



PB98-167919

Transportation Northwest

**DEVELOPMENT OF A PROTOTYPE
TRAFFIC DATA COLLECTION SYSTEM
USING INFRARED BEAM SENSOR ARRAY**

REPORT DOCUMENTATION PAGE

1. AGENCY USE ONLY <i>(Leave Blank)</i>		2. REPORT DATE January 1998	3. REPORT TYPE AND DATES COVERED	
4. TITLE AND SUBTITLE Biological Markers for Characterization of Potential Sources of Soil-Derived and Geologic Fugitive Dust			5. FUNDING NUMBERS 94-321	
6. AUTHOR(S) Kate M. Scow				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of California, Davis Davis, CA 95616			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) California Air Resources Board Research Division 2020 L Street Sacramento, CA 95814			10. SPONSORING/MONITORING AGENCY REPORT NUMBER ARB/R- 98/665	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Release unlimited. Available from National Technical Information Service. 5285 Port Royal Road Springfield, VA 22161			12b. DISTRIBUTION CODE	
13. ABSTRACT <i>(Maximum 200 Words)</i> The project developed methods to extract and identify biochemical tracers of soil organisms and soil microbial communities for use in identifying particular soil micro-environments as sources of airborne soil dust. This initial project was undertaken as "proof of concept". The work emphasized developing laboratory techniques to extract and identify phospholipid fatty acids and DNA/RNA materials from bulk soils and airborne dust, determining the comparability of bulk soil and airborne dust biomarker signatures, and testing the statistical discrimination among soils provided by these chemical signatures. The project successfully demonstrated that: 1) the soil biomarkers studied can be readily and repeatably extracted from both bulk soil and dust samples, 2) that these chemical signatures are consistent between the bulk soil and dust samples tested, 3) that the differences among these signatures allow discrimination of soils as dust sources by crop type and soil type, and 4) that these techniques can be applied to non-agricultural soils as well (e.g. dirt roads). The success of this program justifies further efforts to move from laboratory experimentation to developing this tracer technology for use in detecting sources airborne soil dust.				
14. SUBJECT TERMS Soil dust, biomarkers, PM10, aerosols, aerosol source apportionment, phospholipid fatty acid, PLFA, soil fatty acid methyl ester, SFAME, DNA, RNA, thermal gradient gel electrophoresis, TGGE, randomly amplified polymorphic DNA, RAPD, neural network, soft independent modeling of class analogy, SIMCA, adaptive resonance theory, ART-2a, California, agriculture			15. NUMBER OF PAGES 80	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited	

**Final Report
TNW 98-05**

**DEVELOPMENT OF A PROTOTYPE
TRAFFIC DATA COLLECTION SYSTEM
USING INFRARED BEAM SENSOR ARRAY**

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August 1998

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. WA-RD ____ _TNW 98-05		2. GOVERNMENT ACCESSION NO.		3. RECIPIENT'S CATALOG NO.	
4. TITLE AND SUBTITLE Development Of A Prototype Traffic Data Collection Collection System Using Infrared Beam Sensor Array				5. REPORT DATE August 1998	
				6. PERFORMING ORGANIZATION CODE	
7. AUTHOR(S) Lutfi Raad and Jian John Lu				8. PERFORMING ORGANIZATION REPORT NO. TNW 98-05	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Transportation Northwest Regional Center X (TransNow) Box 352700, 123 More Hall University of Washington Seattle, WA 98195-2700				10. WORK UNIT NO.	
				11. CONTRACT OR GRANT NO. DTRS95-G-0010	
12. SPONSORING AGENCY NAME AND ADDRESS United States Department of Transportation Office of the Secretary of Transportation 400 Seventh St. SW Washington, DC 20590				13. TYPE OF REPORT AND PERIOD COVERED Final Report	
				14. SPONSORING AGENCY CODE	
15. SUPPLEMENTARY NOTES This study was conducted in cooperation with the University of Alaska Fairbanks.					
16. Abstract This research aimed to developing a portable multi-functional traffic data collection system which has the potential to be easily installed in fields and can measure two-way traffic at the same time. The proposed system uses several infrared beam sensors to form an infrared beam sensor array with uniform spacing between the sensors. this infrared beam sensor array will be able to detect traffic characteristics such as traffic flow rate, speed profile, wrong-way movement, traffic density, and occupancy. During the course of the research, a prototype was developed and tested in fields. The prototype has the basic functions of the proposed system for traffic data collection. The main objectives of the research were to develop the prototype and perform field experiments to assess the prototype. The prototype was designed and assembled in the first phase of the research. After that, field experiments were performed September 1997. The field experiments included tests of the prototype's capabilities to collect information on traffic flow rate, speed, speed profile, and wrong-way movements. Field experiment results indicated that the prototype was able to perform the designed functions and produce satisfactory summaries of traffic characteristics.					
17. KEY WORDS Infrared Beam Sensor, Noncontact Detection, Sensor Array, Traffic Data Collection				18. DISTRIBUTION STATEMENT No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616	
19. SECURITY CLASSIF. (of this report) None		20. SECURITY CLASSIF. (of this page) None		21. NO. OF PAGES 34	22. PRICE \$5.25

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Abstract

Traffic data collection systems are used to monitor traffic and estimate traffic characteristics for traffic management and control purposes. Currently, the main systems used for traffic data collection are loop detectors. Loop detectors are contact-type sensors which are relatively difficult to be installed in fields. Besides, loop detectors have some limitations to be used under certain conditions such as pavement types and pavement reinforcement conditions. There are many other types of traffic data collection systems that are available in the market. Most commercialized products are contact-type ones that are relatively easier to be damaged by travelling traffic.

This research aimed to developing a portable multi-functional traffic data collection system which has the potential to be easily installed in fields and can measure two-way traffic at the same time. The proposed system uses several infrared beam sensors to form an infrared beam sensor array with uniform spacing between the sensors. This infrared beam sensor array will be able to detect traffic characteristics such as traffic flow rate, speed, speed profile, wrong-way movement, traffic density, and occupancy. During the course of the research, a prototype was developed and tested in fields. The prototype has the basic functions of the proposed system for traffic data collection. The main objectives of the research were to develop the prototype and perform field experiments to assess the prototype. The prototype was designed and assembled in the first phase of the research. After that, field experiments were performed September 1997. The field experiments included tests of the prototype's capabilities to collect information on traffic flow rate, speed, speed profile, and wrong-way movements. Field experiment results indicated that the prototype was able to perform the designed functions and produce satisfactory summaries of traffic characteristics.

This report summarizes the results of the preliminary research including the design of the prototype and field experiments. It is strongly recommended to continue the research to develop a final product and implement the product in future. However, in order to

develop the final system, there are still a lot research efforts that should be spent and many research barriers need to be overcome.

CHAPTER 1 INTRODUCTION

Traffic data used as feedback information are required for operations of highway systems such as planning, design, safety, construction, maintenance, evaluation, and management. Reliable collection of traffic data has become a basic issue. Vehicle detectors have been in use for over 50 years. Various types of detectors and measurement techniques have been developed over the decades. They ranged from pressure detectors, magnetic detectors, photocells, radar detectors, sonic detectors, inductive loop detectors, magnetometers to coaxial detectors. The techniques for installation and maintenance procedures are described by Federal Highway Administration. All traffic studies consist of three primary activities -- i.e., traffic data collection, traffic data reduction, and traffic analysis. Basic traffic data consist of vehicle volume, vehicle class, vehicle speed, and vehicle weight.

