Technical Report Documentation Page

1. Report No. FHWA/TX-09/0-6004-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A PORTABLE PROFILER FOR PAVEMENT PROFILE MEASUREMENTS		5. Report Date January 2009 Published: May 2009 6. Performing Organization Code
7. Author(s) Roger S. Walker and Emmanuel Fernando		8. Performing Organization Report No. Report 0-6004-1
9. Performing Organization Name and Address The University of Texas at Arlington The Texas Transportation Institute, Texas A&M University		10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project 0-6004
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P. O. Box 5080 Austin, Texas 78763-5080		13. Type of Report and Period Covered Technical Report: January 2009 – April 2009 14. Sponsoring Agency Code

15. Supplementary Notes
Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.
Project Title: Develop a Portable Profiler for Maintenance and Construction Applications
URL: http://ranger.uta.edu/~walker/Reports/recent_research_reports.htm

16. Abstract
This interim report provides a summary of work performed on Texas Department of Transportation (TxDOT) Research Project 0-6004 during the first year of the project. The project was initiated to develop a single path, easy to use, portable profiler. The desired profiler module is being designed to provide TxDOT a unit that can easily be mounted or removed from the front or rear bumper of typical TxDOT vehicles for measurements. The Profile generated is to be compatible with existing TxDOT formats. The project is being conducted by Dr. Roger Walker of the University of Texas at Arlington and Dr. Emmanuel Fernando of the Texas Transportation Institute at Texas A&M University who began work in September 2008 in accordance with the project proposal.

17. Key Words Profiler, Profile Measurement Laser, Surface Pavement Profile	18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Springfield, Virginia 22161 http://www.ntis.gov

19. Security Classification.(of this report) Unclassified	20. Security Classification.(of this page) Unclassified	21. No. of Pages 44	22. Price

A PORTABLE PROFILER FOR PAVEMENT PROFILE MEASUREMENTS

by

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Report 0-6004-1
Project 0-6004
Project Title: Develop a Portable Profiler for Maintenance and Construction Applications

Performed in Cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

January 2009
Published: May 2009

THE UNIVERSITY OF TEXAS AT ARLINGTON
The University of Texas System
Arlington, Texas

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ACKNOWLEDGMENTS

Researchers would like to acknowledge Mr. Phillip Hempel, the Project Director, Todd Copenhaver, and Dr. German Claros of the Texas Department of Transportation. Acknowledgements are also due Gerry Harrison at the Texas Transportation Institute at Texas A&M University, and Jareer Abdel Qader at the Transportations Instrumentations Lab at the University of Texas at Arlington for their part on this project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PROJECT BACKGROUND AND OBJECTIVES

INTRODUCTION

This interim report provides a summary of work performed on TxDOT Research Project 0-6004 during the first year of the project. The project was initiated to develop a single path, easy to use, portable profiler. The desired profiler module is being designed to provide TxDOT a unit that can easily be mounted or removed from the front or rear bumper of typical TxDOT vehicles for measurements. The Profile generated is to be compatible with existing TxDOT formats. The project was initiated in mid-December of 2007. It was originally scheduled for completion in two years, however the research effort was limited to a little over a year and a half. The project is being conducted by Dr. Roger Walker of the University of Texas at Arlington and Dr. Emmanuel Fernando of the Texas Transportation Institute at Texas A&M University who began work in September 2008 in accordance with the project proposal. The research plan was separated into the following tasks:

- Investigate current non-contact displacement, acceleration, and distance sensors;
- Investigate current known profiling methods;
- Investigate portable instrumentation module;
- Develop software module; and
- Test instrumentation package and portable profiler.

Because of the shortened time frame as noted above, some of the tasks were initiated earlier than was originally planned, and others delayed somewhat so as to meet the project objectives. However, it is expected that all the original tasks will be completed as planned.

PROFILER SENSORS

Modern day inertial reference profilers use the following sensors in computing longitudinal profile:

- an infrared start sensor for automated and precise starting of profile measurements,
- a laser for road-body displacement measurements,
- a distance encoder, for measuring distance traveled and synchronizing the computed profile to this distance, and
- an accelerometer for measuring vehicle body displacements.

