Using Machine Vision (Video Imaging) Technology To Collect Transportation Data

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The results of a series of tests of machine vision, or video imaging, technology in the measurement of various kinds of transportation data are presented. The Autoscope system is used to collect flow rate data at both interrupted and uninterrupted flow facilities and vehicle size data at a port of entry. The data are compared with manually measured data. The results show that machine vision technology offers excellent potential for effectively and efficiently collecting transportation data, particularly when combined with postprocessors that can identify special data characteristics such as vehicle paths or vehicle length or height.

A variety of increasingly sophisticated systems have been developed over the years to monitor and control transportation facility operations. Signalized intersections are now controlled using electronics to monitor vehicle arrivals and departures and to implement optimal timing schemes to minimize delays and encourage vehicle progression. Freeways are monitored and controlled using vehicle detection algorithms designed to identify congestion and other incidents that cause delay.

A new generation of technology based on video imaging and machine vision concepts is being developed to improve the accuracy of measuring traffic flow conditions, to reduce the response time to changes in traffic conditions, and to eliminate the persistent maintenance problems that are common to inductive loop in-pavement systems. One such technology, the Autoscope system, was developed by the University of Minnesota and Image Sensing Systems, Inc., and has been described by Michalopoulos et al. (*1*). The University of Idaho has been using the Autoscope 2002 system since 1991 to develop methods for automatically collecting traffic flow and delay data at intersections, to monitor freeway traffic operations, and to measure vehicle lengths and heights at ports of entry. Machine vision technology automates these processes by extracting traffic flow and vehicle size data directly from video images.

Machine vision technology combines video and computer technology to extract traffic data from video images. Video images (either live through an on-line video camera or on tape) are taken of traffic flowing through an intersection or along an arterial or highway. The images are transmitted from a video playback machine into a specially equipped personal computer. The personal computer, with a frame grabber board, takes the video image and digitizes and stores each image at a rate of 30 frames per second. A second computer, the Autoscope, processes each digitized image. The Autoscope recognizes the video content of the stationary background image and identifies any changes in the luminance as potential vehicle movements. Special algorithms sort out actual vehicle movements from other spurious or nonrelevant image changes. The user identifies detector locations (points at which he or she wants to measure traffic movements) on the video display using a mouse. The computer identifies all vehicle movements passing detector points that have been identified by the user. The computer stores the time that each detector is activated by a vehicle (i.e. when the presence of the vehicle is detected) and the duration of the presence detection.

To measure turning movement flow rates, however, two other factors must be considered. First, additional detectors must be included that correspond to points along a path of travel through the intersection; second, the detector activation times must be considered together so that possible vehicle movements or paths can be identified. Figure 1 shows an example of the data produced by Autoscope that can be used to identify a turning movement. Detector 0 is activated at 8:00:03.253, and Detector 6 is activated 2.101 sec later. The event described by these consecutive detector activations is almost certainly a northbound left-turning movement, in the absence of other detector data. If other detectors have been activated during this time, however, the logic imbedded in the software must be able to identify this turning movement event out of other possible events.

This postprocessing of the Autoscope data can be used to generate more complex information about the traffic flow characteristics by combining data from two or more detectors. Postprocessors can be developed that can produce, in addition to turning movement data, vehicle delay and queue lengths at an intersection, vehicle speeds along an arterial or freeway, or vehicle length, width, and height data at a port of entry. The common link in determining each of these data is the identification of a specified event by the analysis of patterns or sequences in the raw Autoscope detector data. For example, the simultaneous activation of seven detectors, with a known geometric relationship, might indicate a truck that is between 3.8 and 3.9 m in height. Or the timing of the consecutive activation of two detectors at a known distance apart might indicate a vehicle traveling at 45 km/hr. Once an event is characterized by a given sequence or pattern of detectors (and suitable time delays or constraints are accounted for), it can be identified by an organized search routine or algorithm applied to the raw Autoscope detector data. The general principle is this: the data from a given detector activation pattern is used to determine that the event has occurred.

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The purpose of this paper is to report the results of a research project on the application of the Autoscope 2002 system to the measurement of three broad classes of transportation data: uninterrupted traffic flow, interrupted traffic flow, and vehicle size. For each class of data, the following information is presented: (a) objective of each measurement test, (b) definition of variable(s) to be measured, (c) description of measurement methodology, (d) presentation of results, and (e) discussion of results and summary of relevant conclusions.