Currently, contact-type sensors such as inductive loop detectors, pneumatic tubes, piezo-electric cables or strips, and capacitance strips are widely used for traffic data collection. In terms of installation, maintenance, life cycle, response speed, and other factors, non-contact-type sensors have advantages over contact-type sensors and will be more widely used in future. An infrared beam sensor is one of the typical non-contact-type sensors for traffic data collection. Research in applying infrared beam sensors has been conducted to classify and count vehicles.

In measuring stream variables of traffic, the most popular sensors are inductive loop detectors. There are two major prerequisites for using an inductive loop detector in the field. First, it is essential that the loop be implanted within stable pavement so that the wires are not exposed and wire movement is minimized. Secondly, inductive loop detectors should also not be used in areas where there is high metal content. The sensitivity of inductive loop detectors can be severely reduced by reinforcement in the pavement.

An infrared beam sensor, considered a non-contact-type sensor, does not have such limitations. A basic characteristic of an infrared beam sensor is that when an infrared beam is cut by a moving vehicle, the output voltage level of the sensor will be significantly changed from one level to another level. Such change indicates the presence of a moving vehicle. However, use of a single infrared beam sensor cannot provide sufficient information about traffic movement. An array, consisting of a number of infrared beam sensors which are evenly distributed along a subsection of a roadway, can have much more capabilities to detect and monitor moving traffic.

Typical applications of an infrared beam sensor array include, but not limited to, the following: (1) identification of two-way vehicular movements (including volume, speed, and density), (2) measurement of two-way vehicular speed profiles, and (3) detection of two-way vehicular wrong-way movements. The key in such applications is to develop a logical model to identify traffic in two opposing directions by an infrared beam sensor array.

A study was performed in the past year to develop infrared beam sensor array detection techniques for identification of traffic movements. The main objectives of the research study were:

1. to design a prototype of a detection system for traffic data collection by using an infrared beam sensor array, and
2. to implement the prototype detection system and run field experiments to assess the system under various conditions.

With the considerations of limited research funding and time, this research was not to develop a comprehensive system, but to develop a preliminary prototype that could be tested in the field. The prototype would have a basic function of the proposed system. A comprehensive system having more functions will be developed in future research study.

In this study, the prototype was developed during February and August 1997 and was tested in September 1997 in Fairbanks, Alaska. The field experiments were performed to

test whether the prototype was functioning in the way that was proposed and designed and to test the prototype's performance in the field including repeatability and accuracy.

This report summarizes the research study to present the system design and field experiments.

CHAPTER 2 SYSTEM PRINCIPLE

The detection system uses binary signals collected by an infrared beam sensor array and logical functions implemented by logical hardware and software to identify two-way traffic movement. Traffic characteristics in two opposing directions can be detected by a single logical array system consisting of several infrared beam sensors. The working principle of an infrared beam sensor is relatively simple. Figure 2.1 conceptually shows an infrared beam sensor and a reflector. The transmitter emits infrared beam to the reflector which reflects the beam back to the receiver. If the infrared beam reflected by the reflector is received by the receiver, the output has a low level of voltage. If the beam is cut by a vehicle, the output of the sensor has a high level of voltage. By assigning logical "1" to high level of voltage and "0" to low level of voltage, then "0" represents no vehicle is detected and "1" means a vehicle is detected.

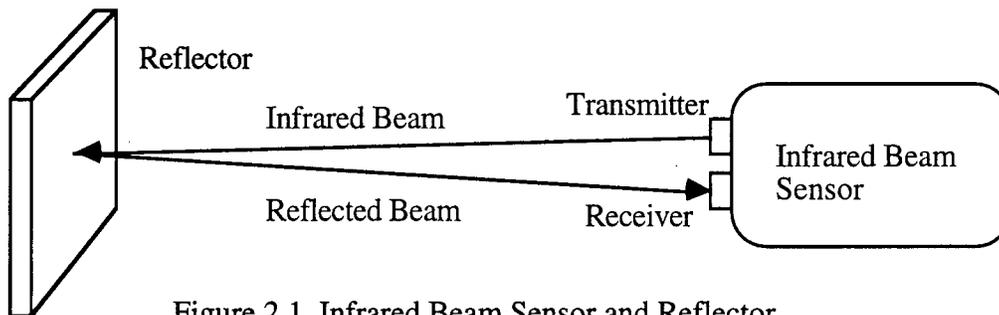


Figure 2.1. Infrared Beam Sensor and Reflector.

An infrared beam sensor array consists of a number of sensors. The sensors are installed along a roadway as shown in Figure 2.2. The spacing between sensors could be uniform and depends on data types and site situation. The array status is determined by the sensor status. A sensor status is referred to as logical "1" or "0". The relationship between number of status of the array and number of sensors is represented by

$$N_{as} = 2^N \quad (1)$$

where N_{as} is the number of array status, and N is the number of sensors. For example, if four sensors are used in the array, then there are 16 logical statuses. Figure 2.3 shows the 16 logical statuses of an array with four sensors.

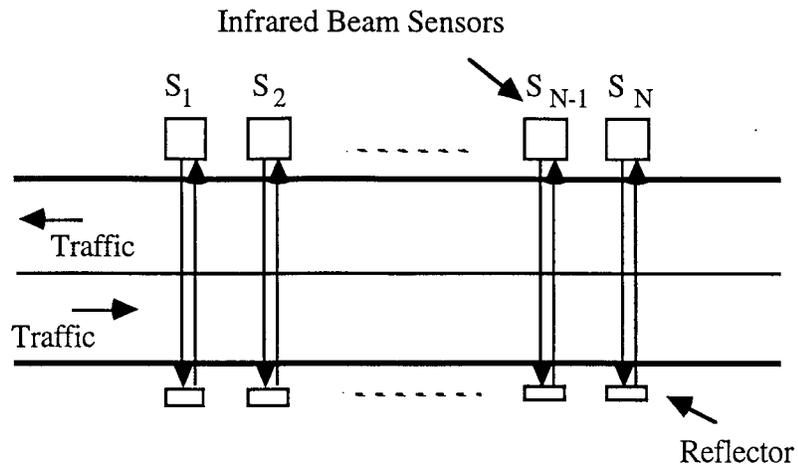


Figure 2.2. Infrared Beam Sensor Array

Array Status	Sensor Status			
	S_1	S_2	S_3	S_4
1	0	0	0	0
2	0	0	0	1
3	0	0	1	0
4	0	0	1	1
5	0	1	0	0
6	0	1	0	1
7	0	1	1	0
8	0	1	1	1
9	1	0	0	0
10	1	0	0	1
11	1	0	1	0
12	1	0	1	1
13	1	1	0	0
14	1	1	0	1
15	1	1	1	0
16	1	1	1	1

Figure 2.3. Logical Status of an Array with Four Sensors.

