DEVELOPMENT OF A BICYCLE AND PEDESTRIAN DETECTION AND CLASSIFICATION ALGORITHM FOR ACTIVE-INFRARED OVERHEAD VEHICLE IMAGING SENSORS

David A. Noyce
Assistant Professor
Department of Civil and Environmental Engineering
University of Wisconsin-Madison
1210 Engineering Hall
1415 Engineering Drive
Madison, WI 53706
Telephone: (608) 265-1882
Fax: (608) 262-5199
Email: noyce@engr.wisc.edu

Arunkumar Gajendran
TJKM Transportation Consultants
Suite 100, 5960 Inglewood Drive
Pleasanton, CA 94588
Telephone: (925) 463-0611
Fax: (925) 463-3690
Email: garun_77@hotmail.com
Formerly:
Graduate Research Assistant
University of Massachusetts – Amherst
Department of Civil and Environmental Engineering
139 Marston Hall
Amherst, MA 01003

Raghuram Dharmaraju
Vermont Agency of Transportation
1 National Life Drive, Drawer 33
Montpelier, VT 05633
Telephone: (802) 828-1329
Fax: (802) 828-2437
E-mail: raghuram.dharmaraju@state.vt.us
Formerly:
Graduate Research Assistant
University of Massachusetts – Amherst
Department of Civil and Environmental Engineering
139 Marston Hall
Amherst, MA 01003

Paper Number: 06-2094
Prepared for the 85th Annual meeting of the
Transportation Research Board, Washington, D.C.
January, 2006

Length of Paper:
4,974 words, 9 figures + 1 table @ 250 words each
7,474 equivalent words

ABSTRACT

The primary objective of this research was to develop and test a pedestrian detection and classification algorithm for active-infrared overhead vehicle imaging sensor technology. The new algorithm would allow the active-infrared technology to detect an object (pedestrian or bicycle) and then appropriately classify it. This paper presents research that led to the development of the algorithm designed to work within the active-infrared technology to automate the simultaneous detection and classification of bicycles and pedestrians along with the field investigations to evaluate its effectiveness.

Existing algorithms in the active-infrared overhead vehicle imaging sensor use length, width, height, and speed as basic parameters to detect and classify eleven different categories of motorized vehicles. Analysis of the existing algorithms determined that they were unable to effectively detect and classify both bicycles and pedestrians. A new algorithm, created as part of this research effort, uses the concept of message sequencing to accurately detect and classify bicycles and pedestrians. The new algorithm was installed within the existing active-infrared technology and evaluated on bicycle and pedestrian trails in Amherst, Massachusetts.

The results of this field experiment showed that the algorithm enhancement was effective in creating an intelligent technology that was able to accurately detect and classify bicycles and pedestrians. Nearly 100 percent of bicycles and pedestrian were successfully detected and approximately 92 percent of bicycles and pedestrians successfully classified.

This research shows that the ability to automate the detection and classification of bicycles and pedestrian is feasible and can be very useful in obtaining more comprehensive travel data and forecasting future demand for design and policymaking related to these non-motorized forms of transportation.

Keywords: Bicycle, Pedestrian, Automated Detection, Automated Classification, Active Infrared Technology

INTRODUCTION

Over the last decade, the field of transportation engineering has witnessed an enormous increase in the application of modern technologies in the form of Intelligent Transportation Systems (ITS). ITS technologies have significantly improved the efficiency and safety with which transportation systems are built, operated, and maintained. The focus of ITS technology applications has largely been limited to motorized modes of transportation; however, the general capabilities of many ITS technologies suggest that these applications may be effectively extended to non-motorized modes as well. Non-motorized modes of transportation (walking and bicycling) are an integral part of the transportation system and must be accommodated to make the system truly efficient and safe. Traffic engineers often find it easy to underestimate the importance of non-motorized modes and thus dismiss efforts to equitably extend ITS technologies in this direction. Current trends in research, planning, and policymaking suggest that this should not be the case.

Changing perspectives, along with Federal legislation and policies, have led to an increasing recognition of walking and bicycling as viable and important modes of travel in the local transportation system. According to the 1999 National Personal Transportation Survey (NPTS), bicycling and walking account for approximately 6.4 percent of all trips made (*1*). Nearly $1 billion dollars has been spent in the U.S. over the last few years on enhancing and providing facilities for these two non-motorized modes of transportation. Nevertheless, U.S. statistics show that 4,749 pedestrians and 622 bicyclists were killed and an estimated 123,000 were injured as a result of collision with motor vehicles in 2003 (*2*). In spite of these figures, non-motorized forms of transportation are often overlooked in planning, design, policymaking, and general transportation management strategies.

The 1994 FHWA *National Bicycling and Walking Study* set a goal of doubling the percentage of trips made by walking and bicycling, while simultaneously reducing the number of pedestrians and bicyclists killed and injured in traffic crashes by 10 percent (*3*). In an effort to achieve these goals, the 1998 *Transportation Equity Act for the 21st Century* (TEA-21) increased the emphasis of pedestrian and bicycle considerations in all planning and operations activities. TEA-21 allowed projects that support or improve pedestrian and bicycle travel to be broadly eligible for major funding programs and provided opportunities to compete with other transportation projects for available funding at the state and Metropolitan Planning Organization (MPO) levels. The legislation has indicated that bicycle and pedestrian projects shall be considered, where appropriate, in conjunction with all new construction and reconstruction of transportation facilities.

Efforts to improve conditions for pedestrian and bicycle travel require data such as travel and facility characteristics, crash and safety information, and user preferences; however, deficiencies and limitations in existing sources of data often hamper these efforts (*4*). Understanding trends in walking and bicycling and forecasting future demand requires accurate pedestrian and bicycle travel data. Pedestrian and bicycle activity varies from place to place and depends on many factors, including distances to be traveled, perceived safety, social factors, access and linkage of facilities, terrain, weather, land use, and environmental factors. The diversity in the extent of usage of pedestrian and bicycle facilities warrants extensive data collection. Hence, localized data is required to supplement generalized data such as those provided by the U.S. Census.

Recognizing the above facts, the Bureau of Transportation Statistics (BTS) completed an assessment of pedestrian and bicycle data needs as an initial step towards filling data gaps and enhancing pedestrian and bicycle data quality (*4*). Data needs were identified through published materials and an extensive BTS outreach program involving planners, advocates, and researchers at federal, state, and local government agencies, universities, and nonprofit organizations. BTS identified data relating to the counting and classification of pedestrians and bicycles by facility or geographic area as a high priority, stressing the need for research to identify technologies to successfully obtain these data.

