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CAMERA POSITIONING AND CALIBRATION TECHNIQUES FOR INTEGRATING TRAFFIC SURVEILLANCE VIDEO SYSTEMS WITH MACHINE-VISION VEHICLE DETECTION DEVICES

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16. Abstract

The Virginia Department of Transportation has invested significantly in extensive closed circuit television (CCTV) systems to monitor freeways in urban areas. Although these systems have proven very effective in supporting incident management, they do not support the collection of quantitative measures of traffic conditions. Rather, they simply provide a moveable platform for trained operators to collect images for further interpretation. Although there are several video image vehicle detection systems (VIVDS) on the market that have the capability to derive traffic measures from video imagery automatically, these systems currently require the installation of fixed-position cameras. Thus, they have not been integrated with the existing moveable CCTV cameras.

This research effort addressed VIVDS camera repositioning and calibration challenges and developed a prototype machine-vision system that successfully integrates existing moveable CCTV cameras with VIVDS. Results of testing the prototype in a laboratory setting demonstrated that when the camera's original zoom level was at a level of 1x to 1.5x, the system could return the camera to its original position with a repositioning accuracy of less than 0.03 to 0.1 degree. This is significantly less that the 0.5-degree accuracy of mechanical camera presets and indicates that such an approach provides the accuracy needed for CCTV/VIVDS integration. This level of positional accuracy, when combined with a VIVDS, resulted in vehicle count errors of less than 1%. Based on these results, the integration of CCTV and VIVDS is feasible, thus paving the way for less costly, more easily maintained traffic monitoring systems in future intelligent transportation system initiatives.

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ABSTRACT

The Virginia Department of Transportation, like many other transportation agencies, has invested significantly in extensive closed circuit television (CCTV) systems to monitor freeways in urban areas. Although these systems have proven very effective in supporting incident management, they do not support the collection of quantitative measures of traffic conditions. Rather, they simply provide a moveable platform for trained operators to collect images for further interpretation. Although there are several video image vehicle detection systems (VIVDS) on the market that have the capability to derive traffic measures from video imagery automatically, these systems currently require the installation of fixed-position cameras. Thus, they have not been integrated with the existing moveable CCTV cameras.

This research effort addressed VIVDS camera repositioning and calibration challenges and developed a prototype machine-vision system that successfully integrates existing moveable CCTV cameras with VIVDS. Results of testing the prototype in a laboratory setting demonstrated that when the camera's original zoom level was at a level of 1x to 1.5x, the system could return the camera to its original position with a repositioning accuracy of less than 0.03 to 0.1 degree. This is significantly less that the 0.5-degree accuracy of mechanical camera presets and indicates that such an approach provides the accuracy needed for CCTV/VIVDS integration. This level of positional accuracy, when combined with a VIVDS, resulted in vehicle count errors of less than 1%. Based on these results, the integration of CCTV and VIVDS is feasible, thus paving the way for less costly, more easily maintained traffic monitoring systems in future intelligent transportation system initiatives.

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INTRODUCTION

A fundamental function of a transportation management center (TMC), such as the Smart Traffic Centers operated by the Virginia Department of Transportation (VDOT) in Northern Virginia, Hampton Roads, and Richmond, is to monitor traffic conditions. Traditionally, two independent subsystems have been used to support this function. First, vehicle presence sensors were installed throughout the network to collect quantitative measures of traffic conditions, including flow rates, average vehicle speeds, and sensor occupancy levels (a surrogate of traffic density). These sensors are costly to install and maintain given the large number required and the harsh conditions in which they operate. The second subsystem is a network of closed circuit television (CCTV) cameras that are typically used by TMC operators to inspect traffic conditions visually and to investigate details of traffic incidents to support improved response. As such, the CCTV subsystem relies on moveable (i.e., pan, tilt, zoom) cameras. This subsystem has proven to be particularly expensive to install given the high communications bandwidth requirements of video transmission.

In Virginia, inductive loop detectors have traditionally been the presence sensors of "choice" for TMCs. However, an attractive alternative that has emerged in the last decade is video image vehicle detection systems (VIVDS). VIVDS use software to analyze digitized video to identify the presence of vehicles in zones manually defined by engineers calibrating the system. In other words, an engineer will install a video camera and define detection zones in travel lanes, and then the software will essentially mimic the operation of an inductive loop detector. The definition of the zones is a very important aspect that must be completed precisely. Research has shown that if the camera is moved, it is quite difficult to reposition it adequately to allow the VIVDS to continue operating using the originally defined zones (Cottrell, 1994). For this reason, the accepted practice is to use VIVDS only in conjunction with fixed-position cameras. This has prevented the integration of VIVDS with CCTV systems.

Of course, the integration of VIVDS with CCTV systems would provide the enormous benefit of combining the infrastructure needed for the two key traffic monitoring functions of TMCs. Simply put, the savings in terms of installation and maintenance costs that would be realized are significant. For this reason, the Virginia Transportation Research Council proposed this project, with the full endorsement and support of VDOT's ITS Research Advisory Committee.

To quantify this benefit conservatively, consider the impact of replacing a portion of the existing loop detectors in the Hampton Roads Smart Traffic Center (HRSTC) with integrated CCTV/VIVDS. The HRSTC currently includes 200 detector "stations," which generally consist of loops in each of four travel lanes. To quantify the benefits, assume that integrated CCTV/VIVDS will allow for the elimination of one fourth of the loops, or 200 loops total.

The costs of the current HRSTC monitoring subsystem, both in terms of initial construction and annual maintenance, have been estimated based on unit costs published by the USDOT's ITS Benefits and Unit Costs database (www.benefitcost.its.dot.gov). Table 1 presents the estimated costs for the current HRSTC system, only considering the 200 loops in question. Since most STCs in Virginia use large fiber-optic communications networks, communications costs are not included in this analysis.

Table 2 presents the costs associated with HRSTC with a CCTV/VIVDS system deployed, eliminating the need for loop detectors.

Thus, this conservative analysis indicates that VDOT could realize over $1 million in construction cost savings for the HRSTC based on integrated CCTV/VIVDS deployment, as well as a reduction in maintenance costs. In addition, the benefit would be even greater given that the integrated CCTV/VIVDS system would not necessitate lane closures to repair detectors as is currently necessitated by loops.