BACKGROUND

Video Imaging Systems

One of the first applications of video imaging technology in transportation was in 1978 when FHWA contracted with the Jet Propulsion Laboratory (JPL) to investigate the feasibility of using video sensors and image processing for automatic traffic monitoring. This study culminated in the development and testing of a breadboard system, the Wide Area Detection System (WADS), for vehicle detection and vehicle velocity measurement (*2*). Two studies were completed recently to evaluate currently available video imaging technologies for highway operations. One study, at the University of California at Berkeley, described the components, advantages, and disadvantages of image processing technology for traffic data collection (*2*). The second study, conducted for the California Department of Transportation by the California Polytechnic State University, evaluated the performance characteristics of several image processing technologies (*3*). This study identified eight systems having good potential for analyzing traffic data. These systems include the Aspex Traffic Analysis System (ATAS); the Camera and Computer Aided Traffic Sensor (CCATS) by Devlonics in Belgium; Sigru, developed by Eliop in Spain; the Traffic Analysis System (TAS); Titan, a French system under development by the Institut National de Recherche sur les Transports et leur Securité; Traffic Tracker; Tulip; and Autoscope. The study considered the performance of each system in measuring different traffic parameters under a variety of site conditions including congested flow, fog, snow, rain, nighttime, and poor lighting conditions.

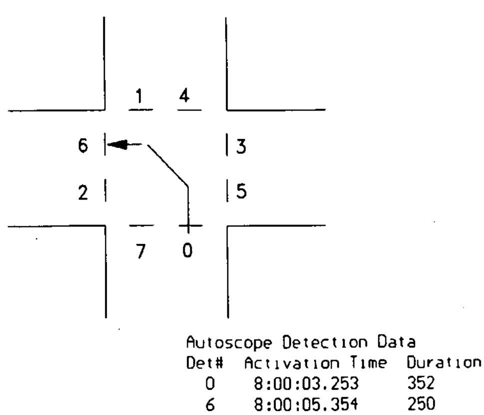

FIGURE 1 Sample Autoscope detector layout and data file for turning movement data.

Applications of Video Imaging

Several recent research projects have tested the use of video imaging technology for the collection of transportation data. At the Environmental Research Institute of Michigan (ERIM), Gilbert and Holmes developed real-time image processing algorithms for detecting and tracking vehicles in actual traffic settings (*4*). The principle that they used for vehicle detection was based on the comparison of the difference in illumination between a defined region of a scene and a passing vehicle. The background color of the scene is taken as the standard of reference, and any passing object with a different light intensity or color is detected as a vehicle.

Frame differencing has been used successfully in two studies. Vieren et al. used frame differencing to define the edges of moving vehicles in successive frames (*5*). Sethi and Brillhart employed video imaging technology to detect the nonconforming behavior of vehicles on roadways in addition to providing normal traffic statistics for traffic monitoring (*6*). They used frame differencing to identify centroids of vehicles for tracking.

Troutbeck and Dods used the Video Detection Data Acquisition System (VADAS) with video data collected from cameras mounted on a 10-m-high telescopic mast to determine vehicle paths (*7*). Taylor et al. also used VADAS for headway and speed data collection on freeways and parking lots (*8*).

The University of Minnesota studied the performance of the Autoscope system for incident detection on a freeway (*9*). In this study, a 5.6-km machine vision laboratory with 38 cameras was designed on Interstate 394 for deployment and validation of the incident detection system. The study reported a false alarm rate of only 3 percent.

The application of video imaging has been used to evaluate pavement surface distress such as cracks, potholes, and depressions. As part of NCHRP Project 1-27, a system was developed to process video images to identify, quantify, and classify pavement distress in terms of types, severity, and extent (*10*). The results have shown an error of 5 to 17 percent, and in some instances it proved to be superior to the visual inspection method currently practiced by the personnel in this field.

Koutsopoulos and El Sanhouri developed a method for automatic interpretation of asphalt pavement distresses, recorded on video or photographic film, with emphasis on segmentation and classification of digitized distress pavement images (*11*). Segmentation is the process of extracting objects of interest from the background, in this case the pavement distresses such as cracks and potholes, and classification is the process of identification of distress type. The preliminary results from this study indicate that it is feasible to automate the process of pavement image analysis.