Vehicular movement at the k^{th} time interval can be identified from previous array status and present array status. This can be conceptually represented by the following expression:

$$[\text{Vehicular Movement}] = F[S(k), S(k-1), \dots, S(k-j)] \quad (2)$$

where $S(k) = [S_1(k), S_2(k), \dots, S_N(k)]$; $S_i(k)$ ($i=1, 2, \dots, N$) is the logical status of the i^{th} sensor at the k^{th} time interval; and j represents the number of previous steps used. The logical function $F[.]$ is a major part for identification of vehicular movement. For different data types, $F[.]$ should have different forms. Figure 2.4 shows a typical infrared beam sensor array consisting of six sensors. If, at the k^{th} time interval, sensors 1, 2, and 5 detect the existing of vehicles (or the infrared beams of sensors 1, 2, and 5 are cut at the k^{th} time interval), then the array status at this time interval is $S(k) = [1, 1, 0, 0, 1, 0]$. Based on the current status and previous states as well as the logic function, traffic movement (characteristics) can be estimated.

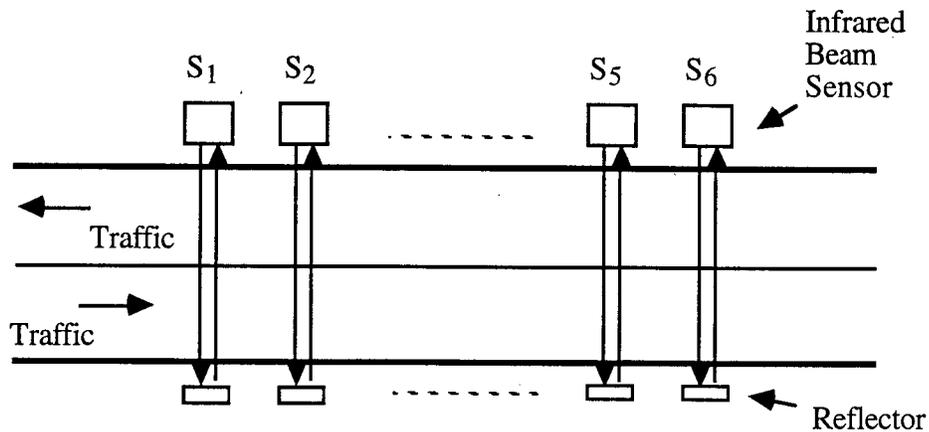


Figure 2.4. Infrared Beam Sensor Array with Six Sensors

The detection system, as shown in Figure 2.5, mainly consists of an infrared beam sensor array, digital input interface, logical software, data processing, and data reporting. Basically, an array status vector is sampled by the computer (a notebook computer) through a PCMCIA I/O interface. The logical hardware simplifies the outputs from sensor array so that the computer processes less logical data. However, if the number of

sensors in the array is less than or equal to the number of PCMCIA I/O interface channels, the logic hardware is not necessary because the statuses of all sensors can be sampled by the PCMCIA I/O interface. The logical software implements the logical functions shown in Eq. 2.

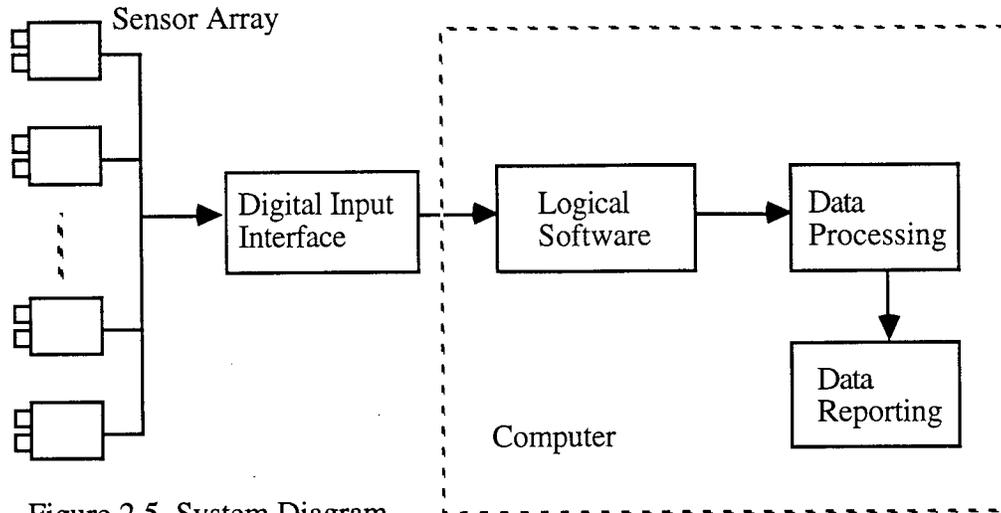


Figure 2.5. System Diagram.

CHAPTER 3 SYSTEM ELEMENTS

As stated previously, the measuring system hardware mainly consists of a notebook computer, a PCMCIA I/O interface, and infrared beam sensors and reflectors. Since these infrared beam sensors are placed along a roadway with certain spacing, a long cable is needed to connect a sensor to the notebook computer. Generally, a cable of 300 feet long is needed. In addition to these parts, a DC-AC power inverter is needed to supply 110 ACV to the system. System logic functions are implemented by software. The Microsoft Visual Basic 4.0 was used to implement the logic functions and windows (forms) for field operations. The windows (forms) created in the study are very user-friendly to be used in fields. Figure 3.1 presents one of the forms created for the system. Detailed description of the software is not covered in this report. The following sections are brief descriptions of each hardware part used in the system.