The BTS report recommended the use of ITS technologies, specifically automated detection technologies, for pedestrian and bicycle data collection (*4*). Recommendations included: evaluating and promoting new bicycle- and pedestrian-counting technologies (i.e., video imaging, infrared sensors) by synthesizing the results of current pilot-testing efforts, sponsoring additional pilot tests and methodological development, and conducting outreach efforts to disseminate successful technologies. Prior to the research presented in this paper, these recommendations have not led to significant research and development activity.

A wide variety of automated detection and classification technologies have emerged in recent years due to advances in science and technology. Though many of these technologies evolved through military and defense applications, they have found use in the transportation industry. Vehicles (not including bicycles) have remained the primary focus of automated detection technologies. Applications for non-motorized transportation modes have so far been limited. Very few applications have developed for pedestrian and bicycle detection and no efficient methods currently exist for pedestrian and bicycle classification other than manual counts. The effectiveness of ITS technologies in automating the collection of non-motorized volume and classification data has not been widely researched.

Recent research has evaluated a wide range of potential technologies for automated bicycle and pedestrian detection including microwave, active-infrared, passive infrared, video imaging, ultrasonic, acoustic, and piezoelectric (*5*). The results of this analysis found that active-infrared technology has significant potential for bicycle and pedestrian applications; however, new algorithms and other technology enhancements were required to allow this technology to be converted from the motorized to non-motorized mode. Current algorithms used in active-infrared technology have been effective in truck, automobile, and motorcycle detection and classification. Although it is believed that the motorcycle detection algorithms can be extended to bicycles, no algorithm has been created to detect pedestrians and other non-motorized transportation system users.

RESEARCH OBJECTIVES

The primary objective of this research was to develop and test a pedestrian detection and classification algorithm for active-infrared overhead vehicle imaging sensor technology. The new algorithm, if successful, would allow the active-infrared technology to detect an object (pedestrian or bicycle) and then appropriately classify it. Additionally, the existing algorithm developed for motorcycle detection in active-infrared imaging was evaluated and tested for applicability and meaningful modifications in bicycle detection and classification.

ACTIVE-INFRARED TECHNOLOGY

Active-infrared technology is currently used to detect and classify all classes of motor vehicles. Through algorithms developed to support the active-infrared system, this technology can create an overhead three-dimensional image of the passing vehicle and classify the vehicle through a predetermined range of size measurements. In a typical application, a detection and classification device scans the roadway with two laser beams by taking a series of range measurements across the width of the road/path. A typical scan set-up is depicted in Figure 1. Each range measurement forms a line across the road with 10 degrees of separation between the beams. When an object enters the beam, the measured distance decreases and corresponding height is calculated using simple geometry. As the object passes, the second beam is also broken in the same manner. Consecutive range samples are analyzed to generate a profile of the object in view. This profile (i.e., the raw data) is then processed by the supporting system to classify the vehicles into respective categories.

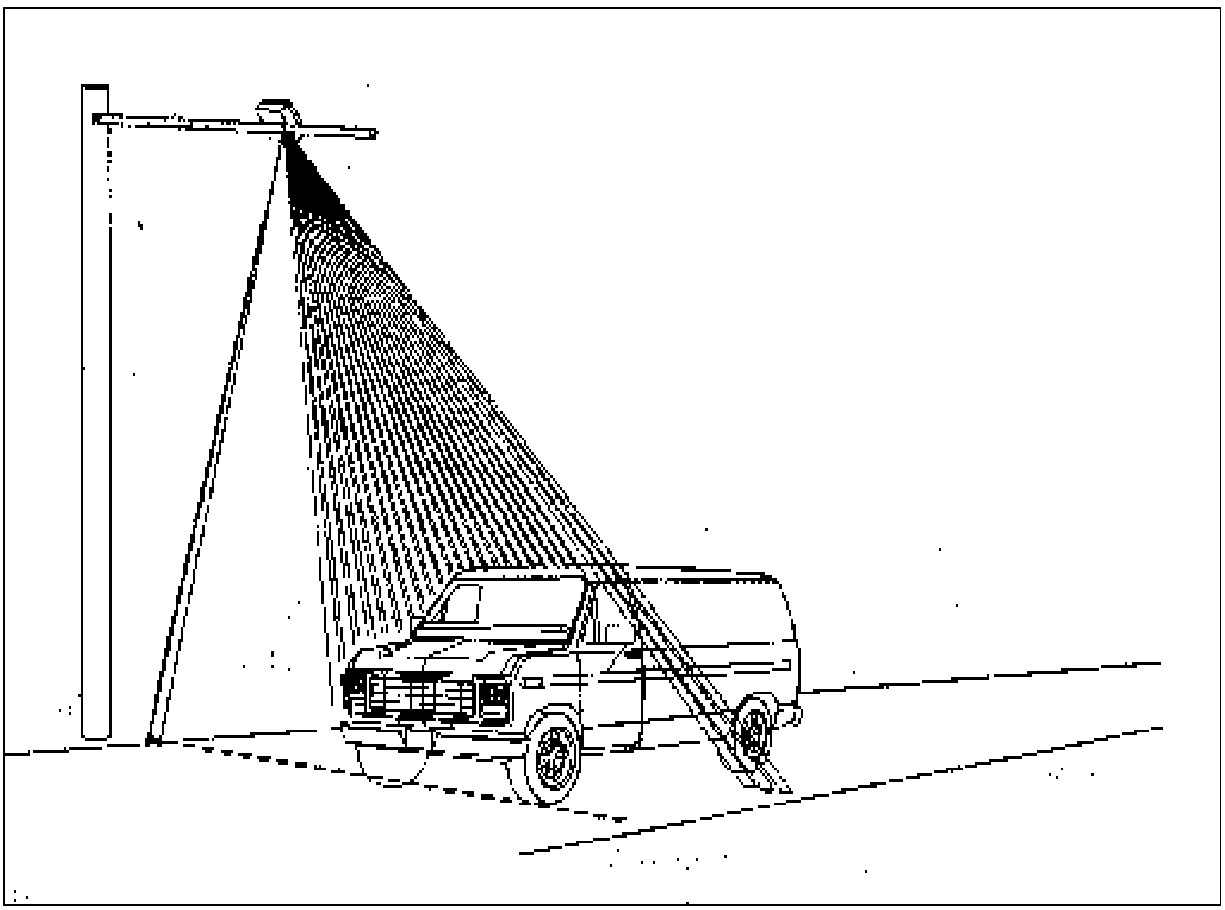

FIGURE 1 Typical active-infrared scan pattern (*6*).

