AN EVALUATION OF TECHNOLOGIES FOR AUTOMATED DETECTION AND CLASSIFICATION OF PEDESTRIANS AND BICYCLES

Raghuram Dharmaraju, David A. Noyce, Joshua D. Lehman

INTRODUCTION

Changing ideology and Federal legislation have led to an increasing awareness of the need to recognize walking and bicycling as viable modes of transportation. Research, planning, and policymaking 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. Data relating to the number of pedestrians and bicycles by facility or geographic area are of high priority. Efforts to collect such data are hindered by the large amount of time, effort and peoplepower required. The use of ITS applications based on automated detection technologies can help to overcome this problem.

Automated detection technologies have been used extensively for motorized modes of transportation, yet very little has been done to extend these technologies to non-motorized modes. This paper describes the initial tasks of a study conducted to evaluate the existing technologies for automated detection, counting and classification of pedestrians and bicycles. Existing technologies were assessed for their suitability to collect pedestrian and bicycle data. ITS applications based on suitable technologies were then evaluated by testing them on site. The study also makes recommendations regarding the possible extension and improvement of existing ITS applications to make pedestrian and bicycle data collection easier.

IMPORTANCE OF BIKES AND PEDS

The potential of pedestrian and bicycle travel to provide mobility, reduce congestion, improve environmental quality, and promote public health has received increasing attention from researchers, planners and policymakers (1). The 1994 National Bicycling and Walking Study set a goal of doubling the percentage of trips made by bicycling and walking, and at the same time reducing by 10 percent the number of bicyclists and pedestrians killed and injured in traffic crashes (2). These goals may be unrealistic because under prevailing conditions, which are often substandard and include narrow bike lanes, high motor vehicle speeds, congestion, and a lack of sidewalks, users often perceive a risk to their safety and health in walking and bicycling. Therefore many potential non-motorized trips are avoided.

Federal policy recognizes this need for improvement of pedestrian and bicycle facilities and for integrating them in the planning process to support any promotion of these modes. Federal policy stresses the need “to promote increased use of bicycling, to accommodate bicycle and pedestrian needs in designing transportation facilities in urban and suburban areas, and to increase pedestrian safety” (3).

The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) also recognized that improving and sustaining bicycling and walking, either alone or in conjunction with other modes is a key factor in meeting air quality goals. The 1998 Transportation Equity Act for the 21st Century (TEA-21) continued the trend of increased emphasis on the inclusion of bicycle and pedestrian considerations in all planning activities. According to TEA-21, bicycle and pedestrian projects are broadly eligible for all of the major funding programs where they compete with other transportation projects for available funding at the State and MPO levels (4). Quoting directly from TEA-21:

- "Bicyclists and pedestrians shall be given due consideration in State and MPO long-range transportation plans;"
- "Bicycle and pedestrian projects shall be considered, where appropriate, in conjunction with all new construction and reconstruction of transportation facilities, except where bicycle and pedestrian use is not permitted;"
- "Transportation plans and projects shall provide due consideration for safety and contiguous routes for bicyclists and pedestrians."

In working towards the goals set forth in TEA-21 and the National Bicycling and Walking Study, Federal Highway Administration (FHWA) has been encouraging state and local planners to regard walking and bicycling as significant modes of transportation and to include them in the overall transportation planning process. As a response to this, most states have initiated programs to improve pedestrian and bicycling facilities by accommodating bicycle and pedestrian traffic in the planning, design, construction, reconstruction or maintenance of any projects undertaken. Nevertheless, there are problems with in the process of accommodating bicycles and pedestrians, not the least of which is the lack of relevant data.

DATA NEEDS

Research, planning and policymaking 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 for data often hamper these efforts (1).

It is important to estimate the extent of future usage of pedestrian and bicycle facilities to be able to appropriately plan, design, and construct new facilities as well as improve existing facilities. Understanding current trends in walking and bicycling before future demand can be forecast 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, and environmental factors (5). The diversity in the extent of usage of pedestrian and bicycle facilities warrants extensive data collection. Hence, localized data needs to be collected to supplement generalized data such as those provided by the U.S. Census (6).