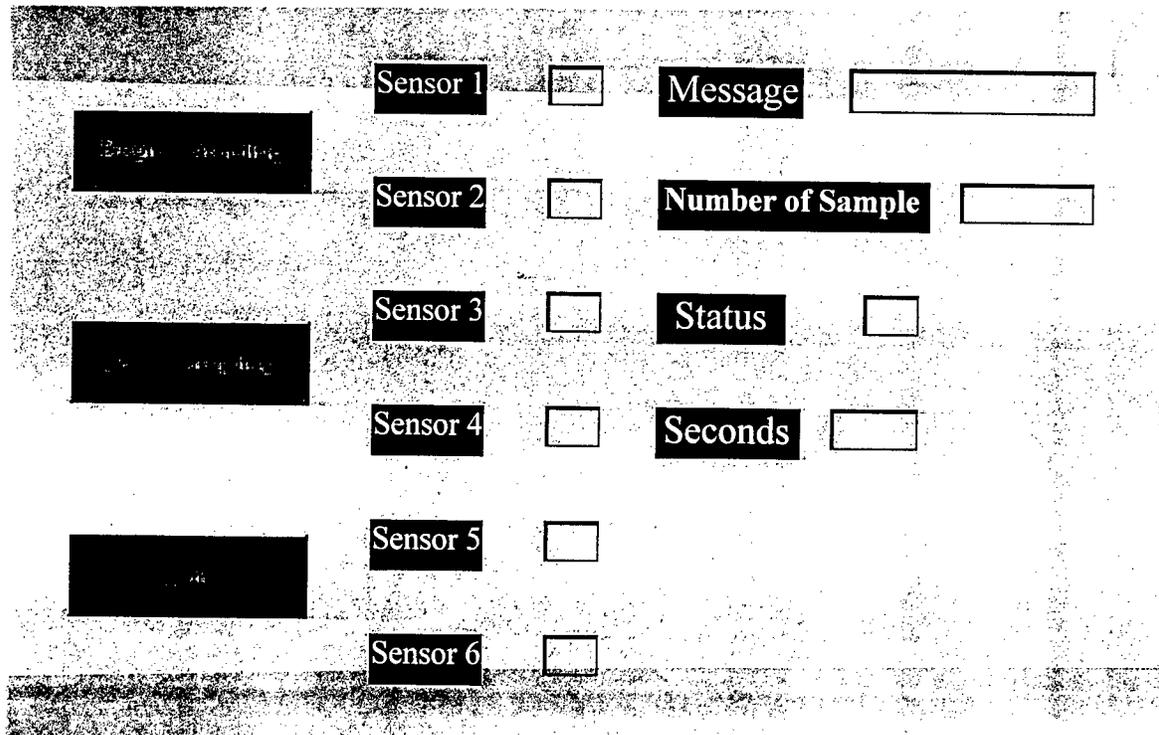


Figure 3.1. The Data Sampling Form Created with Visual Basic 4.0.

Notebook Computer

A Dell notebook computer was used in the system for data collection and processing. The Dell notebook computer has a Pentium 133 MHZ processor. One of the key factors considered for the system design was the system data sampling rate. Since vehicles usually travel at a speed of 30 mph to 60 mph, in order to have each sensor to detect the same vehicle at least twice, the computer or the system should have a very fast sampling rate. If the data sampling program (Visual Basic 4.0) is converted to an executable file, the computer with a Pentium 133 MHZ processor should be fast enough. Field experiments have proved this.

Digital I/O Interface

The system uses a National Instruments' product: DAQCard-DIO-24. The card is designed for PCMCIA slots compatible to PC notebooks. This card has 24 digital input channels, which is sufficient for the system. National Instruments' NI-DAQ Driver Software supports the sampling programming. To sample data from the interface, sampling subroutines included in the NI-DAQ Driver Software should be used. The interface (DAQCard-DIO-24) only inputs logic data (0 or 1) to the computer. Any high level of input voltage (greater than 2.5 volts) to the interface is converted to logic "1" and any low level of input voltage (less than 2.5 volts) is converted to logic "0". Therefore, if the output voltage level of an infrared beam sensor is correctly selected, the status of the infrared beam sensor array can be correctly detected by the computer through the interface. Figure 3.2 shows the picture of the interface. The DAQCard-DIO-24 should be inserted to a PCMCIA slot of the computer when it is used.

Infrared Beam Sensors

For the prototype system, infrared beam alert sensors were used to detect vehicles. The main requirement to the sensors is that the sensors should be able to detect a vehicle from a certain distance such as 40 – 50 feet. Such a requirement can be easily met by the infrared beam sensors. A sensor has two different levels of outputs – the high level and the low level. If a vehicle is detected by the sensor, a high level of voltage is obtained.

Otherwise, a low level of voltage is obtained. Such information can be input to the computer through the digital I/O interface. A DC-AC power inverter is used to supply 110 ACV to the sensors. Figure 3.3 shows a picture of an infrared beam sensor and its reflector. The transmitter and receiver are covered by the sensor's cover. Figure 3.4 shows the transmitter and receiver without a cover. In fields, each sensor should be mounted on a tripod with the height adjusted to the body height of a vehicle.

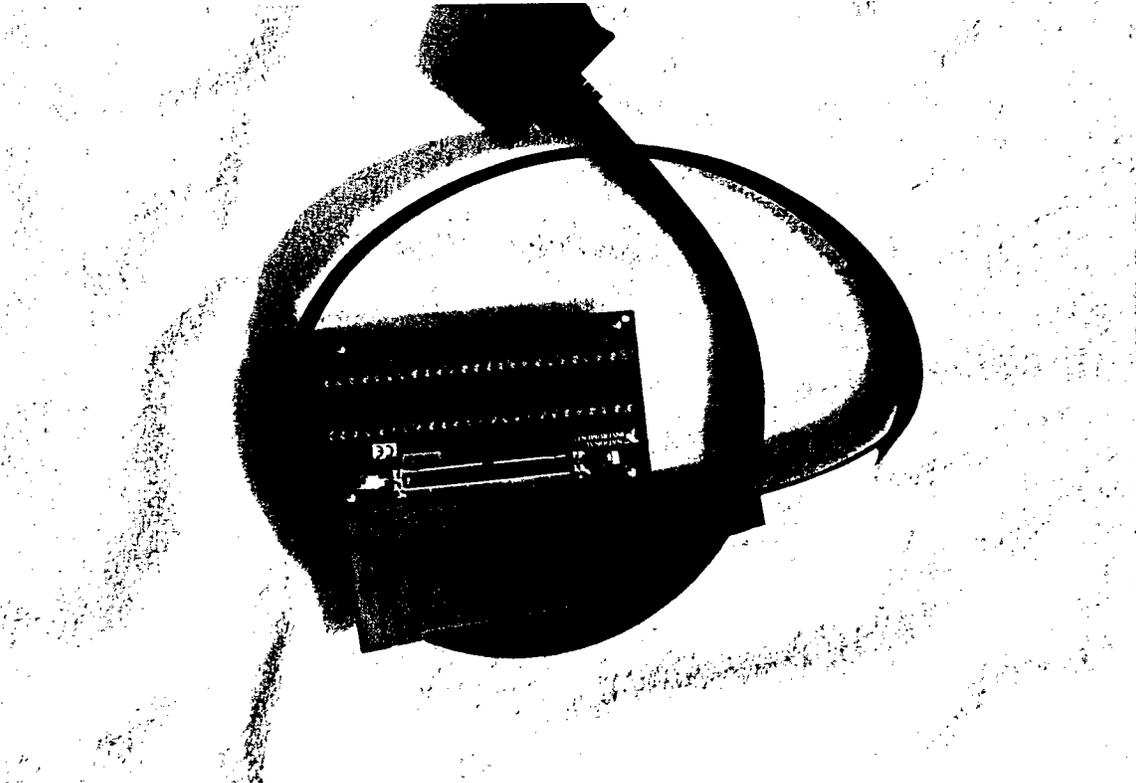


Figure 3.2. Picture of the DAQCard-DIO-24 and Connecting Cable

DC-AC Power Inverter

The main function of a DC-AC power inverter is to provide 110 ACV to the notebook computer and the infrared beam sensors. A minimum requirement is that the inverter should provide enough power to the system. For this project, a Clearline Concepts Corporation's product, PC300XT, was used. This inverter has a continuous power of 300 watts. The input range of the inverter is 10 – 15 volts DC. Thus, the battery supply of a vehicle was used as the input of the inverter. No additional battery was needed in fields. Since the system consumes less than 50 watts, the inverter was directly connected to the

vehicle battery without running the vehicle to charge the battery. Figure 3.5 shows a picture of the DC-AC power inverter (PC300XT).