Table 1. Costs for Existing HRSTC Loops/CCTV

Component	**Magnitude**	**Unit Price - Constr**	**Total - Construction**	**Unit Price - Maint**	**Total - Maintenance**
Loops	200	6,500	1,300,000	650	130,000
CCTV	40	40,000	1,600,000	2,000	80,000
Towers	40	40,000	1,600,000		
Processor and Software for CCTV			150,000		20,000
Integration			250,000		
Total			**4,900,000**		**230,000**

Table 2. Costs for HRSTC with Integrated CCTV/VIVDS Deployed

Component	Magnitude	Unit Price - Constr	Total - Construction	Unit Price - Maint	Total - Maintenance
CCTV	40	40,000	1,600,000	3,000	120,000
Towers	40	40,000	1,600,000		
Processor and Software for CCTV		150,000	150,000		20,000
Processor and Software for VIVDS		150,000	150,000	7,000	7,000
Integration		250,000	250,000	12,000	12,000
Total			**3,750,000**		**159,000**

PURPOSE AND SCOPE

The purpose of this research effort was to evaluate the technical difficulties associated with integrating VIVDS with existing CCTV cameras and control equipment and seek to determine the feasibility of developing automated, machine-vision techniques that effectively address these difficulties.

The scope of this study was limited to prototype development and testing in a laboratory environment designed to emulate a field installation. This minimized development and testing cost and complexity as the feasibility of CCTV/VIVDS integration was investigated.

METHODOLOGY

Four tasks guided the research effort:

1. Review the literature.

2. Design a prototype CCTV/VIVDS integrated system.

3. Implement the prototype.

4. Test the prototype.

Literature Review

A review of the literature was conducted to provide a foundation for the research. The literature review focused on the three areas: (1) CCTV fundamentals, (2) VIVDS fundamentals, and (3) CCTV/VIVDS integration.

Design of Prototype CCTV/VIVDS Integrated System

Based on the lessons learned from the literature review and discussions with VDOT TMC personnel, a prototype design was developed to integrate VIVDS with moveable CCTV cameras.

Implementation of Prototype

Using the design developed in Task 2, the prototype system was implemented in the Smart Travel Laboratory. The system was built using the LabVIEW software package and its associated image processing capabilities.

Testing of Prototype

The prototype system was tested in the laboratory to assess its potential for field deployment. Two series of tests were performed: positioning and performance.

Positioning

The first series of tests were designed to determine the precision to which the prototype system could reposition a camera in the pan/tilt/zoom fields. This set of tests was necessary to ascertain if the repositioning was sufficiently accurate to allow for integration with a VIVDS system.

A grid was created on a 4-ft by 4-ft screen. The grid was broken down into fractions of an inch. Also drawn on the grid was a simple target pattern that could be tracked by the prototype system. This screen was placed 25 ft away from a Pelco Esprit camera and integrated prototype positioning system. A laser was then attached to the top of the camera with the beam pointing in the same direction as the camera lens. Thus, the combination of the laser and grid allowed for a precise determination of the camera's position. Two tests were run using the experimental setup shown in Figure 1.

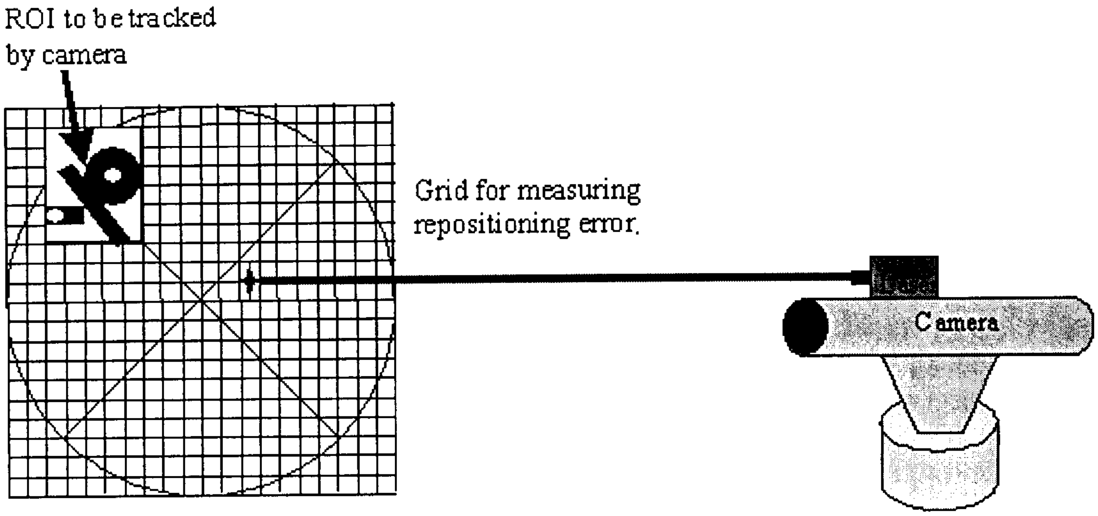

Figure 1. Position Testing Experimental Setup

Test Case A: Zoom

Test A measured the precision of the prototype system when re-zooming the camera to a desired level. First, the size of the grid when viewed on the monitor was measured, and then the camera was zoomed out. Next, the prototype system attempted to re-zoom to the original zoom setting. After the prototype system had finished, the size of the grid when viewed on the monitor was measured. This change in grid size, or re-zooming error, was measured as the percent difference from the original size

Test Case B: Pan and Tilt

Test B measured the prototype system's ability to reposition the camera in the pan and tilt directions given that the zoom field had already been set. The prototype system was used to locate the region of interest (ROI) drawn on the grid and position the camera to a set of coordinates. Once the ROI had been tracked, the position of the laser beam hitting the screen was marked as a reference point. Then the camera's pan and tilt settings were changed, and the prototype system attempted to reposition the camera back to this reference point. This test was repeated 10 times for each of four zoom factors.

Performance

Fundamentally, these tests measured the accuracy of vehicle counts from the VIVDS system after the CCTV camera had been moved and repositioned by the prototype system.