Since the current infrared start sensor is portable, inexpensive, and very reliable, researchers are of the opinion that the available start sensors are adequate for portable profiler use. Thus, no additional investigations of start sensor technology were made. TxDOT has been using these sensors on the department's inertial profilers for about 20 years and this field experience has proven the reliability of these sensors. Researchers thus focused their investigations on the other sensors used for inertial profile measurements. The findings from this work are presented below.

Lasers

The LMI 5000 Selcom laser is relatively inexpensive when compared with most other lasers (the Acuity AR700 being an exception), and successfully used by many profilers in both the U.S. and a number of foreign countries with almost trouble free operations. Additionally, the Selcom lasers have been used for profiling since the mid-1980s. TxDOT has used these lasers exclusively on the department's profilers since about that time. After discussing the current laser usage with project personnel in a meeting on June 23, 2008, the decision was made to use the LMI 5000 for the portable profiler to be developed in this project.

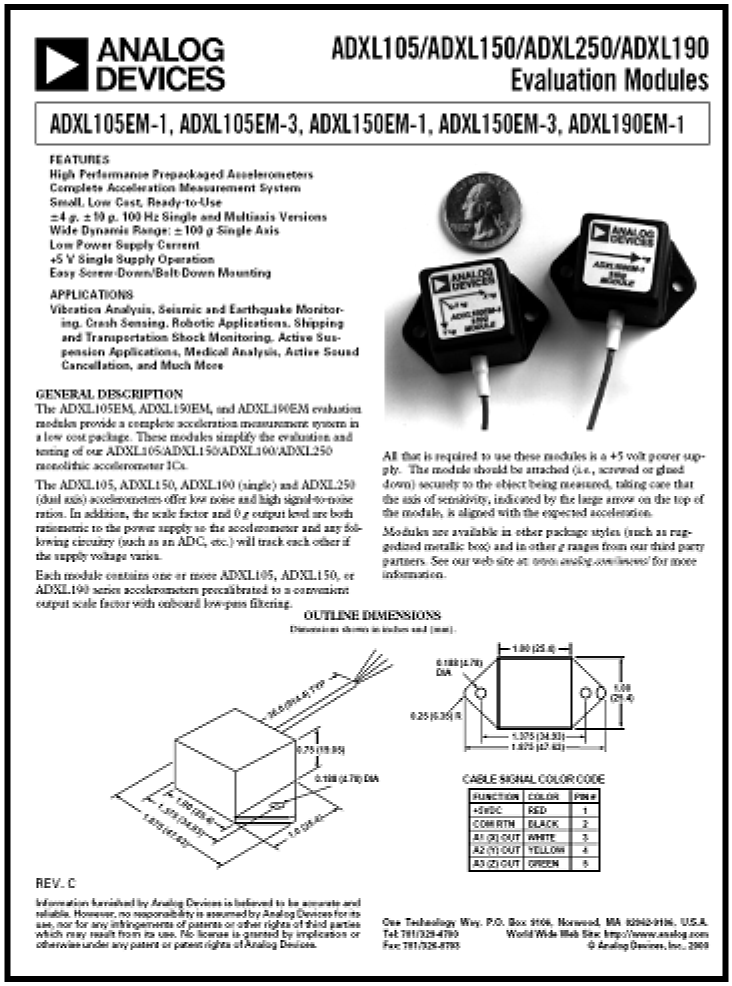
The Acuity lasers are being used by some slow speed profiler manufacturers. The measuring speed of the Acuity sensor AR700 is 9400 readings per second, once not considered adequate for high speed profilers. However, with laser bandwidth considerations and filters, the necessary bandwidth often is much less. These lower sampling rate lasers might be adequate for high speed profilers.
It should be noted that the effects of texture on IRI has been recently under investigation, raising questions on single spot lasers. Selcom has developed a line laser, referred to as the Roline laser, which is currently being implemented in some of the newer versions of the low and high speed profilers. Ames Engineering currently offers profilers with a Roline laser option. Instead of providing a single spot

measurement, the Roline laser provides a transverse set of measurements along the wheel path traveled by the vehicle. The laser can also be rotated 90 degrees, providing a set of longitudinal measurements. Figure 1 illustrates three of the LMI-Selcom profiler lasers

Figure 1. LMI's Selcom Road Lasers (from LMI sales literature).