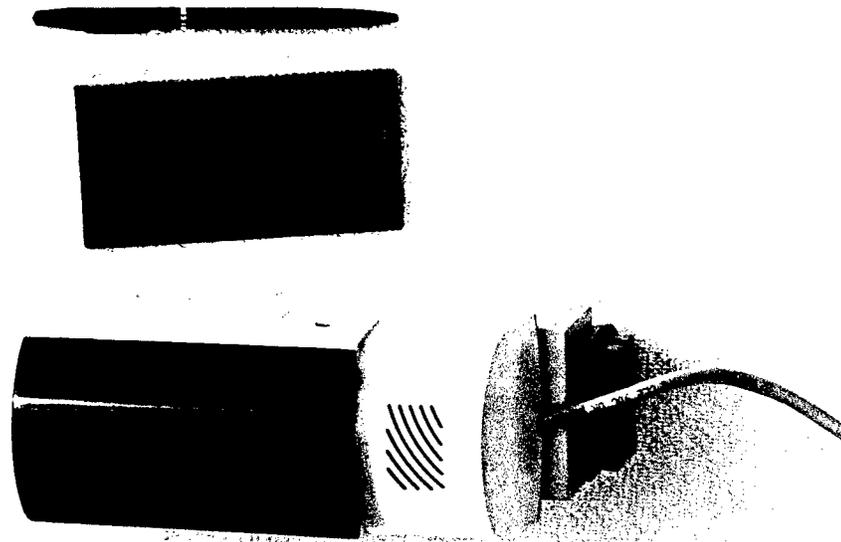


Figure 3.3. Picture of the Infrared Beam and Its Reflector

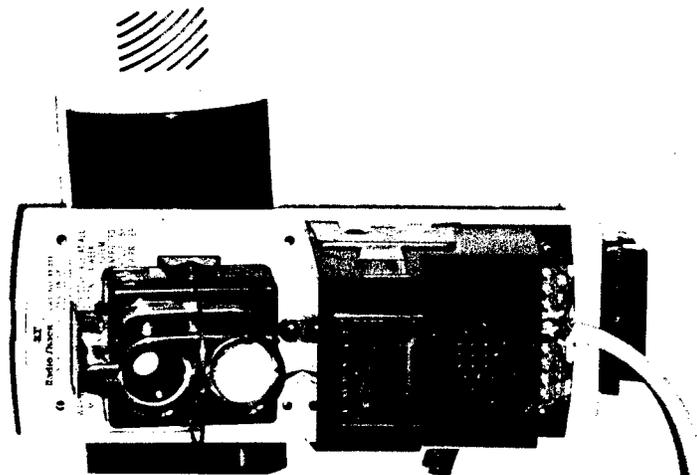


Figure 3.4. Picture of the Transmitter and Receiver

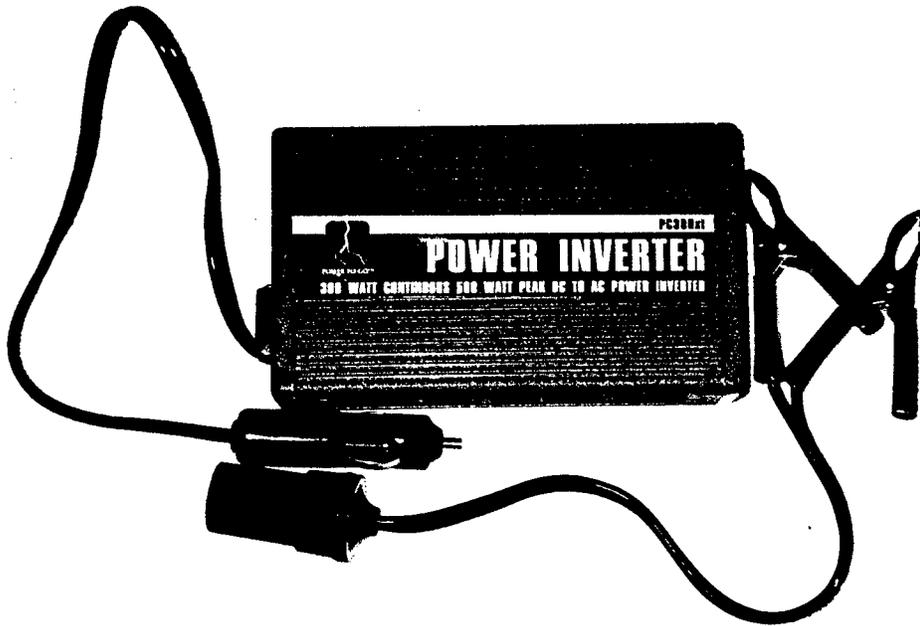


Figure 3.5. Picture of the DC – AC Power Inverter (PC300XT)

CHAPTER 4 FIELD EXPERIMENTS

After the system was assembled, field experiments were performed to test whether the prototype was functioning in fields. The main considerations for the experiments included the impact of roadway surface dust to the reliability of the system, the adequacy of system sampling rate, and performance of the infrared beam sensors. In addition to these tests, traffic data were also collected by the prototype and a video camera which was used to record real traffic characteristics. The data collected by the prototype were compared with the data collected by the video camera. Thus, the system's reliability could be tested. The main traffic characteristics collected in field experiments were traffic flow rate, speed, vehicle speed profile, and vehicle wrong-way movement. Test results of the system performance related to traffic data collection will be presented and discussed in the next chapter.

Field Test Site

The field experiments were conducted in Fairbanks, Alaska in September 1997. Test site was selected in a big parking lot inside of the University of Alaska Fairbanks. Test time was selected to avoid peak parking period so that the disturbance from other vehicles was limited to minimum. Since the tests were performed in the parking lot, all traffic characteristics could be fully controlled with the use of testing vehicles (passenger cars). A test track was set up before testing. An acceleration lane was provided in the test track so that a testing vehicle could speed up from low speed to the specified testing speed within a short time period. Figure 4.1 shows a picture of a part of the test track. From this picture, it can be seen that infrared beam sensors were evenly placed along the side of the test track to form an array. Reflectors were installed on the other side of the test track.

Set-up of the System

The system was set up in two different forms. The first form had a uniform spacing of 50 ft between sensors, and the second form had a spacing of 25 ft. The main reason for setting up different spacing was to check the system's reliability in related to sensor

spacing. The set-up of the system in the experiments was shown in Figure 4.2. Figure 4.2a shows the set-up with 25-ft spacing, and Figure 4.2b shows the set-up with 50-ft spacing. The most difficult task in the set-up was the setting of reflectors. Since the size of a reflector is about 2 inches x 5 inches, it was difficult to aim an infrared beam at a reflector. However, if the size of a reflector were larger, it would have been much easier to set up the reflector.