Testing was conducted in a laboratory setting and was designed to emulate a real-world freeway management system. A video recording of traffic was obtained from the Hampton Roads Smart Traffic Center in southeastern Virginia. The recording was of a four-lane freeway, (three standard lanes and one HOV lane) and was recorded from a CCTV camera mounted on top of a 60-ft tower. During taping, the camera's parameters were not changed (i.e., pan, tilt, and zoom levels were held constant).

The laboratory set up, illustrated in Figure 2, consisted of a VCR, a video projector, a large projection screen, two personal computers, the Pelco camera and positioning system, and the Autoscope 2004 unit. The traffic video was projected onto a large, 15-ft by 15-ft screen. The Pelco Esprit camera and integrated positioning system was positioned 25 ft away from the screen. This distance was such that the video projected onto the screen matched the camera's field of view in the field. Thus the images viewed on the Pelco video camera were of the same scale as those recorded by the original TMC CCTV camera. One PC was connected to the Pelco camera and was used for all image processing and camera control. A second PC was directly interfaced with the Autoscope 2004 unit. After the Autoscope 2004 unit was calibrated, it digitized video frames of traffic from the Pelco camera, processed them, and measured vehicular traffic counts.

Four tests were conducted to evaluate the VIVDS traffic measurement performance using the prototype system:

1. normal field of view during daylight (zoomed at 1x)

2. smaller than normal field of view during daylight (zoomed at 1.5x)

3. smaller than normal field of view during daylight (zoomed at 2.0x)

4. normal field of view at nighttime (zoomed at 1x zoom).

Testing was conducted only at these zoom levels because further zooming would typically eliminate full viewing of the road. Zooming the camera further than this is usually reserved for specific incident inspection where a TMC operator may need to inspect a single lane of traffic very closely to verify the nature of an incident. TMC operators generally prefer to have the CCTV camera zoomed out as far as possible under "normal" conditions so that the amount of freeway they can monitor is maximized.

Each of the four tests evaluated the prototype system performance against two other methods of repositioning: (1) manual repositioning, and (2) camera "preset" repositioning. The tests were run using the following procedure:

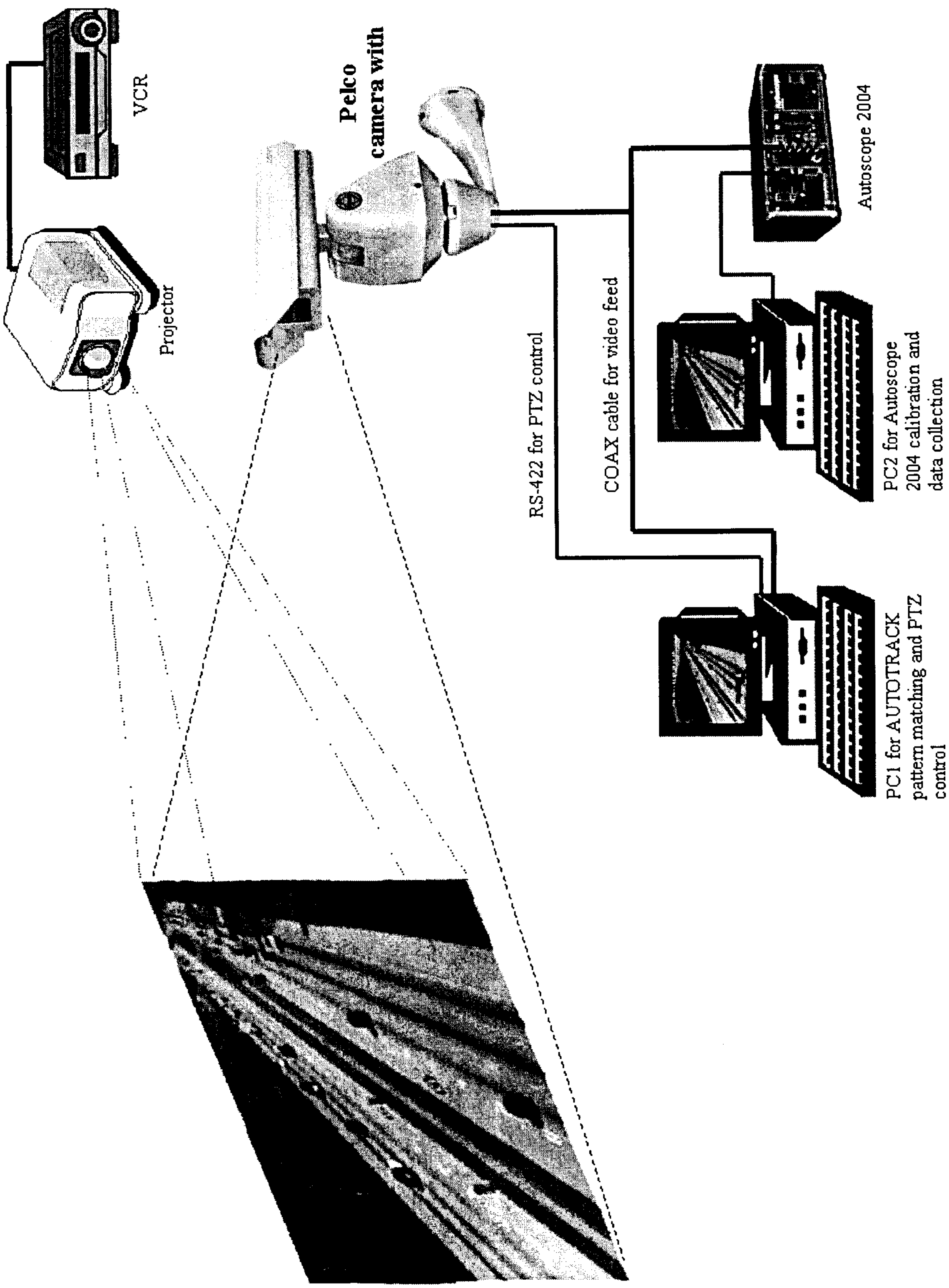

Figure 2. VIVDS Performance Testing Experimental Setup

1. The camera was first aimed at the projection screen and the desired pan, tilt, and zoom (PTZ) fields were set. This PTZ position was programmed into the camera as a "preset."