Lu et al. have illustrated the application of image processing for measuring pedestrian volumes at intersections (*12*). They have developed an algorithm based on television image sequence analysis that automatically counts the number of pedestrians on crosswalks in daytime periods and automatically determines their volume. The tripwire method of detection is employed for this purpose. A band of pixels on the TV image corresponding to the crosswalk are placed perpendicular to the direction of pedestrian movement. A 94 percent accuracy rate was reported in the pedestrian volume measurements.

MEASUREMENT OF UNINTERRUPTED TRAFFIC FLOW

One of the original motivations for developing the Autoscope system was to provide a more comprehensive method of monitoring and controlling freeway traffic operations. Inductive loop systems can provide the flow, speed, and occupancy data required by standard freeway traffic management systems, but machine vision technology offers two primary advantages over inductive loop technology: (a) the concern with maintenance of in-pavement loop detectors is eliminated, and (b) the additional visual information available to traffic engineers monitoring the flow of traffic enables better decisions in incident response.

Objective of Measurement Test and Variable To Be Measured

The objective of measuring uninterrupted traffic flow is to determine how well the Autoscope system can measure freeway traffic flow rates as compared with manual counts measured by an observer. In particular, the relative effectiveness of various detector layout configurations and camera angles was investigated.

The variable to be measured in this test is vehicle volume, in vehicles per time period.

Description of Measurement Methodology

Video cameras were located on overpasses at two locations on I-84 in Boise, Idaho, and videotapes were made for five time periods. Traffic was traveling away from the camera in three of the scenes and toward the camera in two of the scenes. Both horizontally and vertically oriented detectors were tested. (Horizontally oriented detectors are oriented perpendicular to the traffic flow, and vertically oriented detectors are oriented parallel to the flow.) Autoscope was used to collect flow rate data. To determine the accuracy of the Autoscope system, comparison counts were made using a personal computer and the Traffic Data Input Program (TDIP) (*13*). TDIP requires the user to press a key on the computer keyboard corresponding to a particular vehicle event, such as a vehicle passing a point in a given traffic lane. Like Autoscope, TDIP produces a data file of vehicle passage times for each event and summaries of flow rates for each movement that is monitored.

Results

The results of the volume counts from both Autoscope and TDIP are given in Table 1. The table includes 13 comparisons and shows the direction of the traffic flow with respect to the

TABLE 1 Uninterrupted Flow Data

Scene	Duration (minutes)	Lane	Direction	Detector Orientation	Volumes		Percent Deviation	MAPD 5-Minute Data
					Autoscope	TDIP		
2	20	1	Away	H	177	174	-1.7	9.0
2	20	2	Away	H	177	162	-9.3	11.8
2	20	3	Away	V	132	174	24.1	24.5
3	27	1	Toward	H	179	206	13.1	15.9
3	27	2	Toward	H	218	230	5.2	5.2
4	60	1	Away	H	820	825	0.6	2.4
4	60	2	Away	H	424	431	1.6	4.2
4	60	3	Away	H	872	939	7.1	7.5
5	60	1	Away	H	1306	1325	1.4	2.7
5	60	2	Away	H	399	419	4.8	6.3
5	60	3	Away	H	1542	1627	5.2	5.1
7	60	1	Toward	H	1070	962	-11.2	18.9
7	60	2	Toward	H	1370	1346	-1.8	13.2

Notes:

Since neither the Autoscope data nor the TDIP data can be assumed to be completely accurate, percent errors cannot be calculated. Thus in the comparisons presented in this and subsequent tables, the terms *deviation* or *correspondence* are used. The *Percent Deviation* is calculated with respect to the TDIP data.
The *MAPD 5-Minute Data* is the mean absolute percent deviation calculated between the TDIP and Autoscope data for each 5-minute period for which data are available.
Direction indicates whether traffic is traveling away from or toward the camera.
Detector orientation indicates the orientation of the video detector with respect to the flow of traffic. Horizontal orientation (H) indicates that the detector is perpendicular to the flow of traffic; vertical orientation (V) indicates that the detector is parallel to the flow of traffic.

camera, the orientation of the video detector, and the volumes collected from Autoscope and from TDIP.