Accelerometer

TxDOT has successfully used the Columbia Research SA107BHP accelerometer since 1985. This model is also used by several other manufacturers and profilers in other states. The one drawback has been the cost. Researchers had previously investigated the 3-axis ADXL150EM-3 accelerometer (Figure 2) and noted that this alternative sensor might be suitable for some profiling applications. Figure 3 shows the specifications for this 3-axis accelerometer. Since the lower cost accelerometers examined by researchers did not have equivalent specifications as the Columbia Research SA107 series, the question arises as to whether the less expensive accelerometers would be sufficient for pavement profiling applications. This question is addressed in a later section of this interim report. The prototype profiler instrument sensor module developed during the first year of this project included the installation of the ADXL150EM-3 for side by side testing.



ANALOG DEVICES

ADXL105/ADXL150/ADXL250/ADXL190
Evaluation Modules

ADXL105EM-1, ADXL105EM-3, ADXL150EM-1, ADXL150EM-3, ADXL190EM-1

FEATURES
High Performance Prepackaged Accelerometers
Complete Acceleration Measurement System
Small, Low Cost, Ready-to-Use
±4 g, ±10 g, 100 Hz Single and Multiaxis Versions
Wide Dynamic Range: ±100 g Single Axis
Low Power Supply Current
+5 V Single Supply Operation
Easy Screw-Down/Bolt-Down Mounting

APPLICATIONS
Vibration Analysis, Seismic and Earthquake Monitoring, Crash Sensing, Robotic Applications, Shipping and Transportation Shock Monitoring, Active Suspension Applications, Medical Analysis, Active Sound Cancellation, and Much More

GENERAL DESCRIPTION
The ADXL105EM, ADXL150EM, and ADXL190EM evaluation modules provide a complete acceleration measurement system in a low cost package. These modules simplify the evaluation and testing of our ADXL105/ADXL150/ADXL190/ADXL250 monolithic accelerometer ICs.

The ADXL105, ADXL150, ADXL190 (single) and ADXL250 (dual axis) accelerometers offer low noise and high signal-to-noise ratios. In addition, the scale factor and 0 g output level are both ratiometric to the power supply so the accelerometer and any following circuitry (such as an ADC, etc.) will track each other if the supply voltage varies.

Each module contains one or more ADXL105, ADXL150, or ADXL190 series accelerometers precalibrated to a convenient output scale factor with onboard low-pass filtering.

All that is required to use these modules is a +5 volt power supply. The module should be attached (i.e., screwed or glued down) securely to the object being measured, taking care that the axis of sensitivity, indicated by the large arrow on the top of the module, is aligned with the expected acceleration.

Modules are available in other package styles (such as ruggedized metallic box) and in other g ranges from our third party partners. See our web site at www.analog.com/imems/ for more information.

OUTLINE DIMENSIONS
Dimensions shown in inches and (mm).

1.00 (25.4)
0.188 (4.78) DIA
0.25 (6.35) R
1.375 (34.93)
1.875 (47.63)
0.75 (19.05)

CABLE SIGNAL COLOR CODE

FUNCTION	COLOR	PIN #
+5VDC	RED	1
COM RTN	BLACK	2
A1 (X) OUT	WHITE	3
A2 (Y) OUT	YELLOW	4
A3 (Z) OUT	GREEN	5

REV. C

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Figure 2. Analog Device ADXL Accelerometer.