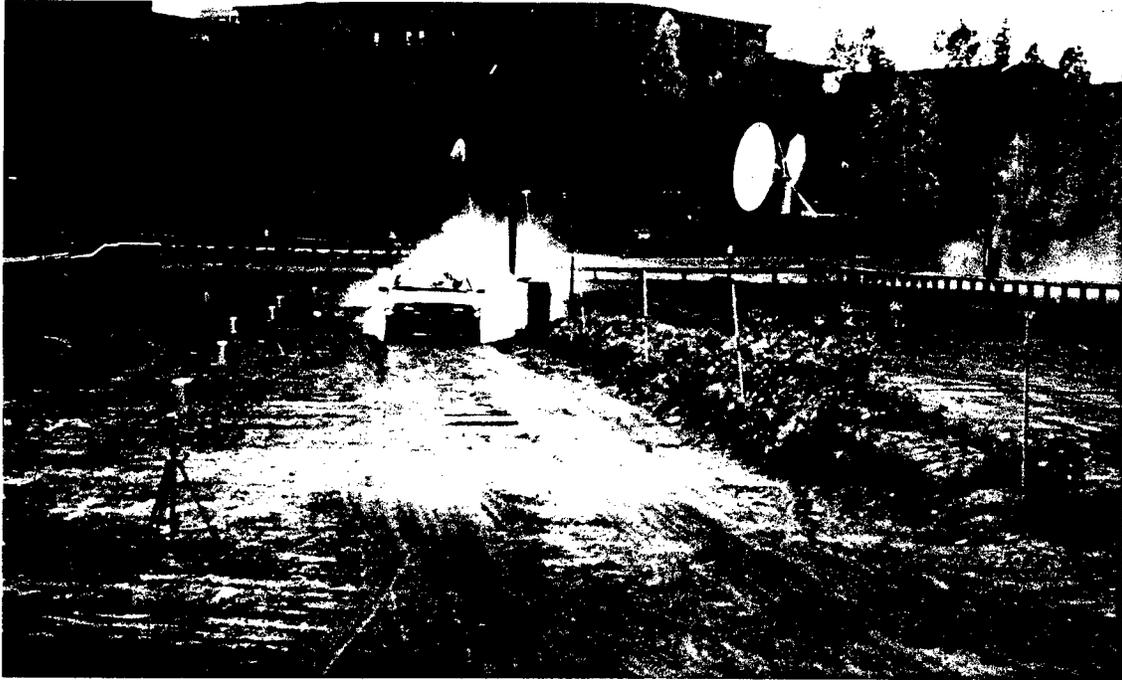


Figure 4.1. Picture of the Test Track

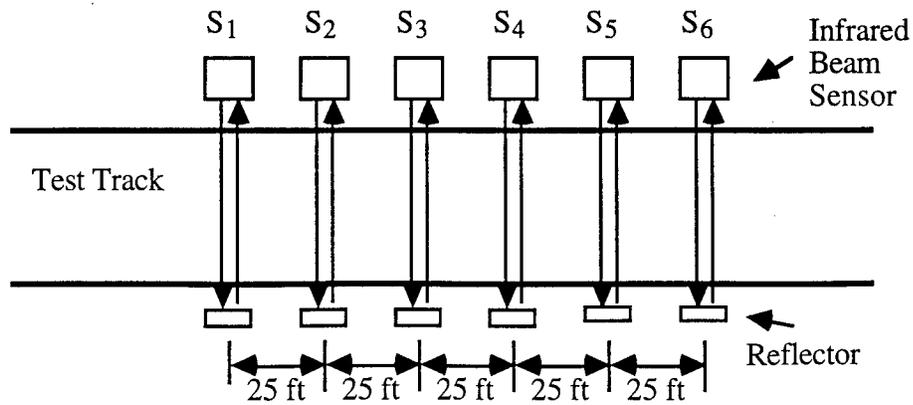


Figure 4.2 a. Infrared Beam Sensor Array with 25 ft-Spacing Between Sensors

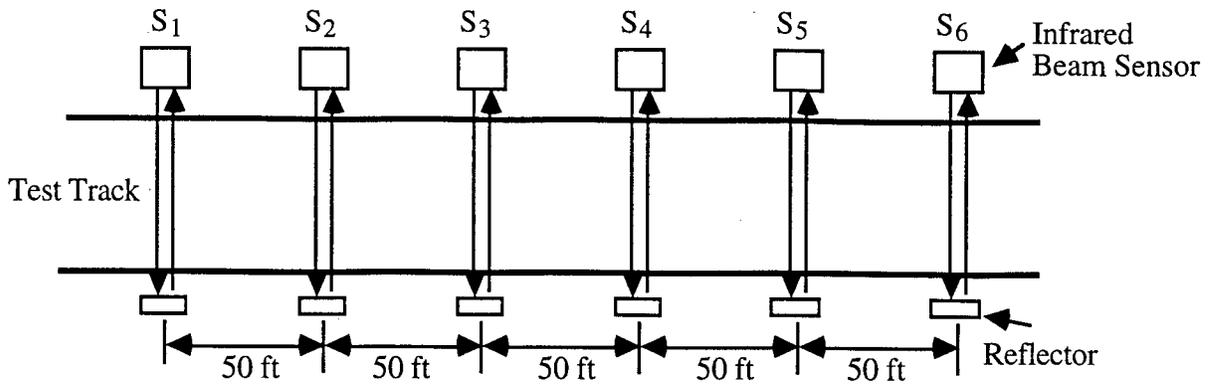


Figure 4.2 b. Infrared Beam Sensor Array with 50 ft-Spacing Between Sensors

The Impact of Roadway Surface Dust

Infrared beam sensors are sensitive to dust if the infrared beam is not powerful enough to penetrate the dust. High-density dust may cut the infrared beam and result in mistakenly informing the computer that a vehicle is detected although no vehicle is there. Practically, a vehicle running at high speed may cause dust after the vehicle. Figure 4.3 shows a typical case that happened during the experiments. From experiments, it was found that sometimes, heavy dust caused by a testing vehicle mistakenly triggered the infrared beam sensor. The reliability of the prototype was thus reduced. One possible way to prevent such a problem is to select the infrared beam sensors with better penetrating capability.



Figure. 4.3. The Effect of Roadway Surface Dust

Sampling Rate

The system was designed to continuously sample the array status without interruption statement. Once the array status is changed due to the existing of vehicle, the detecting system is able to immediately detect it. However, since vehicles travel at fast speeds, a slow sampling rate may not be able to catch all changes in array statuses. One of the tasks of the field experiments was to check whether or not the system's sampling rate met the requirement for sampling fast-moving vehicles. The test procedure was somewhat simple. A testing vehicle was running at a test speed. The array status was displayed on the computer screen. Once the vehicle was cutting an infrared beam, array status change could be clearly monitored from the computer screen. It was found that the system had a fast enough sampling rate such that no vehicle was missing. Therefore, it can be concluded that the system's sampling rate is good enough for the particular purpose.

System's Function

The prototype was tested under different conditions. These conditions included (1) array sensor spacing (50 ft and 25 ft), (2) traffic speed (20 mph constant speed, 35 mph constant speed, and speed from 10 mph to 35 mph), and different traffic movement (south bound and north bound). With all these conditions given, the prototype was functioning very well. Array status data were continuously collected by the system and saved in a data file. Meanwhile, real traffic was also recorded by a video camera for comparison purpose.

CHAPTER 5 FIELD DATA ANALYSIS RESULTS

The main purpose of field experiments was to test whether the prototype could function. Several different traffic data types were collected to get traffic characteristics and test the system reliability. The main traffic data types included traffic flow rate, speed, speed profile, and wrong-way movement. As stated previously, field traffic data were collected by the system and saved to a data file. This data file was taken to a lab for data reduction and processing. The following sections present data analysis results and the comparison between real traffic characteristics recorded by a video recorder and traffic characteristics processed by the prototype system.