All of these tasks are completed using vehicle recognition algorithms written especially for active-infrared technology. Algorithm characteristics by which the vehicles are classified include length, width, and height. Algorithms can also recognize and process a single motorcycle and two motorcycles moving side by side.

More specifically, algorithm detection and classification process begins when an object cuts laser beam 1. Here, the time t_1 at which the front part of the object cuts beam 1 is noted. The object continues to move and cuts beam 2. Here, the time t_2 at which the front part of the vehicle cuts beam 2 is noted. The difference in detection times ($t_2 – t_1$) is calculated. The distance of separation between the two beams is known using the height of installation and the tilt angle of the sensor by trigonometric principles. Speed of the object is derived from distance of separation and the difference in detection times.

The object continues to move and leaves beam 1. Here, the time t_3 at which the rear part of the vehicle leaves beam 1 is noted. The time difference between t_3 and t_1 and the speed calculated are used to derive the length of the object. The object continues to move and leaves beam 2. Here, the time t_4 at which the rear part of the vehicle leaves beam 2 is noted. This time also indicates that the object has left the beam system completely and initiates the classification algorithm to output a classification message. Time t_4 is used to confirm the length and speed of the vehicle derived from previous steps.

During the time window when the object is moving underneath the two beams, parallel processing is done to derive width and height of the object. The hardware set up goes through a series of self tests and configuration tests to define one of the many ambience parameters, specifically the road surface including the range measurement. As a result, the sensor can differentiate between the road surface and the object surface. By the virtue of this capability, it can find the left edge and right edge positions of the object, and the range measurement of the top surface. Width is calculated as the difference between left and right edge positions and height is calculated as the difference between range measurements of road and the top surface of the vehicle.

The classification algorithm uses the already existing database with different templates associated to different category of objects. The template for a particular classification has a unique range of speed, length, width, and height. Also, each parameter has a probability associated to it depending upon where the calculated parameter falls in the range. Therefore, the classification message outputs the name of the object classification with a calculated probability of accuracy.

RESEARCH DEVICE

A commercially available active-infrared device was used for this research. The *AutoSense II* employs a rotating polygon to line scan the diode-laser rangefinder across the pavement (6). The polygon scanner rotates continuously in one direction at a constant speed. The angle between each facet and the base of the polygon alternates between 87.5 and 92.5 degrees for adjacent facets, providing two separate beams with successive scans at 10 degrees angular separation. The device had a unique capability for overhead imaging of vehicles to generate information about the activity detected within its field of view by scanning the roadway at a rate of 720 scans/s and taking a series of range measurements (height profiles) across the width of the road at two locations beneath the sensor. These measurements are processed by vehicle detection and classification algorithms to generate messages that uniquely detect and classify each vehicle and determine speed and position.

As presented in Figure 2, the device is mounted approximately 7 meters (23 feet) centered above the pavement surface. A look down angle of 10 degrees for the first beam and 0 degrees for the second beam is used. A 5-degree forward tilt is provided when mounting the sensor to achieve the recommended beam angles; however, the mounting angle is not critical to performance.

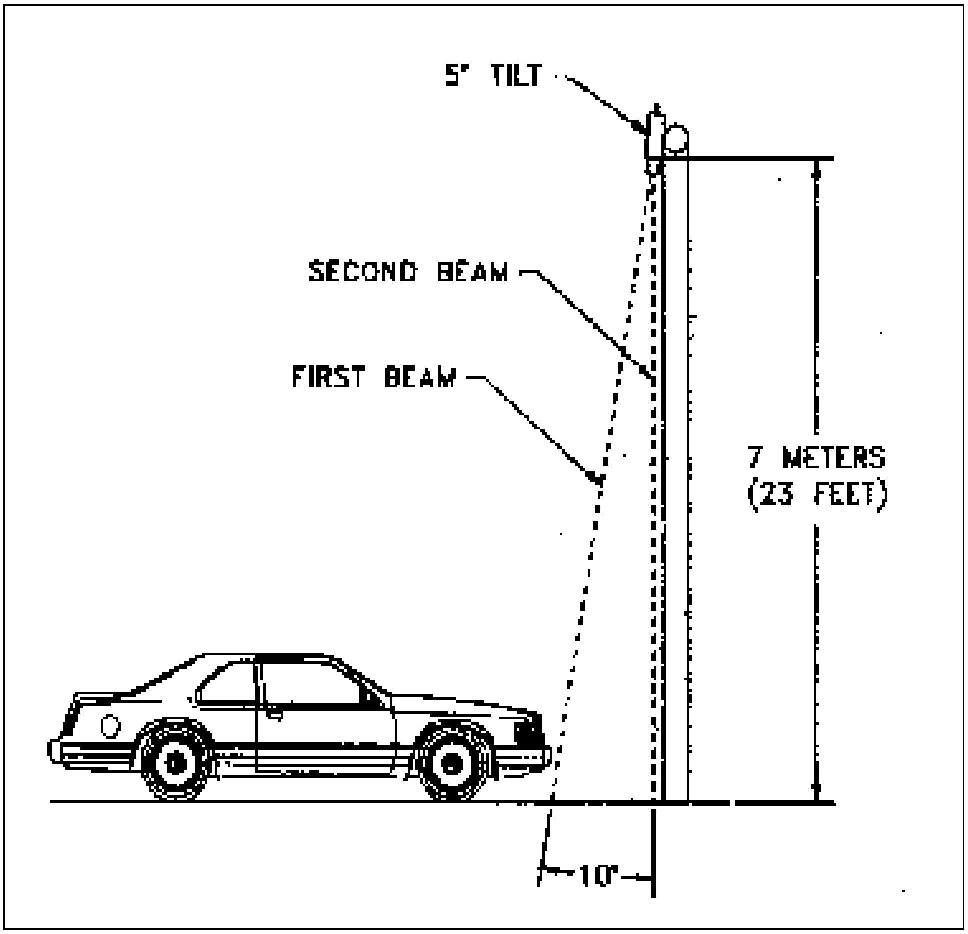

FIGURE 2 Active-infrared device mounting angle (*6*).

The device transmitted as many as five messages for each object that is detected within its field of view. In normal circumstances, each message and the order in which it is transmitted is:

- First Beam Vehicle Detection Message;
- Second Beam Vehicle Detection Message;
- First Beam End of Vehicle Message;
- Second Beam End of Vehicle Message; and
- Vehicle Classification Message.