ADXL105EM-1/ADXL105EM-3/ADXL150EM-1/ADXL150EM-3/ ADXL190EM-1–SPECIFICATIONS

ACCELEROMETER EVALUATION MODULES

Model / Parameters	ADXL105 EM-1 Single Axis	ADXL105 EM-3 Tri-Axial	ADXL150 EM-1 Single Axis	ADXL150 EM-3 Tri-Axial	ADXL190 EM-1 Single Axis	Units	Remarks
Span	±4	±4	±10	±10	±100	*g*	±5%
Sensitivity[1]	500	500	200	200	20	mV/*g*	±5%, @ +5.00 V
Bandwidth	DC–100	DC–100	DC–100	DC–100	DC–400	Hz	±5%
Noise	4	4	10	10	40	m*g* rms	typ
Orientation	Horizontal	Tri-Axial	Horizontal	Tri-Axial	Vertical		
Zero *g* Output[2]	+2.5 ± 0.1	+2.5 ± 0.1	+2.5 ± 0.1	+2.5 ± 0.1	+2.5 ± 0.1	Volts	@ +25°C, @ +5.00 V
Zero *g* Drift[3]	±0.2	±0.2	±0.2	±0.2	±0.2	*g*	0°C to +70°C typ
Span Output	±2.0 ± 0.2	±2.0 ± 0.2	±2.0 ± 0.1	±2.0 ± 0.1	±2.0 ± 0.2	Volts	@ +25°C, @ +5.00 V
Nonlinearity[4]	±0.2	±0.2	±0.2	±0.2	±0.2	% FS	typ
Alignment	±2	±2	±2	±2	±2	Degrees	typ
Transverse Sensitivity[5]	±3.5	±3.5	±3.5	±3.5	±3.5	% FS	typ
Temperature Range	0 to +70	0 to +70	0 to +70	0 to +70	0 to +70	°C	
Shock	500	500	500	500	1000	*g*	Powered
	2000	2000	2000	2000	2000	*g*	Unpowered
Output Loading	>2 kΩ, < 1 nF	>2 kΩ, < 1 nF	>2 kΩ, < 1 nF	>2 kΩ, < 1 nF	>2 kΩ, < 1 nF		max
Supply Voltage							
Specified Performance	+5 ± 0.25	+5 ± 0.25	+5 ± 0.25	+5 ± 0.25	+5 ± 0.25	Volts	max
Functional Range	+5 ± 1	+5 ± 1	+5 ± 1	+5 ± 1	+5 ± 1	Volts	typ
Supply Current	3.5	10	3.5	10	3.5	mA	typ

NOTES

[1] Ratiometric to Supply: $V_{OUT} = (V_S/2) - (\text{sensitivity} \times (V_S/5\text{ V}) \times \text{accel})$.

[2] Ratiometric to supply, proportional to $V_S/2$.

[3] Zero *g* Drift is specified as the typical change in 0 *g* level from its initial value at +25°C to its worst case value at T_{MIN} or T_{MAX}.

[4] Nonlinearity is the deviation from a best fit straight line at full scale.

[5] Transverse sensitivity is error measured in the primary axis output created by forces induced in the orthogonal axis. Transverse sensitivity error is primarily due to the effects of misalignment (i.e., much of it can be tuned out by adjusting the package orientation).

[6] All frequency break points are –3 dB, single pole, –6 dB per octave roll-off.

Specifications subject to change without notice.

Figure 3. Specifications for ADXL150 Accelerometer.

Distance Traveled Sensor

Synchronizing the computed profiles to distance traveled is required for pavement profiler applications. There are several types of distance encoders that are used by profilers. TxDOT currently uses an in-house unit that attaches to the drive shaft of the vehicle. However, because of the mounting required to use this encoder, it was not considered suitable for use in a portable profiler. Most profiler manufacturers use an off-the-shelf distance encoder that attaches directly to the wheel. The attachment apparatus holding the encoder to the wheel hub is typically built by the profiler manufacturer. This setup is typically used in dedicated profiling vehicles where the profiling system is specifically installed in the vehicle by the manufacturer, such as profilers sold to transportation departments for pavement condition surveys. Within the past 5 years, profiler manufacturers have come up with systems that are designed to be used with more than one vehicle. These systems use a method of mounting the distance encoder such as illustrated in Figure 4. This figure provides an illustration of a wheel attachment