Recognizing the above facts, the Bureau of Transportation Statistics (BTS) undertook an assessment of bicycle and pedestrian data needs as an initial step towards enhancing bicycle and pedestrian data quality and filling data gaps. Data needs were reviewed based on published materials and an extensive outreach program involving user groups including planners, advocates, and researchers at federal, state, and local government agencies, universities, and nonprofit organizations (1). The study identified data relating to the number of bicyclists and pedestrians by facility or geographic area as a high priority, and recognized that the quality of such existing data is poor. The study recommended the use of ITS technologies and more specifically automated detection technologies for data collection. The study's recommendations include: evaluating and promoting new bicycle- and pedestrian-counting technologies by synthesizing the results of current pilot-testing efforts; sponsoring additional pilot tests and methodological development; and, conducting outreach efforts to disseminate successful technologies (1).

ITS TECHNOLOGIES FOR PEDESTRIANS AND BICYCLES

A basic underlying concept of the movement towards ITS is that efficiency and safety can be significantly enhanced by providing both the user and the operator with more and better information. The information that these technologies are used to gather varies greatly depending upon application of the information. Real-time traffic information, traffic volume, classification of users, and speed data are examples of necessary information. These ITS applications largely depend on automated detection technologies to collect this data more accurately than conventional techniques. Automated detection, counting, and classification can also help to overcome the need for extensive staff involvement, time, and effort generally required for conventional data collection methods.

A wide variety of automated detection technologies have emerged in recent years due to advances in sensor technology. These technologies have primarily evolved over the years because of military and defense applications. More often than not, new technologies find application in fields for which they were not originally intended for, and sensor technology is no exception. ITS is one of the many fields in which sensor technology is extensively used today. Sensor technology has been widely used for automated detection of motor vehicles. A wide range of devices based on different technologies has been developed as an alternative to the costly inductive loops. Over the years, motor vehicles have remained the focus of automated detection technologies and very few applications have been developed for pedestrian and bicycle detection.

The application of automated detection technologies for non-motorized transportation modes has so far been limited to safety-enhancing applications, such as pedestrian signal actuation. Though research has been conducted to evaluate these technologies from the viewpoint of signal actuation, they are yet to be evaluated for the purpose of data collection. The possibility of non-motorized volume and classification data collection using these technologies remains to be thoroughly explored. To overcome this deficiency, available sensor technologies were researched, and those having the potential for automated detection and classification of bicycles and pedestrians were identified.

AUTOMATED DETECTION TECHNOLOGIES

Several technologies may be effective for automated detection of pedestrians and bicycles. These technologies include:

- Microwave
- Ultrasonic and Acoustic
- Passive Infrared
- Active Infrared
- Video Image Sensing
- Piezoelectric
- Traditional

These technologies vary in their ability to both detect and classify bicycles and pedestrians. To select the technologies most suitable for this purpose, they were evaluated based upon their working principles and their current applications. Note that the current applications used for evaluation have been developed primarily for motor vehicle detection and/or classification.

1. **Microwave:** Microwave radar detectors transmit electromagnetic radiation toward the area of interest from an antenna, mounted overhead or on the side, that illuminates approaching or departing objects. When an object passes through the beam, a portion of the transmitted radiation is reflected back to the antenna. A schematic diagram of the working of microwave radar is shown in Figure 1 below. There are two types of microwave detectors. The first transmits a continuous wave of constant frequency and the change in frequency of the reflected wave is used to calculate the speed of the object on the basis of the Doppler principle. Detectors with such capability alone cannot detect motionless objects. However, detectors that are sensitive to very small motion are being developed. The second type of detectors transmit a saw-tooth waveform, also called FCWM (frequency modulated continuous wave), in which the transmitted frequency constantly changes (7). The FCWM provides both presence and passage detection. Microwave technology is not very suitable for classification purposes.