Messages are produced by the algorithm and displayed on a connected computer screen.

TESTING THE EXISTING ALGORITHM

The effectiveness of the existing algorithm in bicycle and pedestrian detection was tested at two sites. The Norwottuck Trail (Figure 3) in Amherst, Massachusetts was selected because it had the required facilities such as a power supply and an appropriate place to install the active-infrared overhead vehicle imaging sensor. Moreover, a sufficient amount of bicycle and pedestrian traffic volumes existed. Minimum but consistent bicycle and pedestrian traffic on the trail was desired to obtain the necessary data.

FIGURE 3 Norwottuck trail at Route 116, Amherst, MA.

A personal computer with the software designed to run the device was installed in the vicinity to observe and evaluate the messages developed for different users including pedestrians, bicycles, joggers, and skaters. Data collection took place over a period of one month at this trail providing sufficient amount of data for evaluation. Efforts were taken to collect data in all types of light, temperature, and weather conditions. Note that the mounting height of the active-infrared device at this location was slightly lower than recommended by the manufacturer. The lower mounting height slightly decreased the distance separate between laser beams but did not affect operating conditions or results.

The data output in the form of text messages and images were saved for future analysis and development of potential algorithm modifications. The following observations were made:

- The pattern of detection in both the directions;
- Whether the sensor detects all the users including pedestrians;
- Criteria for filtering out messages;
- Criteria for classification;
- Criteria for differentiating pedestrians from bicycles;
- The pattern of message sequence; and
- The individual parameters including speed, width, height, and length.

The other data collection site chosen was an overhead pedestrian bridge that connects Marcus and Marston Hall buildings on the University of Massachusetts-Amherst campus. This site is shown in Figure 4. This overhead bridge site allowed researchers to test the active-infrared device under both a random and controlled environment. The controlled environment was one in which the flow of pedestrians and bicycles, in terms of time intervals and positions underneath the sensor, were staged in a predetermined sequence. Data collected in this fashion were useful in testing the specific pattern of message output for a single object at a particular position underneath the sensor. The evaluation considered the number of pedestrians and bicyclists moving under the system as a single event, along with the position, direction, and speed of the user. Some of the scenarios included:

- A single pedestrian walking along centerline or rightmost or leftmost positions of the road in the forward and reverse direction;
- A single bicycle along centerline, rightmost, and leftmost positions of the road in the forward and reverse direction;
- A combination of two or three pedestrians at different positions in the forward and reverse direction;
- A combination of two or three bicycles at different positions in the forward and reverse direction;
- A combination of two pedestrians or bicycles moving closely to each other but just one behind another;
- A combination of two or three pedestrians or bicycles moving in both directions; and
- A combination of one or two pedestrians in the forward or reverse direction and one or two bicycles in forward or reverse direction.

FIGURE 4 Overhead pedestrian bridge on UMass campus.

The data on all the above were collected manually using data sheets. A snapshot of the datasheets used is presented in Figure 5 where beam A corresponds to beam 1 and beam B corresponds to beam 2. The letter designations A and B were used for the two beams during the experiment though the common terminology used in the software documentation for the two beams were beam 1 and beam 2.

It is known that beam 1 is the 10^o inclined beam to the vertical and beam 2 is the vertical beam. The forward movement is defined as the movement when the object cuts beam A first and then beam B, consequentially. The reverse movement is just the opposite of forward movement where the object cuts beam B first and then beam A, consequentially. The message output corresponding to two beams namely message 1, message 2, message 3, message 4 and the classification message 5 were stored in text files for each event at a particular instant. The storage of message output in text files is done automatically by the software as and when it outputs the message onto the screen after detecting and classifying vehicles. The storage of message output in text files is one of the capabilities of the software which can be used to match the data collected from controlled environment with that of actual message output.

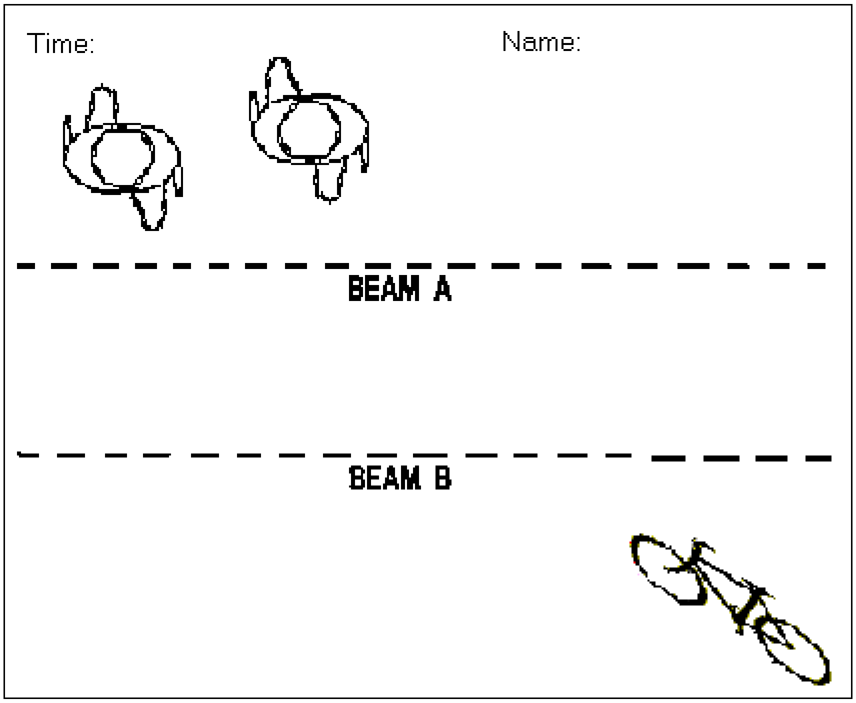

FIGURE 5 Dual pedestrians and bicycle at rightmost Positions in the forward and reverse directions, respectively.

The occurrence of some of the events such as simultaneous movement of multiple objects underneath the sensor is very unlikely in nature. This argument is supported by the observations made at the Norwottuck trail over a span of one month. Nevertheless, heavily used trails will have more simultaneous movements therefore all scenarios were taken into account while developing the algorithm to increase its reliability.

ANALYSIS OF OBSERVATIONS

Testing of the existing algorithm was useful to understand the applicability of the existing algorithm for detection and classification of bicycles and pedestrians. Testing under controlled environment conditions was useful to devise the basic conceptuality which eventually became the core of the new algorithm.