2. An appropriate ROI was selected. For all tests, the ROI used for pattern matching was the HOV diamond already drawn in the HOV lane. Although this is not an ideal ROI, it did have sufficient contrast and was large enough that it could be detected by the pattern matching algorithms.

3. The Autoscope 2004 detection zones were calibrated to the view from this current camera configuration.

4. The traffic videotape was played and traffic volume data were collected with the Autoscope unit.

5. After this "base" dataset was collected, the camera was moved out of position such that the detector zones were no longer in the correct place but the ROI was still visible.

6. The prototype system was then used to automatically reposition the camera.

7. The same 30-minute segment of traffic video was played, and data were again collected with the Autoscope using the same detector configuration.

8. After this second data set was collected, the camera was again moved out of position.

9. An operator was allowed to try and reposition the camera to its originally calibrated position using a simple joystick, similar to those used in TMCs for repositioning cameras.

10. The same 30-min segment of traffic video was played and data were collected with the Autoscope unit using the same detector configuration.

11. The camera was again moved out of position one last time.

12. A command was sent to the camera to return to the "preset" position that had been programmed in step 1.

13. The same 30-min segment of traffic video was played and data were again collected with the Autoscope 2004 using the same detector configuration.

RESULTS

Literature Review

Key findings of the literature review are presented in the areas of CCTV fundamentals, VIVDS fundamentals, and CCTV/VIVDS Integration.

CCTV Fundamentals

TMC operators use CCTV cameras primarily to visually detect and determine the cause of freeway incidents (Federal Highway Administration, 1997a). These cameras are almost always mounted on pan/tilt controllers fixed high atop some type of tower sitting next to the freeway or in the median. The pan/tilt controllers combined with the height of the towers allow TMC personnel to monitor large sections of the freeway should an incident occur. Although most TMCs usually leave the cameras in a fixed position during "normal" conditions, it becomes necessary to be able to PTZ the camera at various levels to inspect or verify an incident.

VIVDS Fundamentals

VIVDS incorporate image processing techniques to analyze frames of video to determine the presence of a vehicle at a specific point on a roadway. All VIVDS require an image sensor (camera) to acquire an image. In addition, VIVDS use a digitizer to convert the analog video signal to a digital image and a microprocessor plus software for real-time video image analysis and traffic parameter extraction. Advanced machine-vision, pattern-recognition algorithms are used to detect vehicles under various environmental and traffic conditions. The detectors (generally count and speed detectors) are generated and configured as overlays on a video monitor through interactive graphics using a PC and mouse (Cottrell, 1994).

Though VIVDS are generally good at collecting traffic data, they can do so only if they are calibrated properly and the camera is positioned correctly. VIVDS are very sensitive to their calibration parameters. In particular, since the detectors are "virtually" defined on a PC monitor and are calibrated to the acquired image, it is imperative that the camera is not moved in either the pan, tilt, or zoom fields. Doing so would mean that the virtual detectors would no longer be in the "correct" place, and the VIVDS would attempt to identify vehicles outside the normal travel lanes, resulting in many missed and false detections.

CCTV/VIVDS Integration

To date, VIVDS have not been successfully integrated with existing moveable CCTV systems. This is primarily due to the fact that VIVDS require a fixed image sensor. As concluded in a 1997 study: "Even slight movement can misalign [detection] zones" (Federal Highway Administration, 1997b). For example, Figure 2 demonstrates how an inability to reposition a camera's pan and tilt fields properly will result in "misplacement" of detection zones.

Several studies have addressed the issue of integrating VIVDS with moveable CCTV systems (Cottrell, 1994; Namkoong et al., 2000). Three basic strategies have been considered: (1) repositioning CCTV cameras to realign with original VIVDS detection zones; (2) automatically recalibrating the detection zones using edge detection and image difference methods to determine where the roadway and each individual lane are positioned; (3) analyzing panning, tilting, and zooming factors of the CCTV cameras to allow for continuously recalibrated detector zones as a camera is repositioned. Finally, it is important to note the difference between "recalibration" and "repositioning" techniques. *Recalibration* refers to the process of redefining where the VIVDS's virtual detectors are placed on the screen. *Repositioning* refers to the realigning, or re-aiming, the CCTV camera such as it was positioned when the VIVDS detectors were originally calibrated. In other words, *repositioning* means that VIVDS "recalibration" does not have to occur and vice versa.

Researchers have met with little success using these strategies. VDOT attempted VIVDS CCTV integration via manual repositioning in 1994 with no success (Cottrell, 1994). It was concluded that operators could not reposition cameras accurately enough to maintain VIVDS effectiveness. Researchers in Korea have attempted to recalibrate the virtual detectors of a VIVDS automatically each time the camera is moved using edge detection techniques (Namkoong et al., 2000). However, this methodology met with limited success because edge detection was relatively ineffective, especially at night. Finally, automatic recalibration of VIVDS suffers from the fact that the VIVDS will be constantly recalibrating itself, even when the camera is awkwardly positioned to investigate an incident, ultimately resulting in poor detection performance.

Given the sensitivity of VIVDS performance to the quality of initial calibration, it is conceptually advantageous to have a professional set up and calibrate a VIVDS so that all of the angles and zoom factors are correct and then attempt to reposition the camera precisely each time the camera is moved. In this research, automated rather than manual repositioning (as in the 1994 VDOT study) was investigated. Though many PTZ controllers now have the ability to reposition cameras using programmable preset positions, these "presets" are accurate only to within ½ of a degree. This degree of precision when a camera is 400 ft from the road (typical for TMC CCTV systems) results in a sensor calibration error of nearly 4 ft. This would be unacceptable for any VIVDS as the detection zones would constantly be improperly repositioned. Thus, there is a need for an alternative repositioning approach with greater precision. In this research, an automated repositioning methodology was developed using machine-vision technology. The system incorporates normalized cross-correlation and pattern-matching techniques to search for a "target" placed near the travel lanes (such as in the median). The design of the prototype system is described in the next section.