Three categories should be noted. The first category shows the deviation calculations for the scenes in which traffic is moving away from the camera and the detector orientation is horizontal. The percentage deviation for these eight comparisons ranged from 0.6 to 9.3 percent, with a mean of 4.0 percent. The second category shows the deviation calculations for the scenes in which traffic is moving toward the camera and the detector orientation is horizontal. In this case, the percentage deviations were somewhat higher, ranging from 1.8 to 13.1 percent. The third category shows the deviation for one scene in which traffic is moving away from the camera and the detector orientation is vertical. This configuration showed the highest percentage of deviation, 24.1 percent.

Discussion of Results

Autoscope clearly has the potential to produce accurate volume counts as shown by the high level of correspondence with the manual volume counts, though care and experience are both needed in the development of optimal video detector layouts and camera placement. The most accurate measurements were obtained when the video camera was placed such that traffic was moving away from the camera and horizontal video detectors were used to collect the volume data. For this configuration, the mean deviation between Autoscope and TDIP volume counts was 4 percent. Mean absolute deviation for 5-min volume counts ranged from 2.4 to 11.8 percent.

Less accurate measurements resulted when traffic was moving toward the camera or when vertical detectors were used. Accuracy was also reduced when daytime light levels were low, such as in the early morning hours, as was the case for Scene 7 in Table 1.

MEASUREMENT OF INTERRUPTED TRAFFIC FLOW

Autoscope was also developed to detect vehicle presence at signalized intersections as a replacement for inductive in-pavement loop detectors. In this set of tests, machine vision technology is used to measure both approach and turning movement flow rates at an intersection. Although the technique used to measure approach flow rate is the same as reported for the freeway volume counts earlier, the turning movement counts involve the development of a postprocessor algorithm.

Objective of Measurement Test and Variable To Be Measured

The objective of these tests is to determine how well the Autoscope system can measure approach volumes and turning movement volumes as compared with manual counts measured by an observer using TDIP.

The variable to be measured in these tests is vehicle volume counts.

Description of Measurement Methodology

Video cameras were placed at elevated locations near four stop-controlled intersections in Pullman, Washington, and Moscow, Idaho. In each case, a single video camera was used to record traffic movements through the entire intersection. Videotapes were made for 12 time periods. Video detectors were located on each approach; to estimate turning movement volumes, video detectors were also placed on the departure lane for each direction, as shown in Figure 2. An algorithm was developed to match entry and exit detectors that fit within a preset time range and that represented logical vehicle paths. The application of this algorithm to the raw Autoscope detector data yielded an estimate of turning movement volumes.

To determine the accuracy of the Autoscope measurements and the turning movement postprocessor, TDIP was used to develop a corresponding set of approach volumes and turning movement counts.

Results

Although a freeway presents a relatively uncluttered traffic scene, an intersection scene can include a significant amount of potentially extraneous images, such as pedestrians. In addition, vehicles do not always follow well-defined paths as they travel through an intersection. For this reason, the placement of the camera is crucial in obtaining a clear and unobstructed view of the vehicles. The height of the camera and angle of the camera view determine whether the image of each vehicle remains unoccluded by either other vehicles or other items that appear in the scene. The results of the comparisons between the TDIP and Autoscope data reflect the importance of these factors. Table 2 gives the percentage of correspondence between the Autoscope and TDIP counts for each approach of the 12 unsignalized intersection cases that were studied. The percentage of correspondence varies widely from very poor levels (a low of 13 percent) to very good levels (90 percent and above). In general, those sites with good viewing angles (where good separation of vehicle images was achieved) and low pedestrian volumes, good correspondence levels (above 90 percent) were achieved. When viewing angles

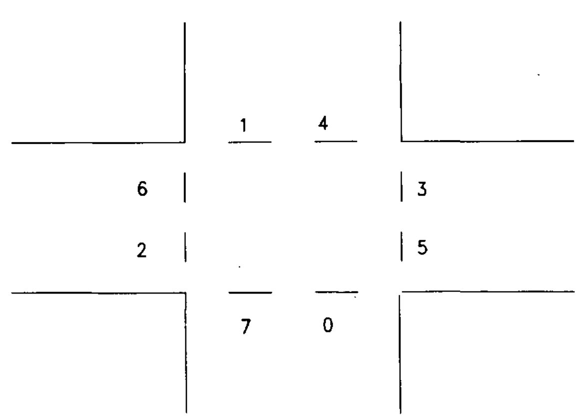

FIGURE 2 Sample detector layout for turning movement data (entry and exit detectors).