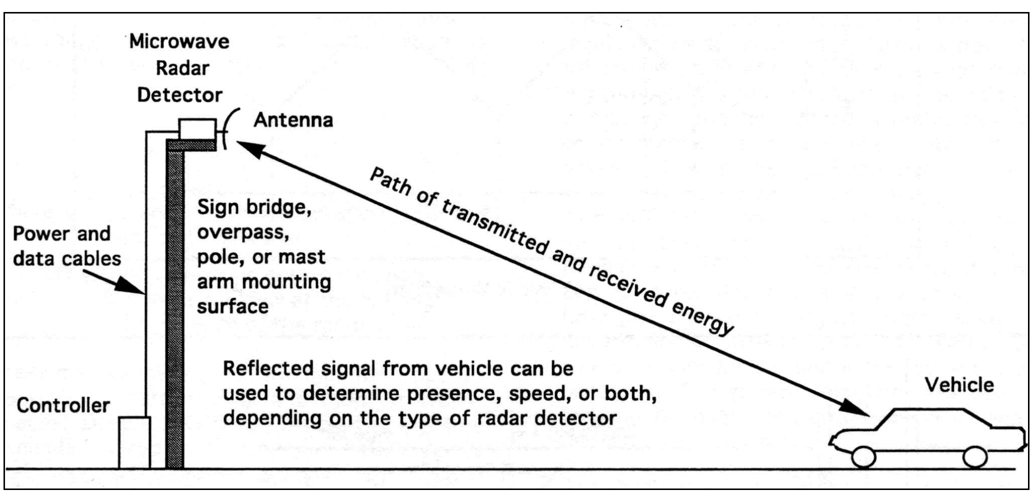

Figure 1 Microwave radar detector (7).

2. **Ultrasonic and Acoustic:** Ultrasonic detectors work on the same principles as the microwave detectors, but use sound waves of selected frequencies instead of microwaves (8). Passive acoustic detectors, which measure sound energy levels, are also used for vehicle detection. Nevertheless, these detectors cannot be effectively used for pedestrians and bicycles as they cause very little difference in the sound energy levels, and can be error-prone in environments with other significant sources of sound.

3. **Passive Infrared:** Passive infrared systems use an energy sensitive detector element to measure the energy emitted by objects in the field of view. The source of emitted energy is gray-body radiation due to non-zero temperature of the emissive objects. When an object enters the field of view, the change in emitted energy is used to detect the object (7,8). Figure 2 illustrates the principles of this technology. Although by principle passive infrared technology can be used for classification purposes, it is not very effective and its performance is contingent upon favorable weather conditions.

4. **Active Infrared:** In active infrared detection systems, the detection zone is illuminated with low power infrared energy supplied by light emitting diodes (LEDs) with higher levels of energy supplied by laser diodes. The infrared energy reflected from objects moving through the detection zone is focused by an optical system onto a detector matrix mounted on the focal plane of the optics. The energy sensitive elements convert the reflected energy into electrical signals.

   Real-time signal processing is used to analyze the received signals and to determine the presence of the object. Changes in received signal levels caused by environmental effects can be accounted for by the signal processing. Infrared devices have the additional ability to image the scene of interest, which allows it to be used as an alternate method of obtaining imaging data (7, 8). Figure 3 shows an image produced by an active infrared detector. Active infrared detectors are designed to provide vehicle presence, counting, speed measurements, classification, and queue measurements. Active infrared detection is one of the technologies that can be effectively used in pedestrian and bicycle applications.

