveillance purposes. The video output of each MVP is terminated to the video input panel of the CCTV matrix switcher. Although the video output of an MVP does feed into the matrix switcher, the TCC operators do not normally view the image from the IS. For troubleshooting and monitoring purposes, the system was designed so that authorized personnel have the ability to view the video from the image sensors on the bank of monitors by using the matrix switcher. The advantage to this design is that from a central location the video from all of the image sensors may be viewed quickly on a large screen automatically without having to connect and reconnect to the video output of each of the eleven MVPs. It is possible to tour through each of the 43 IS to verify that they, as well as the virtual traffic sensors, are all functioning properly and are aimed at the correct location.

Operation

To provide incident detection, virtual detection zones are overlaid onto the field of view for each of the 43 image sensors via the Supervisor software. These detection zones, or virtual detectors, are then downloaded to the MVP corresponding to the specific IS. As the video images feed into their respective MVP in real time, the processors analyze the video and determine speed, occupancy, volume, stopped vehicles, and other traffic parameters as traffic moves through the detector zones. If the AIDA incident detection software residing in the MVP determines that an incident has occurred, an audible

alarm is generated, the live video from the corresponding IS is displayed, and the TCC operators take the appropriate action to confirm and clear a possible incident.

The TCC operators are integral to the process of determining whether an alarm is truly an incident. Six television monitors are utilized by the TCC operators to view traffic conditions on the roadway. The operators have the ability to pan, tilt, and zoom the 20 surveillance cameras. If an alarm is generated by AIDA, precedence takes place and automatically two CCTV cameras associated with the specific alarm, condition pan, tilt, and zoom to their preset alarm positions. The video images from the associated CCTV cameras are broadcast to two previously determined television monitors, which become dedicated to that alarm condition. At that point the operators make the determination whether the alarm is a true incident and take the appropriate action to clear any possible problems and keep the traffic moving freely.

Following system installation the TCC operators are free to attend to other duties without fear of missing incidents. Audible alarms alert the operators to suspected incidents. If an operator steps away from their command post for a moment and an alarm condition arises, when the operator returns, the suspected incident area will be in view on the monitors and the alarm will not clear until the operator acknowledges the alarm and responds to it.

The equipment that was used on this project is an innovative example of the positive steps being taken to keep the traffic on roadways moving. By integrating fiber optics as a transmission system, surveillance cameras for monitoring purposes, and the machine vision processors for incident detection and traffic data storage, this system has been proven to be successful.

Further Design Considerations and Performance

The incident detection design consists of two parallel systems operating separately and in conjunction with one another. First, the image processors collect traffic data and provide alarms of suspected incidents. Second, when no incidents are confirmed or are being responded to, the operators use the surveillance cameras to monitor the roadway, looking for motorists who may be having problems. These two systems are complimentary and work in conjunction with one another during an incident. The video feed from the image sensors is not viewed by the operators for monitoring purposes. Therefore, the operators use the surveillance camera to provide the visual information necessary to determine the corrective action needed without disturbing the machine vision cameras. Once an alarm is flagged, the surveillance system is automatically directed to position two adjacent surveillance cameras to view the incident location where the alarm was generated. After response to the alarm has been made, control of all surveillance cameras and monitors is returned to the operators. In addition, warnings are being displayed through variable message signs and over the highway advisory system to enable the drivers to avoid the problem area. Warnings of delays are also posted on sites on the Internet.

Prior to the new incident management system installation, the average time to clear an incident was 1.5 hours. Since the system has become operational, the average time to clear any incident has been substantially reduced. If a vehicle breaks down, the time to aid the motorist from the incident inception to the clearing of the incident is averaging 19 minutes. Similarly, the time from inception of an incident to clearing is now averaging 31 minutes. To aid in the speed of incident clearing, four tow trucks are stationed at various locations on the roadway.

Since the installation of the system in April 1997, operational test and evaluation have begun. During the month of May 1997, 100 incidents occurred within the 16km area where the system was installed. Of these, 81% were correctly detected by AIDA, 19% were missed, and there were no false alarms. The lack of false alarms is significant because high false alarm rates have historically discouraged automatic incident detection. The low false alarm rates may come at the expense of incident detection accuracy; however, the relatively small drop in detection accuracy (from over 90% to 81%) was considered more than satisfactory by the system operators.