TABLE 2 Percentage Correspondence for Interrupted Flow Data Using TDIP and Autoscope

Site	Case Number	Percent Correspondence			
		Northbound	Southbound	Eastbound	Westbound
1	91031501	70	68	90	95
	91070801	75	53	92	95
	91071901	82	67	95	95
2	91031502	95	90	20	63
	91071101	93	73	40	84
	91071601	83	70	45	70
	91072301	92	63	20	64
3	91071201	86	13	80	56
	91072201	76	26	75	77
	91072501	71	35	89	80
4	91072601	-	53	94	94
	91073101	-	86	99	93

Note:
The data shown for each direction represent the percent correspondence between the TDIP data and the Autoscope data for the entire data collection period for each case cited. The TDIP data are used as the base for the correspondence calculation.

were poor or pedestrian volumes were high, the resulting correspondence between Autoscope and TDIP was poor.

Tables 3 and 4 present the turning movement volume counts from TDIP and from the Autoscope turning movement postprocessor algorithm for the unsignalized intersection sites for four 15-min periods. For the 21 cases in which the TDIP volumes exceeded 25 vehicles, the percentage deviations ranged from 0 to 21.6 percent, with a mean of 8.2 percent.

Discussion of Results

One of the major lessons learned during this part of the study was the importance of camera placement and viewing angle. To function successfully, the Autoscope system needs an unobstructed view of all vehicles passing through an intersection. In addition, detectors must be located such that the likely paths of pedestrians crossing through the intersection are avoided. If these criteria are satisfied, Autoscope can produce accurate approach volume and turning movement counts.

MEASUREMENT OF VEHICLE HEIGHT

Autoscope was not originally intended to measure vehicle size directly, but a process was developed as part of this research project to test how well Autoscope might perform this task. This information was of particular interest to the Idaho Transportation Department in monitoring the conformance of vehicles traveling through ports of entry in meeting legal size requirements.

TABLE 3 Turning Movement Count Comparisons, Eastbound

Case	Eastbound Left Turn		Eastbound Through Movement		Eastbound Right Turn	
	AutoTurn	TDIP	AutoTurn	TDIP	AutoTurn	TDIP
91071601	0	0	2	3	2	1
91071201	3	1	43	43	29	37
91070801	2	1	75	80	3	2
91071901	0	0	58	63	2	1
91072201	3	0	38	42	29	33
91072301	1	0	0	1	1	0
91031501	1	2	94	96	5	5
91031502	3	2	-	-	3	5
91072501	5	1	49	51	35	43
91072601	12	14	39	43	-	-
91073101	21	25	82	89	0	0

Note:
The data shown above are the 15-minute volumes collected directly by TDIP and produced by the turning movement post-processor using the Autoscope data (AutoTurn).

TABLE 4 Turning Movement Count Comparisons, Westbound

Case	Weastbound Left Turn		Westbound Through Movement		Westbound Right Turn	
	AutoTurn	TDIP	AutoTurn	TDIP	AutoTurn	TDIP
91071601	25	28	1	0	10	10
91071201	14	13	46	47	4	1
91070801	2	2	64	66	2	1
91071901	2	3	52	56	0	1
91072201	20	18	60	68	3	0
91072301	12	18	0	0	4	10
91031501	5	7	87	88	4	4
91031502	26	7	-	-	13	4
91072501	23	19	71	77	5	0
91072601	-	-	-	-	-	-
91073101	0	0	114	111	42	47

Note:
The data shown above are the 15-minute volumes collected directly by TDIP and produced by the turning movement post-processor using the Autoscope data (AutoTurn).

Objective of Measurement Test and Variable To Be Measured

The objective of this test is to determine how well Autoscope can measure vehicle height, and the variable to be measured is the height of the vehicle in meters.

Description of Measurement Methodology

The truck heights were measured manually by a standard measuring rod. Data were collected for 79 trucks, representing a variety of truck types.

Each truck was also videotaped as it passed through the port of entry. Reference points were marked on a utility pole at 0.3-m spacing in the camera field of view using colored tape. These points were used as a guide for locating video detectors for the Autoscope measurements. The detector placement and measurement method are shown in Figure 3. Autoscope recorded the time that each of these detectors were turned on and off by the passage of the truck image. The height was estimated by noting the maximum number of detectors that were activated during each truck passage. Effects of camera angle and site geometry were included in this measurement estimate.