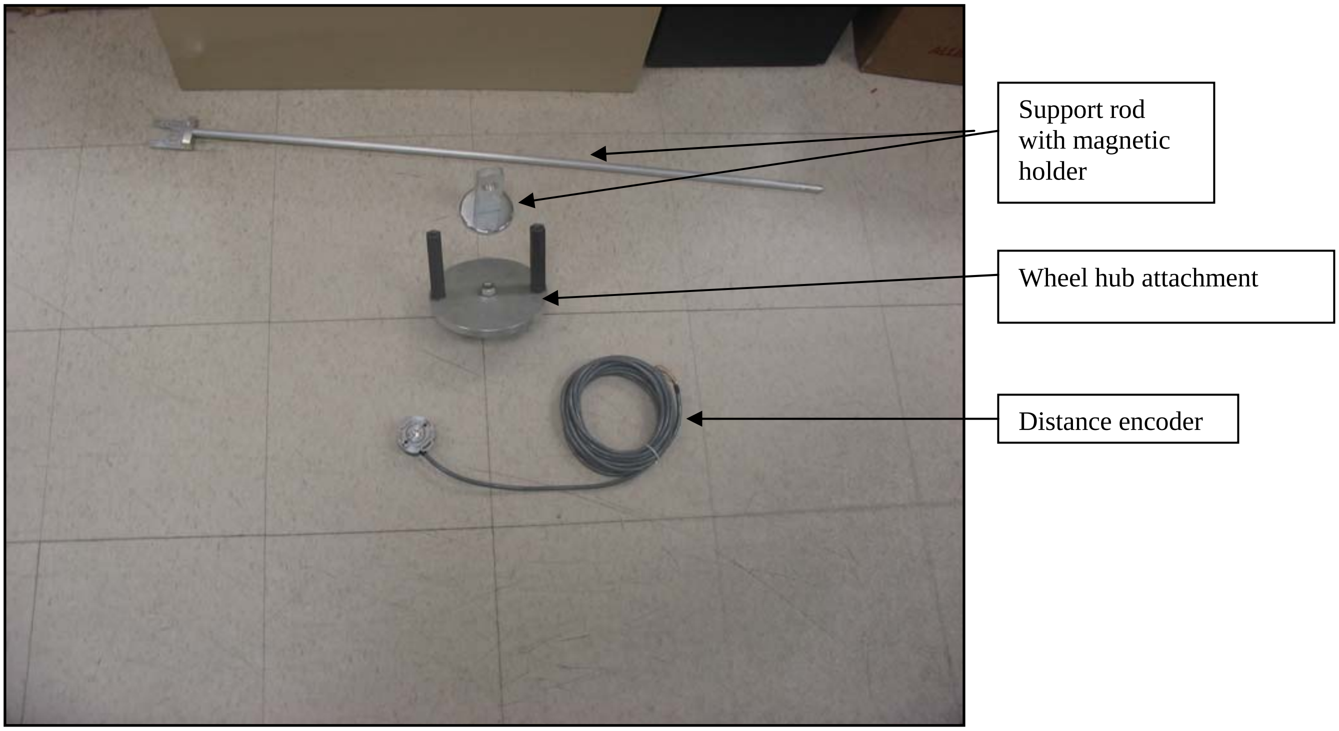

Figure 4. Illustration of Portable Distance Measuring Assembly

Figure 5. Distance Measuring Assembly Used on TTI Profiler.

constructed by TTI and an encoder similar to the one used with the TTI profiler. The encoder is attached to the wheel with special lug nuts and supported by a rod attached to the fender using a permanent magnet. The actual unit used on the TTI profiler is illustrated in Figure 5, with the rod attached to the fender by bolts. Corrsys Datron Inc. offers a portable system (see Figure 6) that attaches directly to the wheel hub in a similar manner as the TTI unit. This unit provides an approximate 0.1 percent horizontal resolution. This method of mounting the distance encoder provides some level of portability for using profiling systems on different vehicles where the wheel hubs are compatible with the mounting hardware.