Additional Freeway Technology Deployment

As mentioned earlier, the enabling machine vision technology described here has now been employed in many ATMS deployment projects worldwide. In what follows, brief descriptions of some representative deployments on freeways are presented to demonstrate the diversity as well as the most common practical uses of the new technology so far.

Atlanta's ATMS Deployment

Atlanta's new ATMS, which was designed for the 1996 Olympic Games, monitors traffic flow along I-75 and I-85 for incident management and provides up-to-date traffic information to the traveling public in the greater Atlanta area. The ATMS currently covers 90km (60 miles) of roadways with 316 IS cameras and 57 six-camera video detection units which are used to generate 5000 virtual detection zones. For this ATMS, the Georgia Department of Transportation (GDOT) selected the Autoscope as the most mature wide area video vehicle detection system for a variety of reasons, including minimizing lane closures during installations and any future maintenance activities. In this project the 57 MVPs provide speed, volume, occupancy, level of service, vehicle classification, stopped vehicle detection, and wrong way traveling vehicle detection, as they accumulate traffic statistics. As part of this ATMS project a 32-bit communications ScopeServer was employed, which runs on a Pentium PC with the Windows(r) NT operating system. A Digi C/CON 16-port concentrator provides separate serial communication channels to different MVP units for multidrop communication. This concentrator is expandable to support a larger number of channels as the Atlanta ATMS grows.

The ScopeServer uses the TCP/IP protocol to support platform-independent client communication. This enables, for example, the ATMS software running on Sun

Microsystems's Solaris Workstation with the UNIX operating system to communicate with the field Autoscoopes. The ScopeServer IDK for client/server communication is also supported. This IDK was used by GDOT to develop a specially designed Count Station Data Acquisition System (CSDAS). Every 20 seconds the ScopeServer polls each of the image processing units and relays the data to the CSDAS database. The database provides real-time traffic data access to all ATMS applications, such as incident detection and map display. The ScopeServer software is fairly robust and well tested. It can retrieve a data package from the largest cluster or "hub" of all 57 six-camera MVPs in the Atlanta ATMS in merely three seconds, using a communication baud rate of 19,200 bps.

There are three major benefits of this machine vision-based ATMS in Atlanta. First, in the Atlanta ATMS, traffic data flows directly from each field MVP to a PC at the TCC, unlike other systems which use additional field controllers to convert the data from video or loop detectors to transmit to the TCC. Second, data acquisition and incident detection are performed in different computers connected through a client-server network, thereby achieving faster incident response, unlike other systems in which incident detection must be done concurrently by the same computer which is acquiring the data and thus significantly slowing down the incident response. Finally, machine vision provides a variety of traffic data and a method to archive this massive amount of data for later analysis, which enables the traffic manager to detect traffic trends and problem patterns. Because of its successful deployment, GDOT is currently in the process of expanding the video detection system and the ATMS to an additional 112km (70 miles) and 300 machine vision cameras. This makes the Atlanta installation the largest known freeway deployment of machine vision worldwide.

New Jersey Turnpike

The NJ Turnpike has eleven four-camera MVP units deployed, and nine more are being designed into projects that will start in 1997. The units are deployed near the Newark Airport monitoring six lanes in each direction. In this deployment machine vision is collecting volume, occupancy, and speed. The occupancy data has proven to be compatible with occupancy obtained for inductive loops from neighboring roadways. The data is fed into a freeway management system running an incident detection algorithm based on occupancy (a version of the modified California Algorithm) from other sensors in the system. The machine vision sensors were deployed prior to construction to provide continuous detection and flexibility of detector placement for traffic diversion. Four cameras were deployed at each station (one camera per three lanes) because the agency was not sure of the traffic re-routing requirements during construction. The sensors are interfaced to local M-170 controllers in the field to collect real-time traffic data and communicate to the central traffic management system. The Turnpike Authority is planning to expand the same instrumentation to an additional 134 miles of freeway. Prior to this decision the performance of machine vision compared to radar detection was evaluated. The radar sensors did not pass the evaluation performance tests.