Prototype CCTV/VIVDS Integrated System

The prototype system, referred to as Autotrack, was developed using the image processing capabilities of the LabVIEW software package. Autotrack incorporates two main phases: (1) a learning and calibration phase, and (2) a pattern matching and camera PTZ control phase.

Figure 3 is a flowchart of the first phase of the process. This phase can be described as a six-step, non-iterative process. Steps 1 and 2 of Phase 1 are performed using the Autotrack algorithm implemented in LabVIEW. Step 3 is performed with the VIVDS system. In step 4, the user selects a ROI on the PC screen using a mouse. In this case, the ROI is the target zone that has been located on the median. This ROI is automatically captured and saved in steps 5 and 6 as a template used in the pattern matching function of Phase 2.

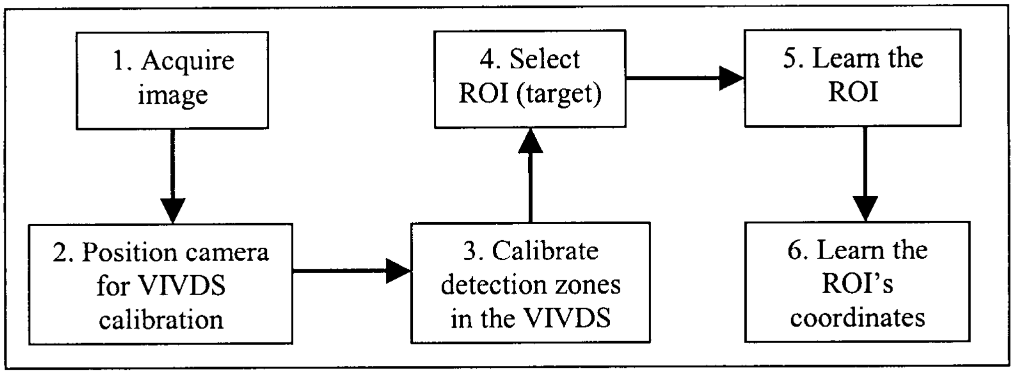

Figure 3. Autotrack Algorithm Phase 1: Learning and Calibration

The second phase consists of the pattern matching and camera control functions. This phase can be broken down into two iterative processes: the zoom repositioning process (Process I), and the pan/tilt repositioning process (Process II). Figure 4 is a flowchart depicting these processes.

The following subsections provide more detail on key aspects of the Autotrack algorithm: pattern matching, scale variation, and pan/tilt control.

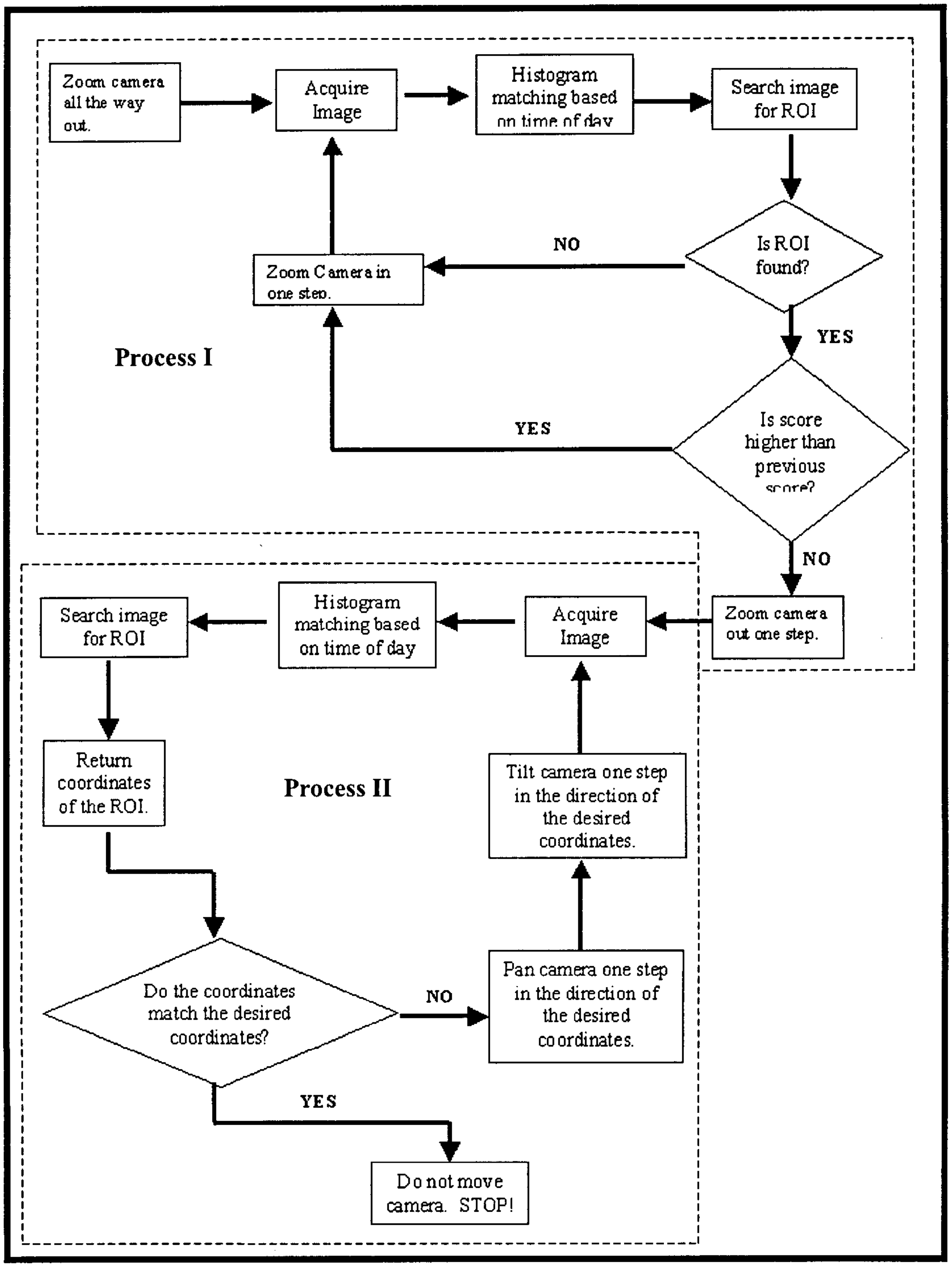

Figure 4. Autotrack Algorithm Phase 2: Pattern Matching and Camera Control

Pattern Matching

Pattern matching is the technique used to locate known reference patterns in an image quickly. Normalized cross correlation is an effective technique for finding patterns in an image, as long as the patterns in the image are of the same size (i.e., they are not scaled) and not rotated. Typically, cross correlation can detect a pattern of the same size up to a rotation of 5 to 10 degrees.