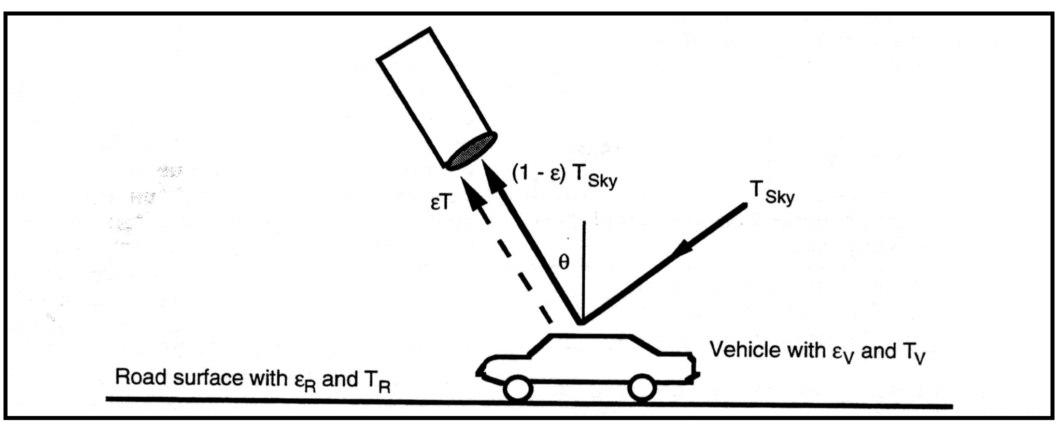

Figure 2 Passive infrared detection (7).

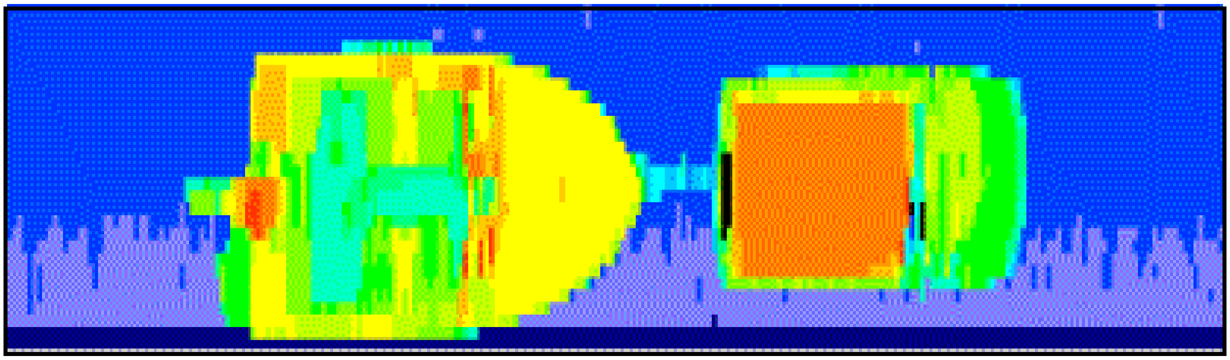

Figure 3 Image produced by an active infrared detector (11).

5. **Video Image Processing:** Video image processing uses video cameras to cover the detection area. The images are digitized and stored using a formatter. A series of image processing algorithms are used to extract spatial and temporal features from the objects in view. Advances in data reduction and image formatting technologies now allow the algorithms to run in real-time (7). Video image processing has been used for motor vehicle detection, counting, and classification, and is ideal for extending to pedestrian and bicycle applications.

6. **Piezoelectric:** Piezoelectric detectors consist of paving slabs with a weight sensitive rubber surface incorporating piezo cable. The object is detected when it passes over the detector as its weight sends an electric signal through the piezo cable. Piezos sensitive to weights as light as 5kg have been developed (9). The characteristics of the electric signal vary depending on the type of the object that passes over it. The objects can thus be classified on this basis. However, piezoelectric systems are not portable and the installation is cumbersome as compared to other ITS technologies.

7. **Traditional:** Traditional methods include pneumatic tubes, inductive loops, etc. ITS technologies are being developed as alternative detection and classification methods to overcome the inherent limitations of these methods.

Products based on promising non-traditional technologies were then evaluated based on their capability to detect, count, and classify pedestrians and bicycles. Other factors taken into consideration include ease of installation, mobility, and performance under adverse weather conditions. The evaluations are summarized in Table 1.

At the conclusion of these preliminary evaluations, active infrared technology applications were identified as an option worthy of further exploration. An active infrared device developed primarily for motor vehicle classification was chosen for experimental evaluation.