The four stages of the movement of a bicycle underneath the sensor are illustrated in Figure 6. One can deduce that the bicycle is very similar to a motorcycle in terms of movement, message output, and classification. It is known that the existing algorithm can classify all motorized vehicles, including motorcycles. Therefore, the existing algorithm can be extended for bicycle detection and classification.

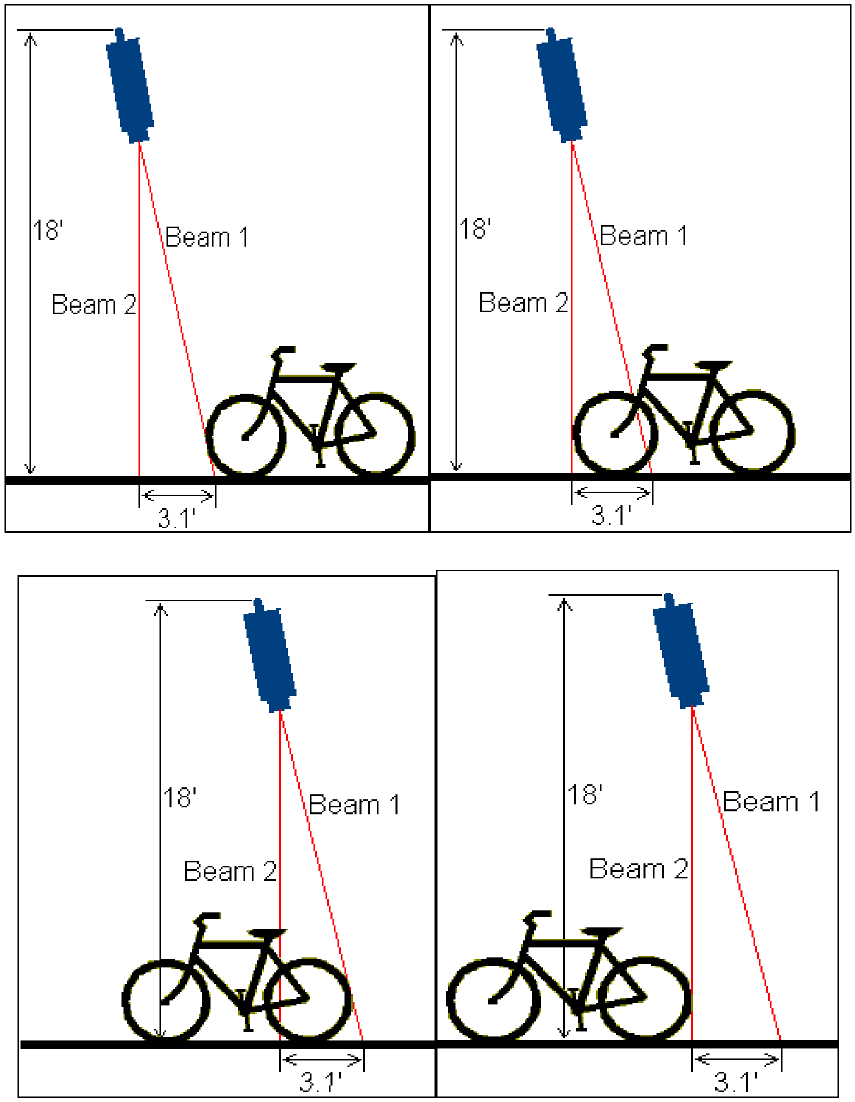

FIGURE 6 Bicycle movement underneath the sensor.

The four stages of the movement of a pedestrian underneath the sensor are illustrated by Figure 7. The pedestrian moving underneath the sensor can intercept the beam in multiple fashions. This results in multiple message outputs depending on whether the hand or the leg enters or leaves the beams. In other words, pedestrian movement is discrete in nature, unlike that of bicycle, motorcycle, car and any heavy vehicle, which is continuous in nature. A vehicle moves as a single unit whereas a pedestrian can have internal movements apart from moving as a unit. A vehicle is understood to have a continuous movement when it cuts one or more of the beams at any time instant between the instant it enters beam 1 and the instant it exits beam 2 and vice versa. On the other hand, a discontinuous or discrete movement is one in which there will be one or more time instants where the object might not cut any of the beams in the time period between entry and exit. For instance, a pedestrian may be present between beams 1 and 2 without cutting either of them while walking underneath the sensor, which is an example of a discontinuous movement.

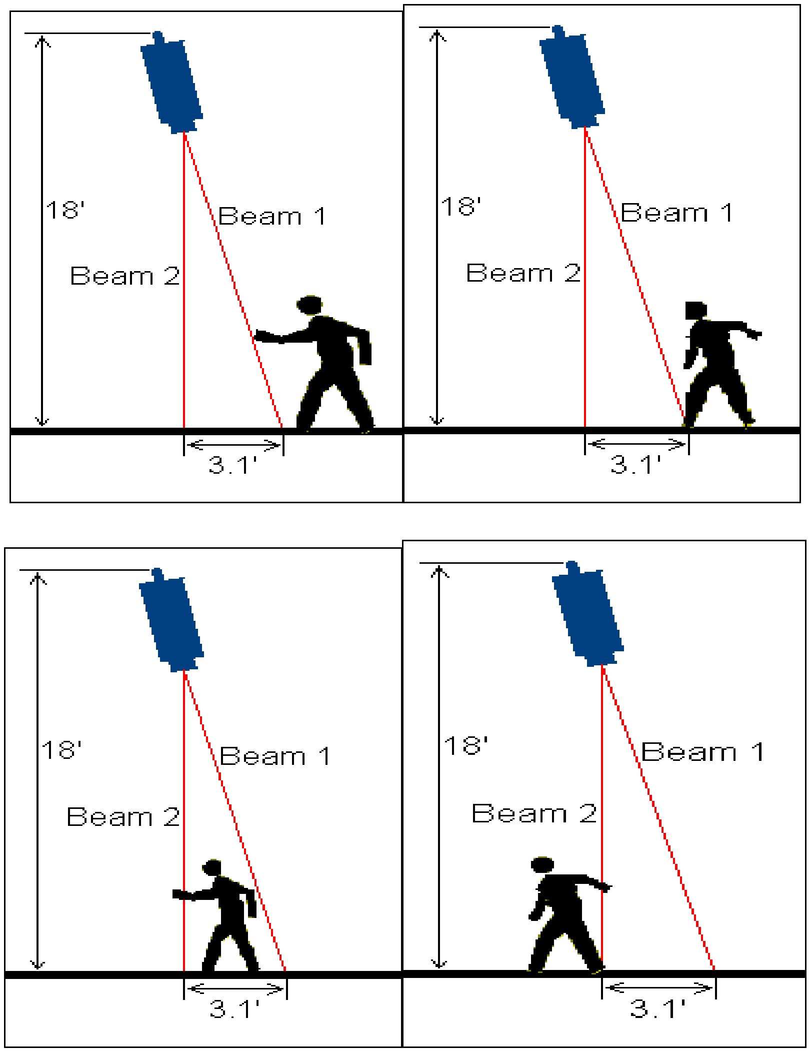

FIGURE 7 Pedestrian movement underneath the sensor.