Results

The times that each detector turned on and off were plotted for each truck. The result of this plot is a profile or representation of the visual image of the truck. A sample plot for one trucks is shown in Figure 4. The shape of the truck components, both the cab and the trailer, are clearly visible.

The field measurements were compared with the height measurements estimated by Autoscope. A histogram of the distribution of the measurement errors is given in Figure 5, which shows that for 70 of the 79 trucks studied, the measurement error between the actual measurement and the height measurement estimated from the Autoscope detector data is less than 10 percent.

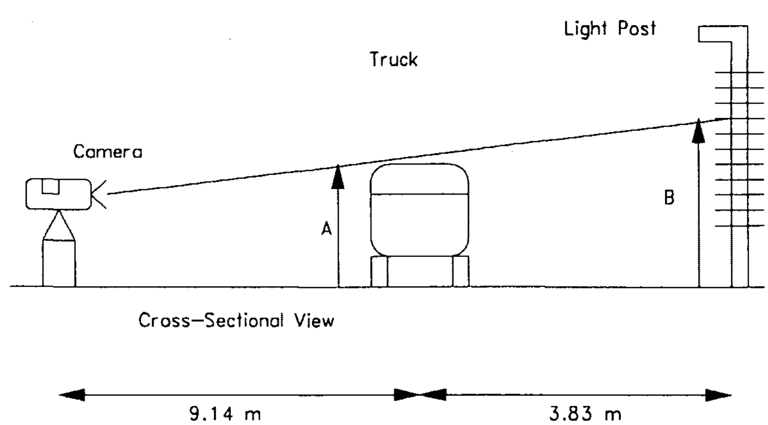

FIGURE 3 Truck height measurement method: actual truck height (A) is estimated from imagined height (B), using cross-sectional geometry shown.

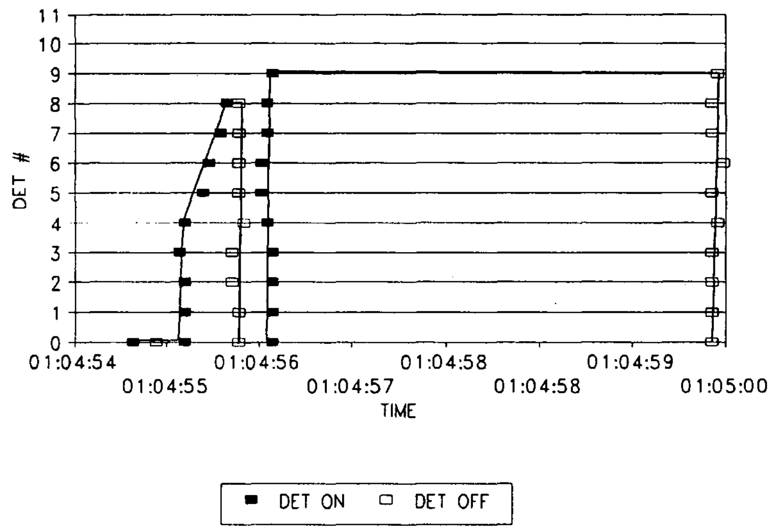

FIGURE 4 Sample truck profile, Truck 17.

Discussion of Results

An analysis of the measurements with the highest errors showed two common problems:

1. Autoscope detected the truck exhaust pipe, which was not included in the manual measurement, and thus overestimated the actual height.
2. Cylindrically shaped light-colored trucks (typically oil or agricultural tank trucks) were not properly detected by Autoscope, resulting in an underestimation of the height. The cause of this latter problem appears to be a some difficulty in differentiating the light intensity produced by the edge of the truck surface from the level produced by the pavement or background.

Figure 6 shows a plot of the actual measured height versus the height estimated by Autoscope, but it excludes the data for trucks that fit the two problem categories described earlier. The results shown in Figure 6 are very promising, particularly when it is noted that the detector grid consists of detectors that are spaced 0.3 m apart. Increased accuracy should be possible when more closely spaced grids are used.

MEASUREMENT OF VEHICLE LENGTH

Vehicle lengths were also measured using the Autoscope system. The results were compared with the data collected using standard manual field measurement methods.