Table 1 Comparison of Products

Product -Manufacturer	Technology Used	Advantages	Disadvantages
Autosense II -Schwartz Electro-Optics, Inc. (10, 11)	Active infrared	Currently classifies vehicles into eight categories. Capable of detecting and classifying bicycles and pedestrians.	Requires a new algorithm for pedestrian classification. Performance affected by adverse weather.
Traffic Vision -Nestor Traffic Systems, Inc.) (12)	Video image processing	Neural network based technology. Capable of detecting and classifying bicycles and pedestrians.	Needs to be extended to bicycles and pedestrians. Performance affected by adverse weather.
SmartWalk 1400/1800 -Microwave Sensors, Inc. (13)	Microwave radar	Primarily used as pedestrian detection tool at intersections.	Not designed for classification and counting.
Pedestrian Tactiles -Traffic 2000 Ltd. (9)	Piezoelectric	Tools to differentiate between the characteristic electric signals caused by pedestrians and bicycles can be developed for classification purposes.	Widespread use for data collection is difficult as setting up piezos requires excessive effort.
IR 200 Dynamic Detectors -ASIM Technologies. (14)	Passive infrared	Developed for detection applications.	Classification is not addressed, although it is possible. Less effective than active infrared. Performance affected by adverse weather.
Traditional	Tubes, Inductive loops	Combinations of traditional devices may be capable of classification.	Limitations with respect to mobility, detection and/or classification. No single device is capable of classifying both pedestrians and bicycles

WORKING OF ACTIVE INFRARED DEVICE

Active infrared (AIR) technology has the capability for overhead imaging of objects to allow classification and size measurements. The operation of the device is illustrated in Figure 4. The device scans the roadway by taking 30 range measurements across the width of the road at two locations beneath the sensor using two laser beams. Each set of range measurements forms a line across the road with 10 degrees separation between the beams. The plan of the laser beams is shown in Figure 5.

When an object enters the beam, the measured distance decreases and the 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 (10,11). The object profile is constructed using the range measurements. The length, height, and breadth characteristics extracted from this profile are then used by an algorithm to classify the object. The algorithm presently used is capable of classifying motorcycles. Therefore, it is expected that minor modifications should allow the algorithm to detect and classify bicycles as well. Most likely, a new algorithm will be required for pedestrian detection and classification.