The pattern-matching algorithm used in Autotrack returns a list of matches, the position of each match, and a score indicating the closeness of each match. The number of matches, in this case, is not a concern since only one ROI is being searched for. The returned coordinates will, however, be extremely important. Further, the "score" will also be extremely important later when searching for scale variations.

The pattern-matching algorithms used in LabVIEW's IMAQ VISION software are fairly robust. They tend to work well even when lighting is poor, some blur is present, or the image is noisy; however, the pattern-matching algorithms compensate only minimally for changes in scale. It will return matches with scale variations of up to about 5%. For this particular application, changes in scale would be due only to changes in the zoom parameter of the CCTV camera. As the camera zooms in or out, the ROI will appear to either grow or shrink in size. The challenge then was how to locate the ROI even when the camera was zoomed in or out such that the ROI was no longer detectable due to changes in its scale.

Scale Variation

Camera zoom control is adjusted until the ROI is detectable by the normalized cross-correlation procedure. Once the ROI is located, the camera continues to zoom as the pattern matching score returned by the algorithm increases. As soon as the score begins to decrease, the zoom backs out again to the last, highest score. This is then considered to be the proper zoom level.

Pan and Tilt Control

When the ROI is detected and coordinates are received, the Autotrack algorithm sends move-stop commands to the pan/tilt unit to reposition to the original ROI coordinates.

Prototype Implementation

The following procedure functionally describes how Autotrack works:

1. The camera's PTZ fields are adjusted by an operator for the VIVDS traffic data collection calibration.

2. The ROI is located on the screen, and a box is drawn around it using the mouse. In the example provided in Figure 5, note that an HOV "diamond" serves as a very effective ROI.

3. The "Learn" button is pressed, and an automatic template is created that stores information about the ROI for tracking purposes.

4. VIVDS (in this case Autoscope 2004 by Econolite) virtual detectors are then defined and calibrated (as demonstrated visually in Figure 6), allowing traffic data collection to begin.

5. Once the camera is moved out of the position at which the VIVDS was calibrated (such as when an operator pans, tilts, and zooms to investigate an incident), the "Track" button is pressed. The Autotrack program then locates the ROI in the field of view of the camera and repositions the camera in the PTZ fields.

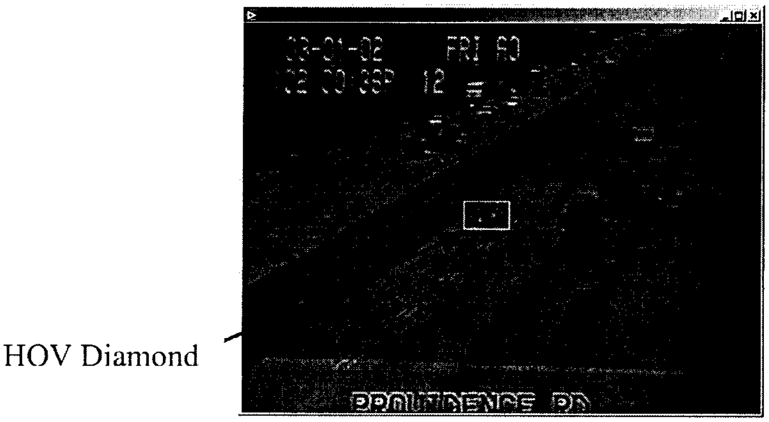

Figure 5. Locating an ROI

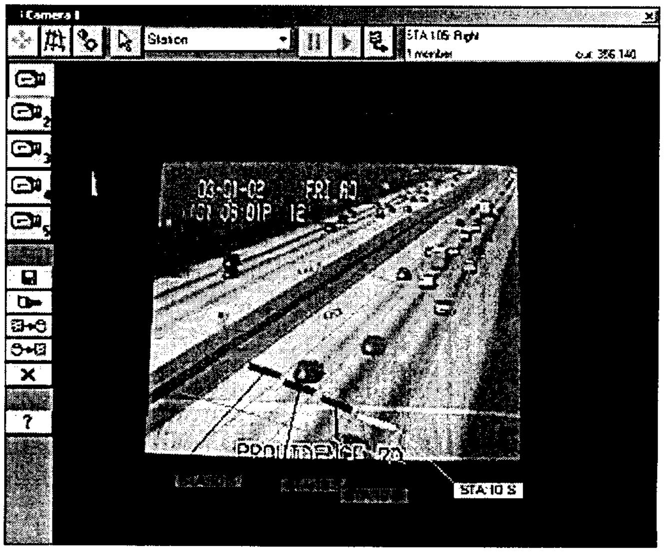

Figure 6: VIVDS Virtual Detectors

Testing

As described in the methodology section, two series of tests were conducted to evaluate CCTV positioning and VIVDS performance. This section presents the results from this testing.

CCTV Positioning

Two test cases were considered for the CCTV positioning series of tests. Test A examined the effectiveness of automatic zoom control, and Test B considered pan and tilt control.

Test Case A: Zoom

The results of this test are presented in Figure 7. As seen in these results, zoom control accuracy is non-linear and difficult to quantify. Re-zooming to a low zoom level is nearly 100% accurate; however, when repositioning to a higher zoom level, 3x for example, an error of 5% is not uncommon.