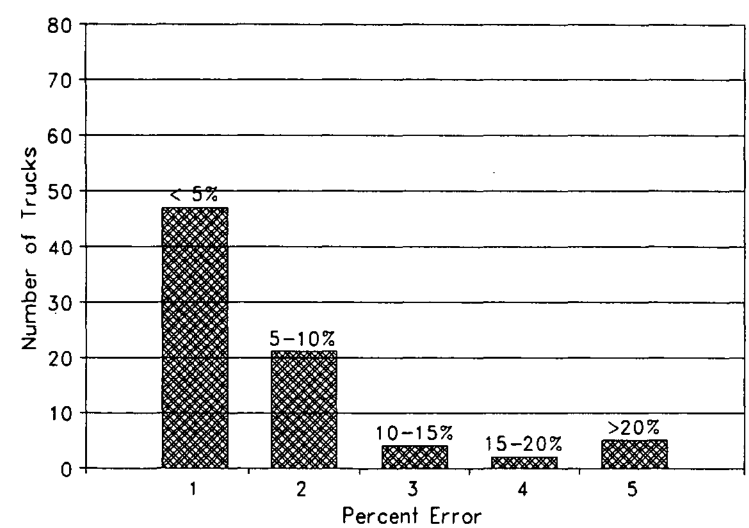

FIGURE 5 Distribution of percentage errors for truck height measurements.

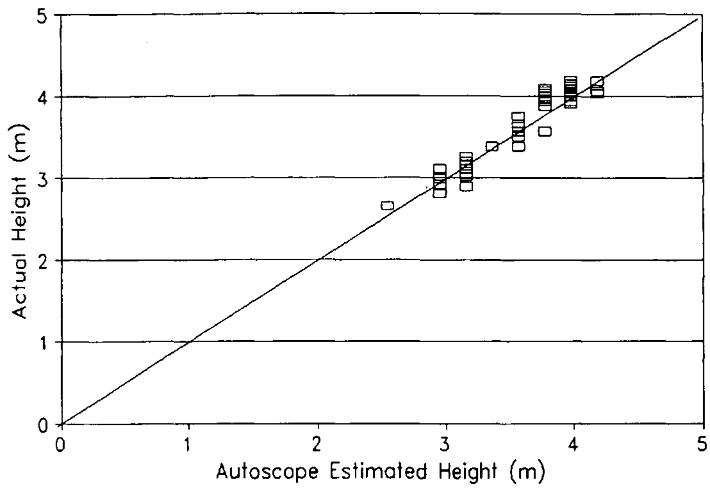

FIGURE 6 Comparison of actual and estimated truck heights, selected vehicles (shape and color) eliminated.

Objective of Measurement Test and Variable To Be Measured

The objective of this test is to determine the effectiveness of the Autoscope system in measuring vehicle length, and the variable to be measured is vehicle length in meters.

Description of Measurement Methodology

As in the vehicle height test, manual measurements of bumper-to-bumper vehicle length were made of 79 trucks at the Lewiston port of entry. A video camera was placed approximately 9.1 m from the truck lane to record the passage of the truck through the port of entry. The camera angle was established so that the entire truck image could be captured. The actual view of the truck passage was therefore not straight on, but somewhat oblique.

To collect the Autoscope data, vertical video detectors were plotted at 1.5-m intervals along the path of the truck. As the truck progressed through the field of view, the detectors were activated in order from the left to the right of the field. The detector activation data are plotted on a time-distance diagram to indicate the progression of each truck through the detector chain. An example of this procedure is given in Figure 7. The horizontal line noted by "Estimated Truck Length" in the figure represents the maximum number of detectors simultaneously activated during the time of truck passage.

Results

The maximum number of detectors activated by a truck passage was plotted against the field measured length for each truck. This plot is shown in Figure 8. The correlation coefficient between the actual length of the truck and the number