Traffic Flow Rate Measurements

Traffic flow rate is defined as the number of vehicles per unit time. Usually, for operations purpose, directional hourly rate is used, i.e. – vehicles per hour (vph). Sometimes, subhourly flow rate is used to be converted to equivalent hourly rate. This study used subhourly flow rate for the field experiments. Traffic flow was recorded by a video camera and measured by the prototype. The traffic data recorded by the video camera were used as reference to assess the accuracy of the prototype. Several conditions were tested to include different testing speed, different array spacing, and different traffic moving directions. Testing speeds were 15 mph, 25 mph, and 35 mph. As stated, the tests were conducted on an unpaved test track. Since higher speed caused a lot dust which could block the infrared beam, higher speed was not tested. Array spacing could be another factor which may affect the accuracy of the measurements. A spacing of 25 ft and 50 ft was tested, respectively, to assess the impact of array spacing on the measurement accuracy. North bound traffic and south bound traffic were also measured to test whether the prototype could measure traffic flow rates from different directions. Table 5.1 presents the experiment results for the function of traffic flow measurement.

Table 5.1 Comparison of Field Measurements of Flow (vph) with Real Flow (vph)

		Sensor Spacing: 25 ft				Sensor Spacing: 50 ft			
		South Bound		North Bound		South Bound		North Bound	
		Real Flow Rate	Measured Flow Rate	Real Flow Rate	Measured Flow Rate	Real Flow Rate	Measured Flow Rate	Real Flow Rate	Measured Flow Rate
Speed (mph)	15	135	134	124	124	121	121	122	123
	25	179	182	194	195	169	170	170	172
	35	254	258	267	273	286	291	260	265

Testing speed effects

It can be seen from Table 5.1 that traffic flow rate at low speed (15 mph and 25 mph) were accurately detected by the prototype. The relative measurement errors at a low speed were less than 2%. However, at higher speed (35 mph), the relative measurement error was greater than 2%, but less than 4%. The main reason was due to the fact that the dust caused by traffic at high speed may block the infrared beam and mistakenly triggered the sensor. A feasible way to eliminate such a problem is to use more powerful infrared beam sensors or larger-size reflectors. Technically, a more powerful infrared beam sensor transmits a stronger infrared beam which can more easily penetrate dust to reach the reflector and be reflected back to the sensor as compared with a less powerful infrared beam sensor. Also, a larger-size reflector can more easily receive an infrared beam as compared with a smaller-size reflector. However, the choice (more powerful sensors or larger-size reflectors) will depend on the cost of sensors and reflectors and practical application considerations. This should be further evaluated in future research.

Array spacing effects

The main considerations for deciding array spacing are the particular application of the measuring system, system sampling rate, vehicle size, and test site conditions. Generally, if test conditions permit, a larger spacing would be preferred because a larger spacing

between sensors would make the measuring system better distinguish vehicles that are cutting infrared beams as compared with a smaller spacing. However, for some applications such as monitoring traffic at freeway ramps, toll gates, and approaching lanes to intersections, there is not enough spacing available for installing the sensor array at a large spacing between sensors. In this case, a smaller spacing may have to be used.

As stated previously, the system has a very fast sampling speed. Therefore, sampling rate is not a problem when selecting the spacing between sensors. To effectively distinguish vehicles, vehicle size may need to be considered. If a vehicle's size is longer than the spacing between sensors, the vehicle cuts two infrared beams in the same time. This may require a much more complicated algorithm to process the data and estimate the traffic characteristics. It is better to design a measuring system with the spacing between sensors larger than the size of the largest vehicle in the traffic stream. In this experiment, only passenger cars were tested. A passenger car usually has a size of 20 ft or less. Thus, 25 ft was used in the experiment as the smallest spacing. According to the test results shown in Table 5.1, it can be concluded that the spacing between sensors does not present significant impact on measurement results of traffic flow rates. However, this conclusion was based on the condition that the spacing should be larger than the length of the largest vehicle in the traffic stream.

Flow rates of south bound and north bound

To collect traffic flow data from different directions does not need to change system set-up. The only thing that needs to be changed is the software. In this test, traffic flow was moving from north bound then south bound. From Table 5.1, it can be seen that the system's performance (relative measurement error) for the measurements of traffic flow from north bound and south bound did not show significant difference.

Traffic Speed Measurements

Traffic speed is a very important measure to evaluate traffic operations and used for real-time traffic control and route guidance. Practically, space-mean-speed and time-mean-speed are of interests for such applications. The prototype has the capability to measure

both space-mean-speed and time-mean-speed. In field, testing speeds of 15 mph, 25 mph, and 35 mph were selected. True speeds were recorded by the video camera and processed after the experiments. Since the testing speeds were controlled by a driver inside the vehicle, it was very difficult to run the vehicle at the exact given speed. Therefore, the measured speed should be compared with the speed recorded by the video camera, not the given speed. The array was set up in two forms. The first form had a spacing of 25 ft between sensors, and the second had a spacing of 50 ft. Such set-up may show the impact of array spacing on the measurement of speed. Table 5.2 presents the test results.

Table 5.2 Comparison of Field Measurements of Speed (mph) with Real Speed (mph)

		Sensor Spacing: 25 ft				Sensor Spacing: 50 ft			
		South Bound		North Bound		South Bound		North Bound	
		Real Speed	Measured Speed	Real Speed	Measured Speed	Real Speed	Measured Speed	Real Speed	Measured Speed
Speed Range (mph)	15	16	15.8	14	14.6	15	14.5	17	16.8
	25	24	25.1	23	24.5	27	26.3	24	25.8
	35	34	35.5	36	37.1	37	38.4	33	35.2

As shown in the table, higher speed resulted in relatively larger measurement errors as compared to slower speed. The main reason for this could be the dust caused by the traffic running at high speeds. As stated previously, to minimize the impact of roadway surface dust on the output of the system, more powerful infrared beam sensors or larger-size reflectors should be used to replace the current sensors or reflectors.

By reviewing the test results, it was found that the array spacing between sensors did not show significant impact on the measurement errors. This is similar to the conclusions on the measurement of traffic flow rate. Basically, since the testing vehicle size was smaller than 22 ft long which was less than the spacing between sensors, the prototype could catch all vehicles' speed and calculate the speeds.

Speed Profile Measurements

A speed profile is a speed curve reflecting vehicle speeds at different locations along a roadway section. Speed profiles at highway curves, freeway ramps, toll plaza approaching lanes, intersection approaching lanes, and other critical locations may be used to evaluate traffic performance and safety. Since the array consists of several sensors placed along the roadway section with uniform spacing between sensors, the prototype is able to measure the traffic speed profiles. Field experiments were carried out to test the accuracy of the prototype to measure a speed profile with 50 ft between sensors. The same test track was used for this purpose. However, in order to test the prototype in measuring speed profiles, test vehicle's speed was changed from high speed to low speed when the testing vehicle was moving on the test track. The speed range was from 10 mph to 35 mph, and traffic from both directions were tested. To evaluate the performance of the prototype in measuring vehicle speed profiles, an average speed profile based on different speed profiles from different runs was used. The true average speed profile collected by the video camera was used to compare the measured average speed profile. Figures 5.1 and 5.2 presents the test results for speed profile measurements. It can be visualized that the speed profiles from both directions measured by the prototype were close to the true speed profiles recorded by the video camera. Based on the test results, it can be concluded that the prototype is able to measure vehicle speed profiles with acceptable accuracy.