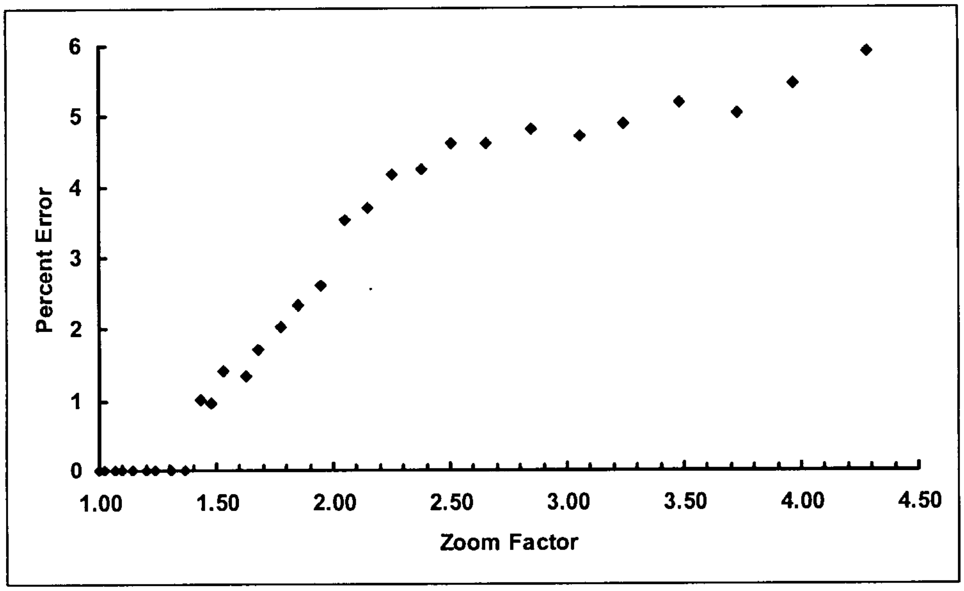

Figure 7. Results of Test Case A: Zoom Control Error

Test Case B: Pan and Tilt

The displacement errors for each repositioning attempt were measured and are presented in Table 3. Note that the average error, measured in degrees, never rises above ¼ degree of precision (as opposed to the ½ degree of precision offered by mechanical presets). As was stated earlier, most camera positioning systems with "preset" programmability operate with a repositioning accuracy of ½ degree of precision. This indicates that the Autotrack algorithm can reposition the camera more accurately than most camera PTZ positioning preset systems.

Table 3. Pan/tilt Displacement Error by Zoom Level

Run	Zoom Level					
	1.0x	1.25x	1.5x	1.75x	2.0x	
1	0.05	0.04	0.00	0.00	0.05	Error In Degrees
2	0.00	0.00	0.15	0.17	0.07	
3	0.03	0.11	0.15	0.19	0.00	
4	0.05	0.13	0.15	0.06	0.00	
5	0.00	0.00	0.00	0.00	0.23	
6	0.00	0.06	0.00	0.00	0.00	
7	0.03	0.00	0.00	0.19	0.21	
8	0.03	0.05	0.15	0.11	0.10	
9	0.00	0.00	0.00	0.05	0.00	
10	0.03	0.10	0.14	0.00	0.21	
μ	**0.02**	**0.05**	**0.08**	**0.08**	**0.09**	
σ	**0.02**	**0.05**	**0.08**	**0.08**	**0.10**	

VIVDS Performance

The results from the four tests to evaluate the VIVDS traffic measurement performance using the prototype system are presented here.

Normal Field of View at Day (1x Zoom Level)

The first test was conducted with the camera at a zoom level of 1x. The results presented in Table 4 are the vehicle count average of three runs of the test procedure. The count error percentage associated with the Autotrack's performance, seen in Figure 8, is negligible for this run and is thus difficult to see on the graph. In all instances, the count error with the Autotrack system was less than 1%. Note that the error when manual repositioning is used is significantly higher than both the camera's "preset" repositioning and the Autotrack repositioning. The highest error observed, 38%, occurred using the manual repositioning approach in the HOV lane.

Table 4. Count Results for Day Testing at 1x Zoom Level

Lane	Vehicle Count			
	Initial Calibration	AUTOTRACK	Manual	Preset
HOV	152	152	94	148
Left	653	654	629	660
Middle	811	813	912	825
Right	705	708	845	700

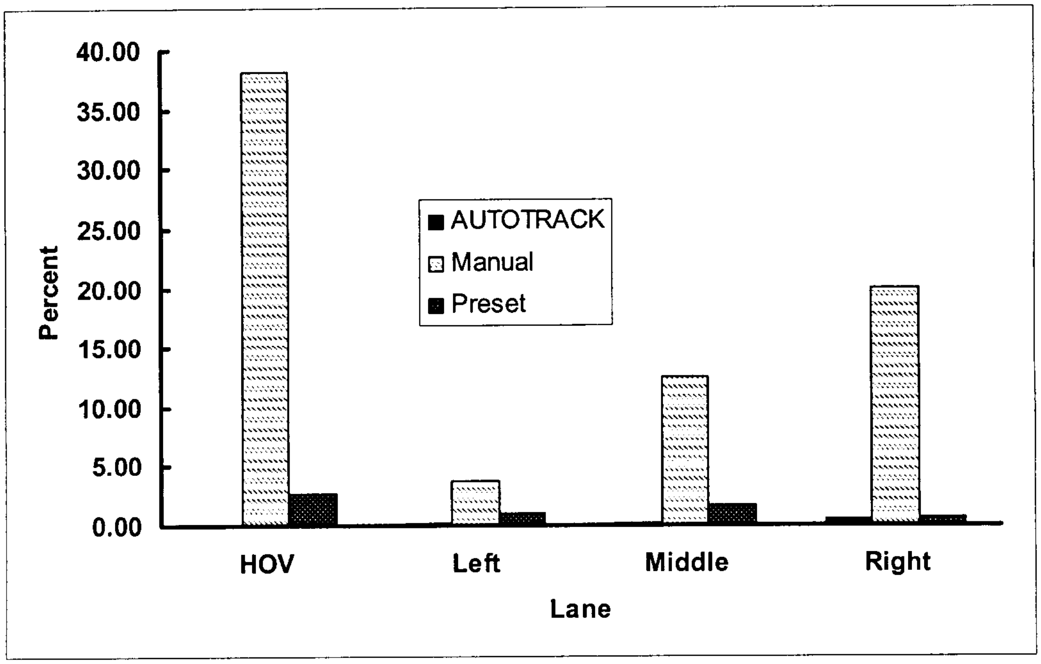

Figure 8. Percent Error for Day Repositioning Tests: 1x Zoom. Autotrack error is essentially 0 in the left, middle, and HOV lanes.