The existing algorithm has the capability to detect pedestrians and bicycles with high accuracy. However, the existing algorithm cannot distinguish between bicycles and pedestrians. It was observed that most of the bicycles were classified as motorcycles due to the similarity of shape, length, height, and width. The results of the existing algorithm showed that 98 percent of the 753 bicyclists observed were correctly detected. Over 95 percent of the 316 pedestrians were also detected. Approximately 72 percent of bicyclists were correctly classified, although they were shown to be motorcycles. Pedestrians were not classified, either erroneously shown as a vehicle type or as a device error. Pedestrian movement produced varying messages due to the motion of arms and legs. Multiple detection messages were produced for each beam in the case of most pedestrians. The existing algorithm was found to be incapable of handling this situation and a new algorithm was clearly necessary for pedestrian detection.

The functionality of the existing algorithm was observed and studied separately from quantifying the performance. The calculated parameters such as speed, length, width, and height were observed for objects moving in either direction of the trail underneath the sensor. The messages produced were saved in text files for future reference. These text files with saved messages were used for further analysis and were used as test cases for the new algorithm.

DEVELOPMENT OF NEW ALGORITHM

Methodology

Existing algorithms were studied to consider flow of data, basic ideas used in the algorithm, and general working principles. It was found that although the algorithm can be easily modified for bicycle detection and classification, the basic format used in the algorithm could not be extended to pedestrians. Pedestrian movements provided various combinations of movements that the algorithm could not recognize. Moreover, the existing algorithm was designed to work for vehicle flow in one direction. Pedestrians and bicycles may move in both directions depending upon the need of the designed facility. Therefore, after modifying the existing algorithm for bicycles, a new algorithm that uses different concepts was required. The idea of having different algorithms for bicycles and pedestrians was inefficient; hence, a new algorithm involving common conceptuality that can detect and classify both bicycles and pedestrians simultaneously was developed.

The testing of the existing algorithm under the controlled environment at the overhead bridge site provided much needed information on the common conceptuality to devise the second method. It was understood that Autosense II can detect any object that goes underneath and outputs five messages namely message 1 through 5 (6). The fifth message is the classification message, which uses the existing classification algorithm. Therefore, this method used the data available in messages 1 through 4 and the order in which these four messages are produced to develop the new algorithm. In other words, the data associated with messages 1 through 4 were used and message 5 was discarded.

Different mounting heights were tried to differentiate pedestrians from bicycles in terms of message sequence (1 through 4) and the information available in these messages. At a height of 23 feet and above the message sequence provided for pedestrians was different compared to that of bicycles due to arm swing and various body movements. Recall the 23 feet of mounting height would result in a minimum of 4 feet separation between the two beams at the ground surface. The four types of directional movement, namely pedestrian in forward direction; pedestrian in reverse direction; bicycle in forward direction; and the bicycle in reverse direction had four different characteristic message sequences. There were very few overlaps of message sequences but even those can be overcome by data associated with each message in the overlapping message sequences.

Message Sequence (Pattern)

The message sequence for pedestrians moving in forward direction was 1-3-2-4. The movement is described in a step-wise fashion as following:

- The pedestrian initially enters beam 1 which is message 1.

- The pedestrian leaves beam 1 before entering beam 2 which is message 3.
- The pedestrian enters beam 2 which is message 2.
- The pedestrian leaves beam 2 which is message 4.

All motorized vehicles in the forward direction have a message sequence 1-2-3-4 because they enter beam 2 before leaving beam 1. Clearly, this would not work for pedestrians. The mounting height of 23 feet with 10^o separation between two beams results in enough separation between two beams on the road for the pedestrian to leave beam 1 before entering beam 2. Lower mounting heights were considered but found to be undesirable as some probability existed of a pedestrian arm swing cutting beam 2 and initiating message 2 before message 3, amongst other problems. Considering all potential scenarios, heights greater than or equal to 23 feet was considered necessary to get the desired message sequence. The same concept held true for pedestrian moving in the reverse direction, in which case the message sequence is 2-4-1-3. Therefore, the message sequences for pedestrians moving in forward and reverse directions were 1-3-2-4 and 2-4-1-3, respectively.

The message sequence for bicycle moving in forward direction is 1-2-3-4 which is identical to the current algorithm sequencing. The bicycle movement in the forward direction is described in a step-wise fashion as following:

- The bicycle initially enters beam 1 which is message 1.
- The bicycle enters beam 2 before leaving beam 1 which is message 2.
- The bicycle leaves beam 1 which is message 3
- The bicycle leaves beam 2 which is message 4.

The same mounting height of 23 feet with 10^o separation between two beams results in an ideal separation between two beams on the road for the bicycle to enter beam 2 which is message 2 before leaving beam 1. The same concept holds true for bicycle moving in reverse direction and the message sequence is 2-1-4-3. Therefore, the message sequences for bicycles moving in forward and reverse directions are 1-2-3-4 and 2-1-4-3, respectively. The four basic message sequences for a bicycle and a pedestrian moving in forward and reverse directions were used as building blocks for deriving other complicated message sequences associated with the multiple objects moving underneath the sensor.

Confirmatory Checks

The confirmatory checks originated from the data associated with messages 2 and 3. The data associated with each message is shown in Figure 8. It was found from the analysis that the date, time, left edge position and right edge position comprised the set of useful information. Vehicle ID and speed were not considered because vehicle ID was the number the existing algorithm tags to a vehicle as soon as it entered the field of view. Vehicle IDs could not be used in the case of pedestrians because multiple IDs could be tagged to the same pedestrian due to arm and leg movement underneath the sensor.