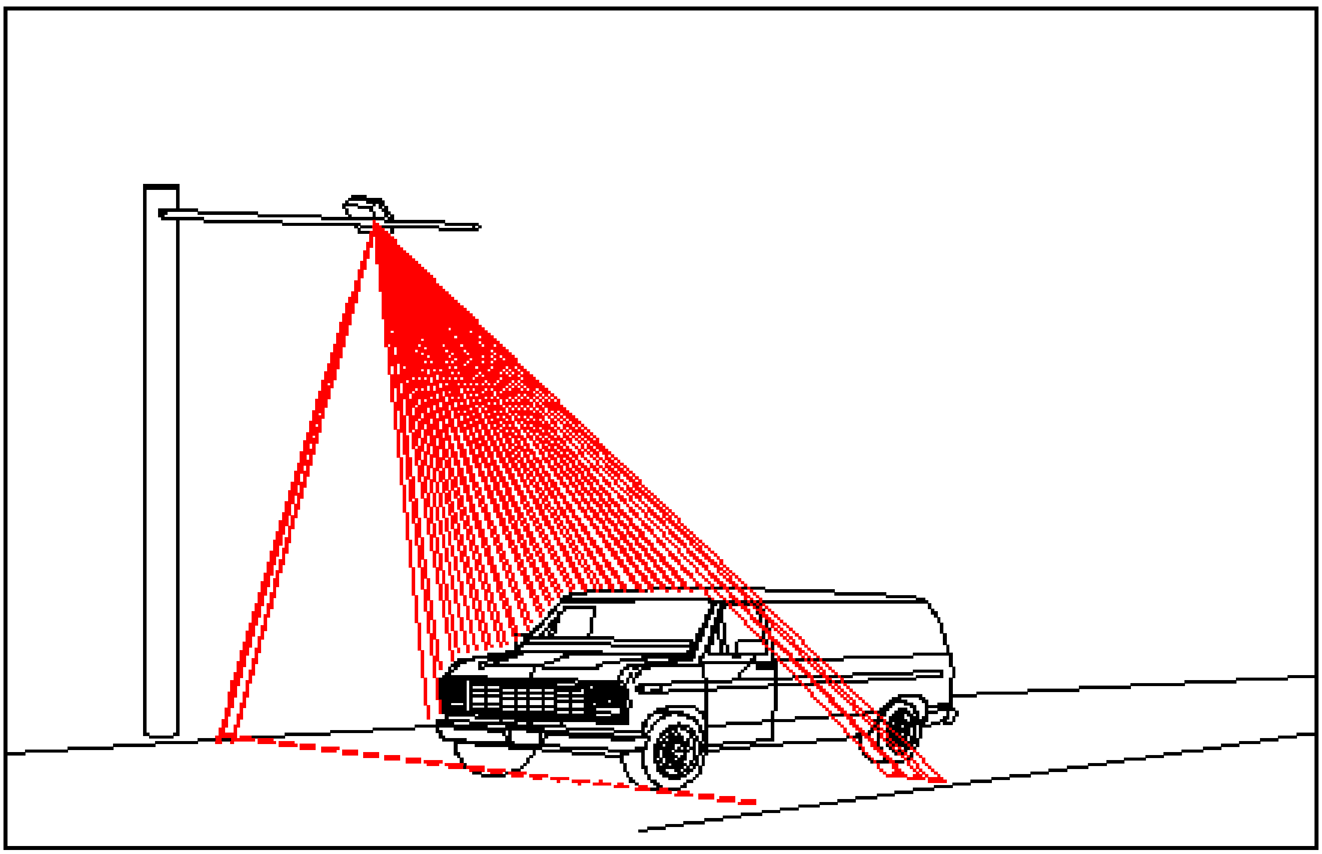

Figure 4 Working of an Active Infrared Detection Device (11).

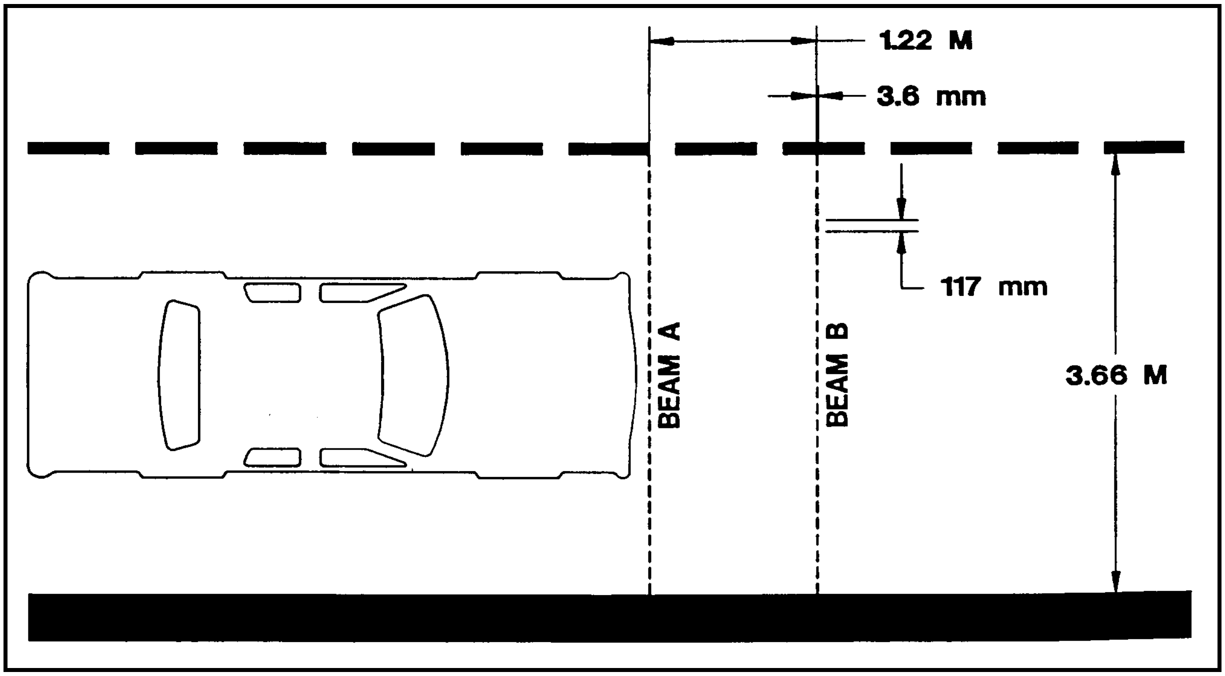

Figure 5 Plan of the laser beams on road surface (10).