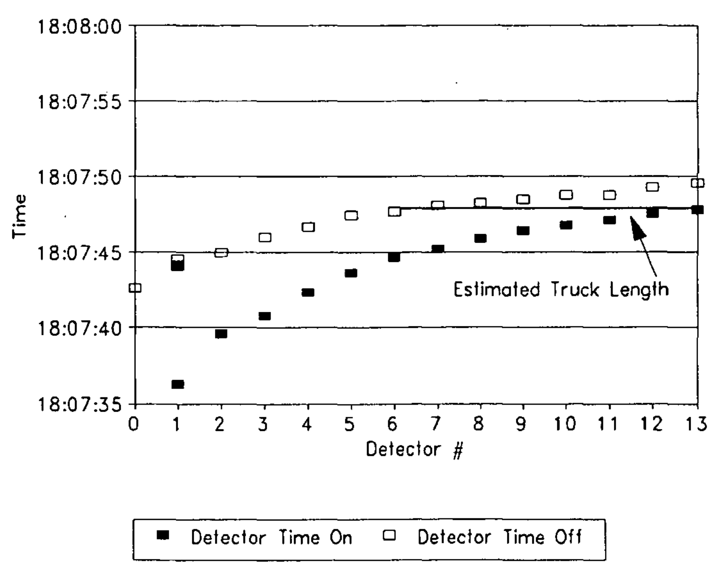

FIGURE 7 Truck length measurement.

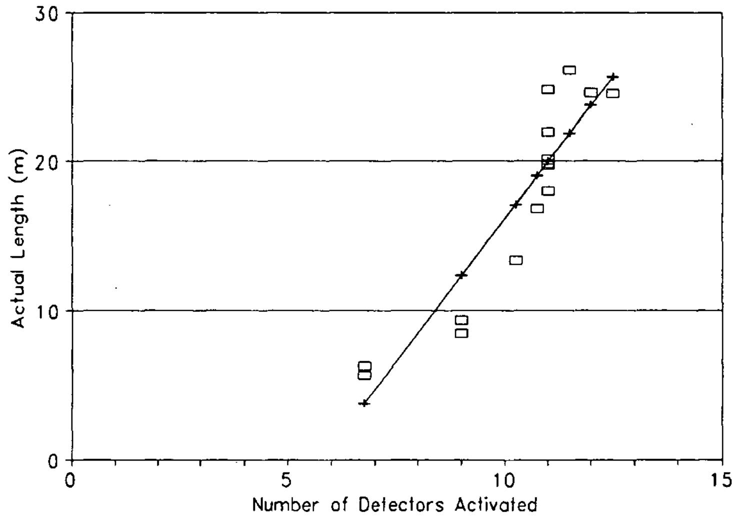

FIGURE 8 Measured truck length versus number of activated detectors.

of simultaneously activated detectors is 0.85, indicating a good level of correspondence between the actual length measurement and the Autoscope estimate. This is particularly encouraging since the detector grid (with 1.5 m between each detector) was relatively coarse. Unfortunately, a direct estimation of the length using the Autoscope data was not possible because of the obliqueness of the camera angle.

Discussion of Results

The test shows that there is potential for using video imaging to measure truck length. However, better camera placement will be required to obtain a more direct view of the truck image passing through the field of view. An improved orientation of the truck image will allow a calculation of the length from the site geometry.

SUMMARY AND CONCLUSIONS

The purpose of the paper is to present the results of a series of tests of the Autoscope 2002 video imaging system in collecting transportation data. The following is a summary of the primary results of this study:

- Proper camera placement and the establishment of an obstructed view of all vehicles passing through the field of view are both essential to the successful collection of data using video imaging techniques. Occluded views of vehicles as well as the presence of extraneous images (such as pedestrians) may degrade the quality of the results obtained.
- Postprocessors have the potential to increase significantly the value of the data produced by a video imaging system by providing the analyst with additional information about a transportation system.
- The results of the four measurement tests are promising:
  - –In the measurement of freeway traffic volume counts, Autoscope produced data that varied from 0.6 to 9.3 percent of manually collected data, when proper camera angle and detector configurations were selected.
  - –Autoscope produced approach flow rates with correspondence levels of 90 percent or greater with manually collected data for unsignalized intersections when suitable camera angles were selected and when pedestrian volumes were low.
  - –The turning movement postprocessor produced volume estimates that were within 8 percent of the manual counts.
  - –Height estimates generated by Autoscope were within 10 percent of the manual height measurements for 70 of the 79 trucks studied.
  - –The correspondence between the manual length measurement and the number of simultaneously activated video detectors showed a correlation coefficient of 0.85.

Clearly more work needs to be done in the validation of this system in a wider variety of situations and in the development of suitable postprocessors so that additional transportation data can be collected more efficiently and more accurately. But these initial results show good potential for machine vision as a tool in the collection of transportation data.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of the Idaho Transportation Department and the University of Idaho during the research project described in this paper.

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Publication of this paper sponsored by Committee on Transportation Data and Information Systems.