1. 1st BEAM VEHICLE DETECTION 05-03-02 09:31:52.23

   ID = 109

2. 2nd BEAM VEHICLE DETECTION 05-03-02 09:31:53.10

   ID = 110

   Left Edge Pos: 15

   Rght Edge Pos: 17

   Speed (mph)..: 0

3. 1st BEAM END of VEHICLE 05-03-02 09:31:52.61

   ID = 109

   Left Edge Pos: 13

   Rght Edge Pos: 18

4. 2nd BEAM END of VEHICLE 05-03-02 09:31:53.38

   ID = 110

FIGURE 8 Data associated with the messages.

Speed was one of the parameters calculated by the existing algorithm which is designed for object movement in one direction. Speed was not calculated in the opposite direction and thus it was not considered. Messages 2 and 3 had information on left edge and right edge positions, unlike 1 and 4. The width was calculated as the difference between left and right edge positions. It was found that the width calculated for beam 2 could be used to differentiate a pedestrian from a bicycle. This is particularly useful when the message sequence 2-1-4-3, which was actually a characteristic message for bicycle moving in a reverse direction, is given out for a pedestrian moving in reverse direction. It was also found that the width calculated for beam 3 can be used to distinguish single vehicles from multiple vehicles detected as a single vehicle. This was useful when a single message sequence 2-1-4-3 instead of two (e.g., 2-1-4-3-2-1-4-3) was given out for two bicycles moving very close to each other. These cases were considered to increase the accuracy and reliability of the algorithm though they constituted a negligible portion of entire data set.

OUTLINE OF NEW ALGORITHM AND TESTING

The test device had the capability to write the message output that appears on the screen into a text file as and when they occur in the *as2test* mode. The user entered the name of the text file in which the output messages was saved. This text file was used as the input for the new algorithm. The messages in the text file were processed and an array of message sequences related to independent events was formed. During the processing of text files, messages 1 through 4 and pertinent data were used. Message 5 was discarded. An independent event was defined by a unique sequence of messages where two consecutive messages were not separated by more than one second. It was observed and understood that when an object moves underneath the sensor, the time difference between any two consecutive messages of the corresponding message sequence defining that event was on the order of fractions of a second. This accuracy could be used to delineate events when two consecutive messages were more than one second apart with one of the messages signaling the start of an event and the other preceding message signaling the end of the previous event. After this delineation of events, the message sequence corresponding to each and every independent event was compared with the characteristic message sequence by string matching. Confirmatory checks were done in parallel with string matching to finalize the classification.

All the executable algorithm code was written in Perl language. Perl was selected because of its user-friendly format and ability to meet the needs of the research. The executable code developed, titled ‘Bikepedalgorithm.pl’, had the capability to save all output in a text file. A sample command line operation of the algorithm software on text files and sample message outputs are shown in Figure 9.

Statistical sample size calculations were used to determine the minimum number of observations needed for algorithm evaluation (*7*). A minimum of 267 observations were required for both pedestrians and bicycles to estimate the accuracy of detection and classification with an error of three percent at a 95 percent level of confidence. Note that all statistically-based sample size calculations provide only a minimum estimate of the number of samples needed and in most cases significantly more were obtained.

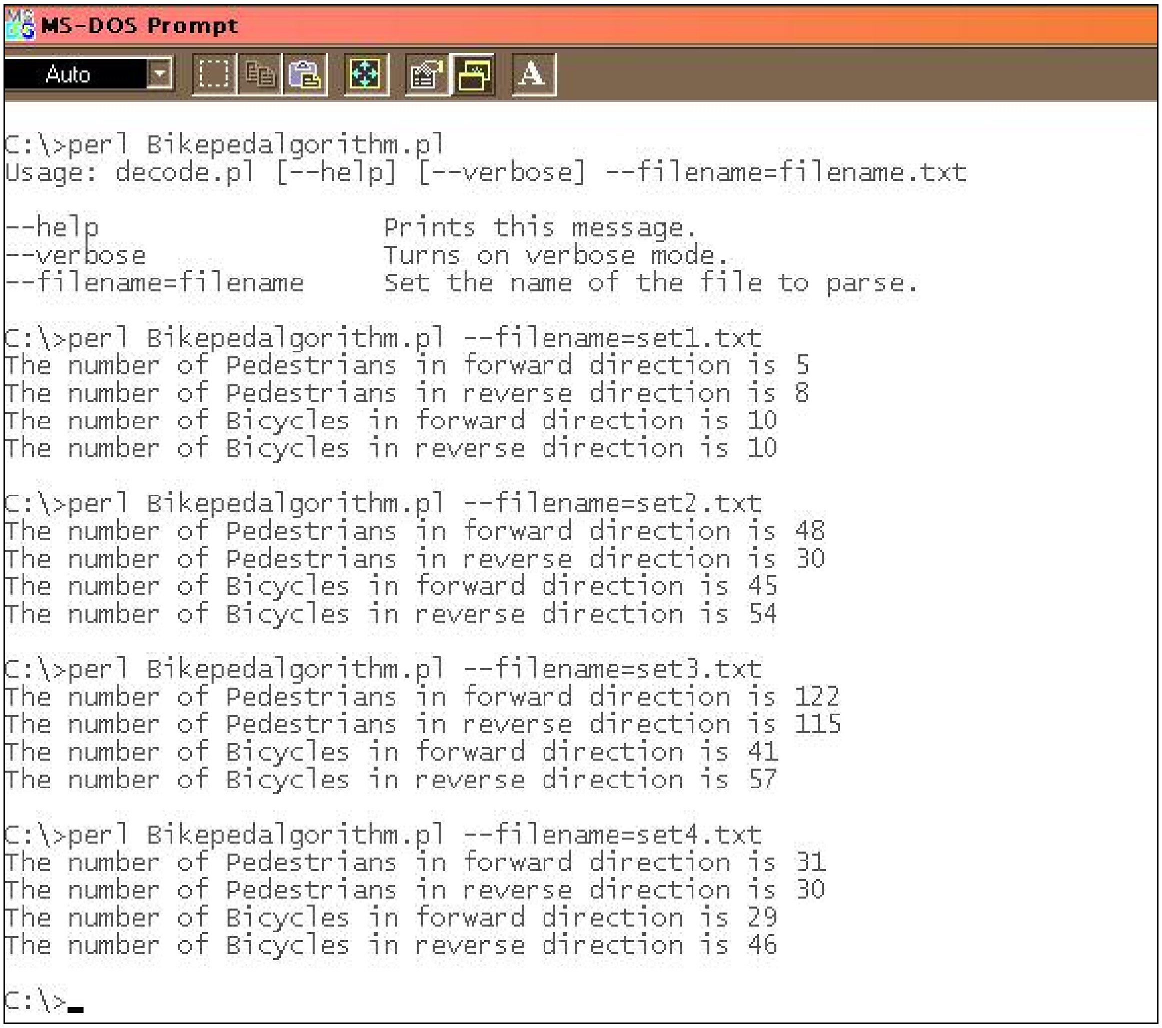

FIGURE 9 Sample of algorithm execution.