EXPERIMENTAL EVALUATION

The active infrared device is currently being tested at a site on the Norwottuck Rail Trail in Amherst, Massachusetts. The Norwottuck Rail Trail is an 8.5-mile path linking Northampton, Hadley, Amherst, and Belchertown along the former Boston & Maine Railroad right-of-way (15). The path's level terrain provides safe passage for pedestrians, wheelchairs, joggers, skaters, bicyclists, and cross-country skiers of all ages and abilities. The site was chosen after ensuring that it has the required facilities for power supply and installation. Most importantly, the site is located on a section of the trail that has substantial pedestrian and bicycle traffic. A 'Special Permit,' was required for the installation of the device, and was obtained from the Regional Office of Department of Environmental Management (DEM).

The AIR device was mounted on a frame provided by the manufacturer above the area of observation. The device operates from an AC power source of 90-130 VAC with any frequency from 47 Hz to 440 Hz. An optional configuration will allow operation from 170-240 VAC. The device is equipped with a three-contact plug for connection to both power source and protective ground. The protective ground contact on the plug connects to the external metal parts. The device is intended for continuous operation, and hence, a power switch is not provided (10). The device communicates with a roadside computer during operation. While a 486 or a higher PC is required for this purpose, a Pentium 200 is currently being used. The relevant executable software necessary for the setup, testing and operation of the device was installed on the computer. Any change in configuration of the device and communication characteristics will have to be done using the software. The software has the option of saving all output to a text file, and thus accommodates review of results after the site experiment has concluded.

PRELIMINARY RESULTS

Data collection was started once the installation of the device was complete. The data being collected consists of total trail user counts, and separate pedestrian and bicycle counts. The data collected is compared with manual counts to evaluate the performance of the device in terms of detection as well as classification.

All the bicycles that passed under the device in either direction were successfully detected and classified as motorcycles. Though all pedestrians were detected, the device's final response fell under the following categories:

- Single detection for one pedestrian
    - Acknowledged and classified under one of the vehicle types.
    - Filtered out and not counted as any vehicle.
- Multiple detections for one pedestrian
    - Each detection acknowledged and classified under one of the vehicle types.
    - Some detections filtered out and some classified.
    - All detections filtered out.

Thus, while the device has had considerable success in detecting and classifying bicycles, it has been less accurate in detecting and classifying pedestrians. The underlying reason may be the current configuration of the device. The device is currently configured so that it acknowledges only those detections where both the first and second beams are simultaneously cut by the object. At the current (recommended) installation height of around 23 feet, many pedestrians do not cut both the beams at the same time. As a result, pedestrian detections are being filtered out as erroneous detections. On the other hand, the movements of pedestrians' arms and legs sometimes result in multiple detections.

The experiment will be continued until a sufficiently large number of data points are obtained. For a confidence level of 95 percent and a margin of error less than 2 percent, 601 observations are required. One-tailed test of hypothesis is being used, testing for the proportion of defective responses. A defective response in case of detecting and counting is defined as "either not counting a user correctly or counting in the absence of a user." A defective response with respect to classification is defined as "either classifying a user incorrectly or not classifying at all."

The process of installation and data collection may be repeated again in the course of the project if and when needed. Efforts shall be made to test the device under all types of light, temperature and weather conditions.

CONCLUSIONS

Currently, none of the available devices completely serves the purpose of detecting, counting, and classifying pedestrians and bicycles. However, there are many such devices that detect, count and classify motor vehicles. Efforts to reasonably accommodate pedestrians and bicycles in planning, design, and construction at all levels require extensive pedestrian and bicycle data.