Smaller Than Normal Field of View at Day (Zoomed 1.5x)

The second test was conducted with the camera at a zoom level of 1.5x. The count data presented in Table 5 are an average of three runs of the test procedure. The count error percentage, presented in Figure 9, associated with the Autotrack's performance is again consistently less than 1%. The Autotrack repositioning method continues to outperform the manual and "preset" positioning methods. However, because the repositioning accuracy in the zoom level is decreased as the zoom level increases, more error is present than in the previous test.

Table 5. Count Results for Day Testing at 1.5x Zoom Level

Lane	Vehicle Count			
	Initial Calibration	AUTOTRACK	Manual	Preset
HOV	150	151	138	148
Left	650	652	670	658
Middle	815	818	840	825
Right	708	712	706	715

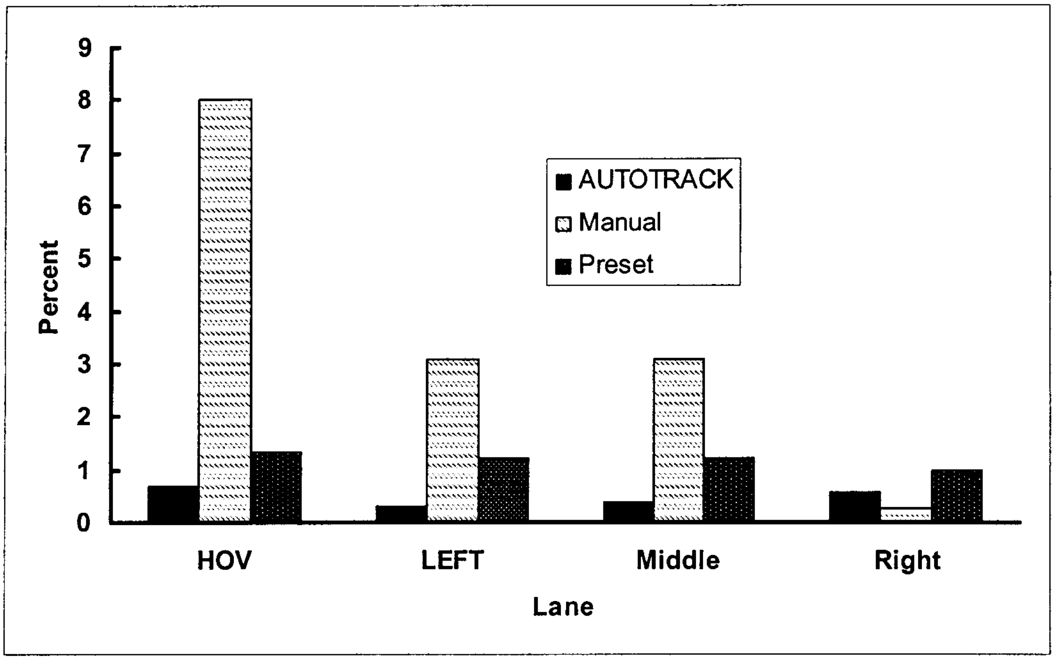

Figure 9. Percent Error for Day Repositioning Tests (1.5x Zoom)

Smaller Than Normal Field of View During Daylight (Zoomed at 2.0x)

The third test was conducted with the camera "starting" at a zoom level of 2x. The maximum percent error associated with the Autotrack repositioning method increased to 3.7% in the HOV lane when the zoom level was increased to this level. Full details of the evaluations from this test are available elsewhere (Pack, 2002). This increase in error at higher zoom levels, as seen in the positioning tests, indicates that the prototype system should be used only at low zoom levels.

Normal Field of View at Nighttime (1x Zoom)

The performance of the Autotrack program at night compared to the performance of the two other repositioning methods was nearly identical with the performance of the Autotrack system during the day in terms of the percent error. The largest error for this run was in the right-most lane of traffic and was still under ½ of 1%.

Factors Affecting Performance

Although the prototype Autotrack algorithm demonstrated an excellent performance, a number of reasons indicate that the results presented are likely those of a "worst case" implementation for the following reasons:

- The Pelco Esprit camera used for testing is a high-speed camera. That is, the speed at which the zoom lens was rotated was quite fast. Thus, it proved difficult for the Autotrack algorithm to issue a stop command fast enough in the zoom repositioning process. This resulted in zoom "overshooting" errors. Many cameras on the market provide the ability to control the speed at which they zoom. Such cameras would be better suited for this application. Further, older cameras that zoom more slowly could also work better.

- The video images that were processed using the prototype system were a digitized video projection of a VHS recording being displayed onto a screen. This adds degradation layer upon degradation layer to the quality of the video. This combined degradation limits the system performance.

CONCLUSION

This research investigated the premise that existing TMC CCTV cameras and equipment could be used effectively in conjunction with VIVDS. Integrating CCTV with VIVDS presents challenges because VIVDS traditionally require a fixed-position camera to operate properly and TMC CCTV cameras are free to be moved in the PTZ directions.

The research team developed a machine vision-based automatic recalibration procedure that enables the integration of VIVDS/CCTV. This was demonstrated with a prototype system that supported nearly error-free volume data collection (on the order of 1% or less at reasonable initial camera zoom levels) in a laboratory test. This is a significant conclusion that contradicts the prevailing opinion in both research and practice. The conclusion that VIVDS/CCTV is feasible paves the way for significant costs savings in ITS system deployment and maintenance.

RECOMMENDATIONS

1. *Develop a modified prototype Autotrack system that is suitable for field deployment with existing CCTV cameras.* The field-level Autotrack prototype should be evaluated extensively to make a final decision regarding CCTV/VIVDS integration in future and redesigned/redeveloped transportation management systems.

2. *When purchasing new or replacement CCTV hardware during the field testing period, procure cameras that support software-based PTZ control.* In addition, cameras should be purchased that allow for software-based control of zoom speed. This will support future implementation of a field version of the Autotrack system.

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