PERFORMANCE OF NEW ALGORITHM

The new algorithm was tested at one of the same locations as previously mentioned, namely the overhead bridge location in a trial application. Data collection through manual methods as well as video recording was done in parallel to compare and evaluate the performance of active-infrared device equipped with the new algorithm.

The results of the analysis are presented in Table 1. A total of 307 bicycle and 426 pedestrian observations were made. All bicycles and pedestrians were successfully detected providing a detection accuracy of 100 percent. The accuracy of the algorithm classification of bicycles and pedestrians moving in forward as well as reverse directions was 91.5 percent and 92.0 percent, respectively. Recall that classification using the original algorithm was 72 percent for bicycles and zero percent for pedestrians. The device-based algorithm classifications being less than the observed classifications were due to data lose during staged events, including multiple bicycles and pedestrians passing simultaneously. The results were very accurate when multiple pedestrians or multiple bicycles traveled together.

TABLE 1 Performance of the New Algorithm

Trail Users	Direction	Number of Observations	Correct Classifications and Counts	Percentage Correct (%)	Cumulative Percentage (%)
Bicycles	**Forward**	138	125	91	
	Reverse	169	157	93	
	Total	307	282		92.0
Pedestrians	**Forward**	224	206	92	
	Reverse	202	183	91	
	Total	426	389		91.5

CONCLUSIONS

Accommodating bicyclists and pedestrians in planning, design, and construction of transportation facilities requires accurate data. The algorithm developed as a part of this research successfully detected and classified bicycles and pedestrians with a high degree of accuracy. This algorithm has the capability to count and classify bicycles and pedestrians in both the forward and reverse directions, and simultaneously in multiple groups. Automated data collection using the active-infrared in an overhead vehicle imaging sensor, equipped with this new algorithm, is a significant improvement in forecasting future demand for design and policymaking of the non-motorized transportation facilities. The new algorithm uses the common conceptuality of message sequences for accurate detection and classification of bicycles and pedestrians.

Several final points can be made regarding the active infrared device equipped with the new algorithm. There is a variety of trail users, each with unique characteristics. It may not be possible to identify each of these user types using this new algorithm but detection and general classification as bicycles and pedestrians was effectively done. Although the device was only evaluated on a pedestrian and bicycle trail for experimental convenience purposes, the device can be used at a sidewalk or any pedestrian and bicycle facility. The ability of combining all algorithms to create a device that could work on trails, sidewalks and roadways and simultaneously detect both motorized and non-motorized travelers is feasible, but was not explored. Given the experimental nature of the device and computer control, the cost of a typical installation as described in this paper was not calculated.

The algorithm worked with a reasonable accuracy of approximately 92 percent for both bicycles and pedestrians. The loss in accuracy is due to extreme cases that include multiple objects of four or more moving underneath the sensor simultaneously. These extreme cases are unlikely to occur on trails, sidewalks, or other common locations, but of course are possible.

The active infrared device installation and operation was not labor intensive and it could be installed on a temporary basis in 30 minutes or less. Two people and an appropriate mounting source (pole, grade crossing) and power supply were required for installing the device. The active infrared device was not affected by general light, temperature, and weather conditions. Reliability appeared to be excellent.

RECOMMENDATIONS

For the concept of message sequences to work in the algorithm, the required mounting height of the sensor should be 23 feet above the ground surface. This height is necessary for attaining the required minimum separation between beams at the ground surface. It is anticipated that this mounting height will not be feasible at all locations and thus hardware modifications are required to accommodate the minimum beam separation irrespective of the mounting height. This modification could be related to the adjustment of the rotating polygon to get the desired angle of inclination of the sensor with respect to the vertical.

The device now operates at the high scan rate of 720 scans per second, as it was designed to work with fast moving vehicles. This scan rate of 720 scans per second was found to have no effect on the performance of the newly developed algorithm; thus, no changes to this feature are required.

The automated detection and classification of bicycles and pedestrians is currently not done on a real-time basis. This algorithm works externally using the text file output option of active-infrared device. Though the post-processing time is negligible (few seconds), the new algorithm should be incorporated internally to provide real-time output under these data collection schemes. Consequently, it is recommended that the algorithm written in Perl language should be transformed to assembly (or current) language so that it becomes an integral part of the software. This would result in real-time output of detection and classification messages facilitating bicycle and pedestrian counts without post-processing. It is also recommended that an inbuilt option be developed for the user to run the software in the bicycle-pedestrian mode for the purpose of exclusive detection and classification of bicycles and pedestrians.

High speed data produced in the form of false color images should be explored for applicability in accurate detection and classification of bicycles and pedestrians of all types (carriages, roller blades, etc.). The only foreseen problem with these data is that there may be a shadow effect over the intensity of the images when two objects move close to each other.

REFERENCES

1. *Non-Motorized Applications of ITS.* ITS America, Washington, D.C., December, 1999. http://www.itsa.org/resources.nsf/urls/nomoto.html, Accessed on June 2, 2004.
2. National Highway Traffic Safety Administration (NHTSA). Traffic Safety Facts 2003. http://www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/TSFAnn/TSF2003F.pdf. Acccessed, May 12, 2005.
3. National Bicycling and Walking Study – 10 Year Status Report. Federal Highway Administration, Washington, D.C., October, 2004. http://www.fhwa.dot.gov/environment/bikeped/study/. Accessed June 24, 2005.
4. Bureau of Transportation Statistics *Bicycle and Pedestrian Data: Sources, Needs & Gaps,* June 1998, Washington, D.C. http://www.bts.gov/publications/bicycle_and_pedestrian_data/entire.pdf. Accesed July 23, 2005.
5. Dharmaraju, Raghuram. *An Evaluation of Technologies for Automated Detection and Classification of Pedestrians and Bicycles.* Master’s Thesis, 2001 University of Massachusetts, Amherst, MA.

6. Schwartz Electro-Optics Inc., Autosense II Vehicle Detection & Classification Sensor Installation, Operation, Service and Parts Manual, March 2000, Orlando, FL.
7. Mendenhall, William, Robert J. Beaver and Barbara M. Beaver, Introduction to *Probability and Statistics*, 10^{th} Edition, Duxbury Press, 1999, Glenwood, IA.