Integrated Corridor Traffic Management

Mn/DOT initiated the Integrated Corridor Traffic Management Project (ICTM) in 1994. Its goal is to instrument a parallel arterial corridor to a major freeway (I-494) with an adaptive intersection control (SCATS) and divert traffic to the arterials during heavy congestion or incidents. The project includes eleven four-camera MVPs deployed on intersections, ramps, and freeways. Five MVPs were acquired for use in the first three phases on a section of arterial roadway under construction. The units are providing stop line detection to enable signal phases during construction and will remain permanently installed at the end of the project to provide strategic and tactical detection for the SCATS. Additional units will be installed in follow-on phases on the freeway for adaptive ramp control, freeway incident detection, and freeway count station detection during roadway resurfacing that will destroy all inductive loops.

The technology is also being used by Mn/DOT at several freeway construction sites for detecting incidents and controlling variable message signs. For this purpose a special portable video detection system had to be developed which transmits wireless video and data to a central location in the Twin Cities.

Additional Deployments

Another example of an installation that will be using the AIDA system is in Albuquerque, New Mexico. This installation not only uses machine vision-based incident detection at major on and off ramps, but also will control the signalized intersections located at these on and off ramp points. A total of four video detection units, each processing four cameras, will be deployed initially for this project. In this setup, twelve of the sixteen cameras will be used for intersection control, and four cameras will be used for freeway monitoring and incident management. An additional two to three four-camera video detection units will likely be installed in the near future as the project expands. Two recent examples of machine vision installations which are monitoring freeway status (but not using incident detection), are in Houston, Texas and in Brazil. The installation in Houston is along the I-610 ring road circling the Houston metropolitan area. This installation is being implemented in several phases. The technology described here has already been chosen for two of the phases for a total of 44 MVP units and 127 cameras. A third phase is in the acceptance stage currently. This phase will include an additional 20 MVP units and 73 IS cameras. Machine vision will be used to report vehicle speeds and counts back to a central location via special controllers for traveler information and for general traffic management.

The Brazilian installation uses two video detection units and eight IS cameras to monitor bi-directional traffic on one stretch of freeway. The MVP units will report real-time data via a serial link back to a central location which will then disseminate the information and provide travelers with updated reports about traffic conditions via the Internet.

Overseas Deployments

As the technology is being accepted and deployed overseas, large-scale deployment is being experienced there as well. The largest known so far is a multiphase freeway traffic management project in Korea. The first phase of the project will cover 18km of the eight-lane Olympic Road highway from the airport to downtown Seoul.

The management system is designed to monitor the freeway traffic as well as manage and control day-to-day traffic. Machine vision will provide average vehicle speed, volume, and occupancy data, while AIDA will detect incidents on the freeway. The data and live video signals will be transmitted to the City's traffic management center via fiber optic lines. Special-purpose custom application software will poll each MVP every 30 seconds through the ScopeServer communication server. Processed data will then provide estimated travel time, and Changeable Message Signs (CMS) will display this information to motorists. The initial phase of the project included 34 cameras and seventeen two-camera Autoscoptes. Construction commenced in 1996, and the machine vision equipment was installed in May of 1997.

Concluding Remarks

After many years of experimentation and several generations of video sensors for wide area vehicle detection, it appears that the Minnesota technology is now mature and cost-effective for truly advanced traffic management applications. This, of course, did not occur without relentless, dedicated, long-term field experimentation and countless tests, comparisons and feedback from government agencies, as well as the foresight and willingness of the engineers responsible for the many projects incorporating the technology to take risks. To be sure, many difficulties were encountered, ranging from poor camera quality and placement to deficiencies in communications and the machine vision software. In the end, initial failures were turned into successes because of the willingness of the engineers to work with the developers of the technology, the spirit of pioneering new technology and, perhaps most importantly, the persistence and determination to succeed.

In the Gowanus Expressway project the decision to keep the system after construction is complete demonstrates the confidence of the responsible authorities in the system's reliability and performance, as well as its user-friendliness. In Atlanta, bringing together many different technologies, including machine vision, meant overcoming integration challenges of both infrastructure and software. Despite the initial problems encountered, the satisfaction of the GDOT and the benefits for Atlanta and the surrounding communities far exceeded expectations. It is for this reason that the ATMS system, including the machine vision part, is currently more than doubling its Centennial Olympics' size.

Hopefully, this paper presented at least a glimpse of the potential of successful machine vision deployment in innovative ATMS applications. As this and other technologies improve and take hold, traffic management systems such as the ones described here will become more common. The lessons learned in such projects should not only lead

to more effective utilization of machine vision technology, but also to greater technology accessibility as well to lower costs.

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