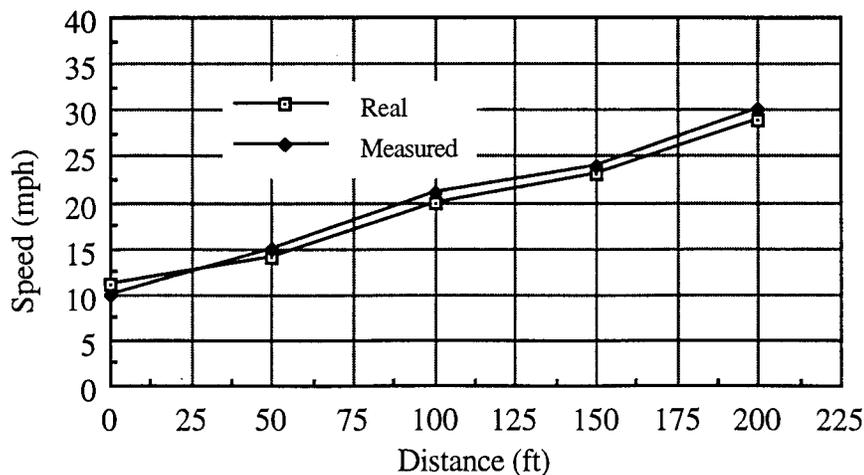


Figure 5.1 Speed Profiles Measured by the Video Camera and the Prototype (South Bound)

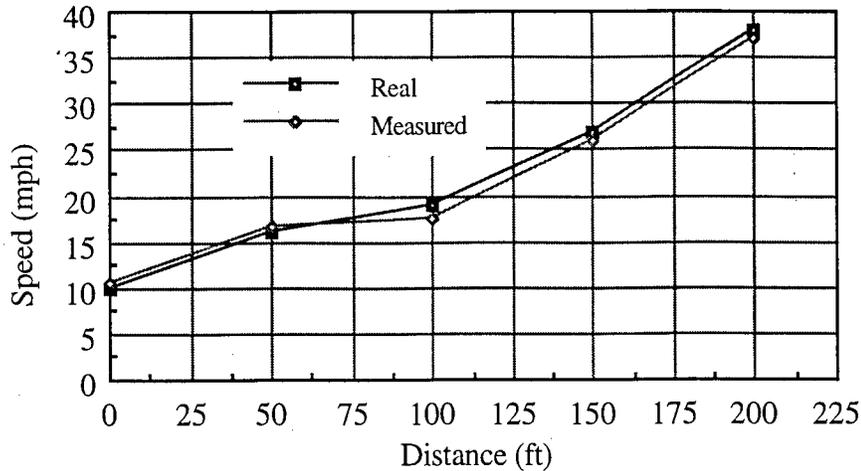


Figure 5.2 Speed Profiles Measured by the Video Camera and the Prototype (Nouth Bound)

Wrong-Way Movement Measurements

Wrong-way movement of traffic is one of the main attributes contributing to severe traffic crashes at locations such as work zones, freeway ramps, toll plazas, and urban arterial. To effectively prevent traffic crashes due to wrong-way traffic movements, traffic detection systems and warning systems should be installed. The prototype designed in the project can be used for wrong-way traffic movement detection purposes. Theoretically, to detect traffic wrong-way movement, at least two sensors should be used. However, in order to obtain reliable information on traffic wrong-way movements, more sensors may be desired. Since the prototype has a array of six sensors, detection of wrong-way traffic movements should be feasible and the results should be more reliable as compared with a system with only two sensors. To test the reliability of the prototype in measuring traffic wrong-way movements, a testing vehicle was arranged to move from the wrong-way direction for more than 30 runs for each testing speed (15 mph, 25 mph, and 35 mph). Based on field test results it was found that the prototype was able to detect wrong-way traffic movements at all testing speeds. The correct detection rates from all testing speeds were about 100% except in the case that high density dust existed and caused wrong detection.

CHAPTER 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summaries

This report summarizes a preliminary research study performed to develop an infrared beam sensor array system for traffic data collection. The research project aimed at developing a prototype and running preliminary field experiments to test the prototype's workability in real situation and test whether the prototype functioned according to the designed functions.

The project was divided into two phases. In the first phase, a prototype was designed. Based on the design, all necessary hardware were purchased and assembled to form the prototype. In addition, all necessary software was developed to support the system's data sampling and processing functions. In the second phase, field experiments were conducted to test the prototype and assess the prototype's performance in measuring traffic characteristics. Field data collected by the prototype and recorded by a video camera were processed in the lab and summarized in the report.

Conclusions

1. The infrared beam sensor array system can be considered a non-contact-type traffic detection system. A non-contact-type detection system has several advantages over contact-type detection system such as longer service life, faster response time, less impact from moving vehicles, and easy to install and replace in fields.
2. The system developed in the research uses an array consisting of several infrared beam sensors with the uniform spacing between sensors. An sensor array is able to detect traffic characteristics in both directions. The main traffic characteristics that can be detected by the prototype developed in the preliminary study include traffic flow rate, speed, speed profile, and wrong-way movements. In fact, there are more macroscopic and microscopic traffic characteristics that the proposed

system can detect such as density and occupancy. The most significant advantage over existing technologies is that the system has the potential to detect traffic characteristics in both directions at the same time. However, since the limited scope of the research, such function was not fully tested in the preliminary project.

3. Field experiments were conducted in the study to assess the prototype's performance. Several factors were included in the experiments such as speed, sensor spacing, and vehicle moving directions. The field experiments were conducted on a test track set up in a big parking lot.
4. The main traffic characteristics collected by the prototype in the experiments were traffic flow rate, speed, speed profile, and wrong-way traffic movement. Based on the test results, it can be concluded that the prototype developed in the preliminary study worked very well. The prototype could reasonably collect information on traffic flow rate, speed, speed profile, and traffic wrong-way movement.
5. It was found from field experiments that roadway surface dust has certain impact on the prototype's performance. The main reason for this was that high-density dust caused by fast-moving vehicle may block the path of an infrared beam, resulting in mistakenly triggering the sensor. Therefore, the system's performance may be affected. To minimize the problem, it is suggested to use more powerful infrared beam sensors and larger-sized reflectors.
6. The prototype used low-power infrared sensors and small-size reflectors. Such sensors and reflectors made it difficult to set up the array because it was not easy to aim the infrared beam to the reflector. However, such a problem can be easily solved by using more powerful sensors and larger-sized reflectors.

Recommendations

1. This research project is a preliminary one with limited research scope and funding. To fully implement the system, a research project with larger scope and funding resources should be performed.
2. The current functions of the system should be expanded in the next research to include the detection of traffic density and occupancy.
3. Infrared beam sensors with more power should be searched to replace the existing ones. In addition, larger-sized reflectors are also needed to replace the existing ones. With such changes, the problems associated with dust and system set-up can be minimized.
4. More software needs to be developed in the next research for the measurements of traffic characteristics in both directions. The system should be fully developed and tested in future research.