This warrants extension of the available technologies to pedestrian and bicycle detection, counting, and classification. Active infrared and video image processing are identified as the technologies best suited for detection, counting and classification of pedestrians and bicycles. Further evaluation and extension of these technologies for pedestrian and bicycle data collection is highly recommended.

Experimental evaluation of the active infrared device has thus far shown that it is fairly accurate and consistent for detection and classification of bicycles. However, at the current configuration, the device is not very accurate in detecting and classifying pedestrians. The basic installation and configuration of the AIR device may require some changes to detect and classify pedestrians accurately. The mounting height of the equipment may also need to be reduced from the recommended 23 feet to approximately 12 feet, so that a pedestrian passing underneath the sensor can simultaneously penetrate both the AIR beams simultaneously. Another possible modification might be a reduction in the scan rate. The device now operates at a high scan rate of 720 scans per second, as it was basically designed for motor vehicle detection and classification. This scan rate may need to be reduced for bicycles and pedestrians. The number of range measurements may also need to be increased from 30 to approximately 45.

Further recommendations regarding active infrared technology and the device will be made after completion of the experiments.

AUTHOR INFORMATION

Raghuram Dharmaraju
Graduate Research Assistant
University of Massachusetts
Amherst, MA 01003
Student Member of ITE.
Phone: 413-577-1318
Email: rdharmar@ecs.umass.edu

David A. Noyce
Assistant Professor
University of Massachusetts
Amherst, MA 01003
Associate Member of ITE.
Phone: 413-545-2509
Email: noyce@ecs.umass.edu

Josh Lehman
Bicycle-Pedestrian Program Coordinator
Massachusetts Highway Planning
Phone: 617-973-7329
Email: josh.lehman@mhd.state.ma.us

ACKNOWLEDGEMENTS

The work described in this report was completed as part of a research project, "Automated Detection and Classification of Trail Users," funded by the Massachusetts Highway Department (MassHighway) and supported by the U.S. Department of Transportation (U.S. DOT) and Federal Highway Administration (FHWA).

REFERENCES

1. Bureau of Transportation Statistics, Bicycle and Pedestrian Data: Sources, Needs & Gaps, June 1998

2. FHWA, The National Bicycling and Walking Study: Transportation Choices for a Changing America, 1994.

3. Massachusetts Highway Department, Statewide Bicycle Transportation Plan, 1998.

4. TEA-21 Moving Americans into the 21st Century, http://www.fhwa.dot.gov/ tea21/, Accessed on: May 21, 2000.

5. Massachusetts Highway Department, Massachusetts Pedestrian Transportation Plan, 1998.

6. FHWA, Bicycle/Pedestrian Trip Generation Workshop: Summary, March 1998.

7. FHWA, Development of IVHS Traffic Parameter Specifications – Task - A Report for Detection Technology for IVHS, June 1994.

8. ITS Decision, http://www.path.berkeley.edu/~leap/, Accessed on: Feb.10, 2000.

9. Traffic 2000 Products and Services, http://www.traffic-2000.co.uk/, Accessed on: Jan. 15, 2000.

10. Schwartz Electro-Optics, Inc., Autosense II Vehicle Detection & Classification Sensor – User's Manual & System Specification, April 1998.

11. Schwartz Electro Optics, Inc., Autosense Products, http://www.seord.com/ Commercial %20Sensors%20Division/autosense.htm, Accessed on: Jan.14, 2000.

12. Nestor Traffic Systems, http://www.nestor.com/Nstraffic/, Accessed on: Aug.11, 2000.

13. Microwave sensors, http://www.microwavesensors.com/, Accessed on: Jan 15, 2000.

14. ASIM Technologies, http:// www.asim.ch/, Accessed on: Jan 28, 2000.

15. Department of Environmental Management – Norwottuck Rail Trail, http://www.state.ma.us/dem/parks/ nwrt.htm, Accessed on: May 21, 2000.

16. Massachusetts Office of Travel & Tourism, Outdoor Adventures – Biking – Norwottuck Rail Trail, http://www.mass-vacation.com/outdoor/bike_ norwottuck. html, Accessed on: May 21, 2000.