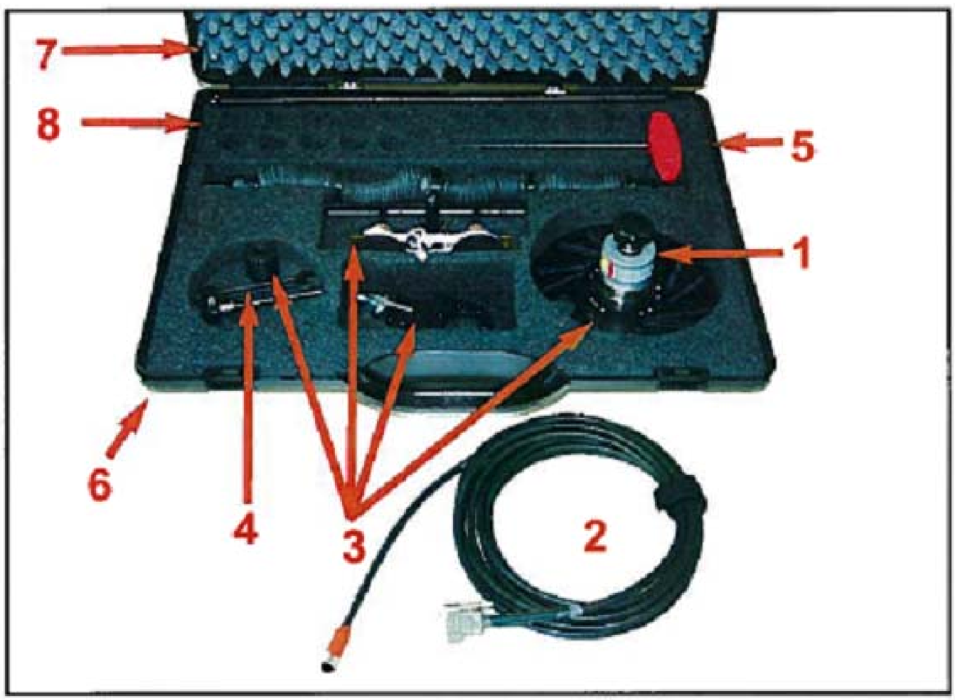

Figure 6. Corrsys Datron Portable Distance Measuring System.

During a project meeting in August, a radar-based distance measuring system was discussed that, at that time, was being tested at TTI on another project. Following this meeting, UTA purchased this noncontact unit. Although not recommended for slow speed applications, this distance measuring instrument will be investigated during the latter part of the project. This unit would not require attaching to the wheel hub or axle, and if found suitable could potentially provide a very portable option.

PROFILE COMPUTATIONAL METHODS

The Spangler Profiling Method

Two profiling methods or derivations of these methods are commonly used by today's profilers. The first method was developed by Elson Spangler and William Kelly in the early 1960s. They developed and patented a device known as the GMR Profilometer while working at the General Motors Research Laboratory (*1*). The GMR profilometer was commercialized through KJ Law in the late 1960s and one of the first such units was purchased by the University of Texas at Austin (*2*) during a research project sponsored by the Texas Department of Transportation. The method (see Figure 7) uses an accelerometer to measure the acceleration of the vehicle mass motion $\ddot{Z}_m$. The mass displacement is then determined by the double integration of the acceleration. The mass displacement $(W\text{-}M)_m$ is determined by a laser (originally measured using a road following wheel and linear potentiometer). The measured profile is then computed by summing Z_m, the double integrated mass acceleration with the mass displacement, or $(W\text{-}M)_m$, yielding W_m or measured road profile. In this original system, the sensors provided an analog voltage proportional to the acceleration and road-body displacements which were then processed (double integration, summing, and filtering) in real-time using an analog computer.

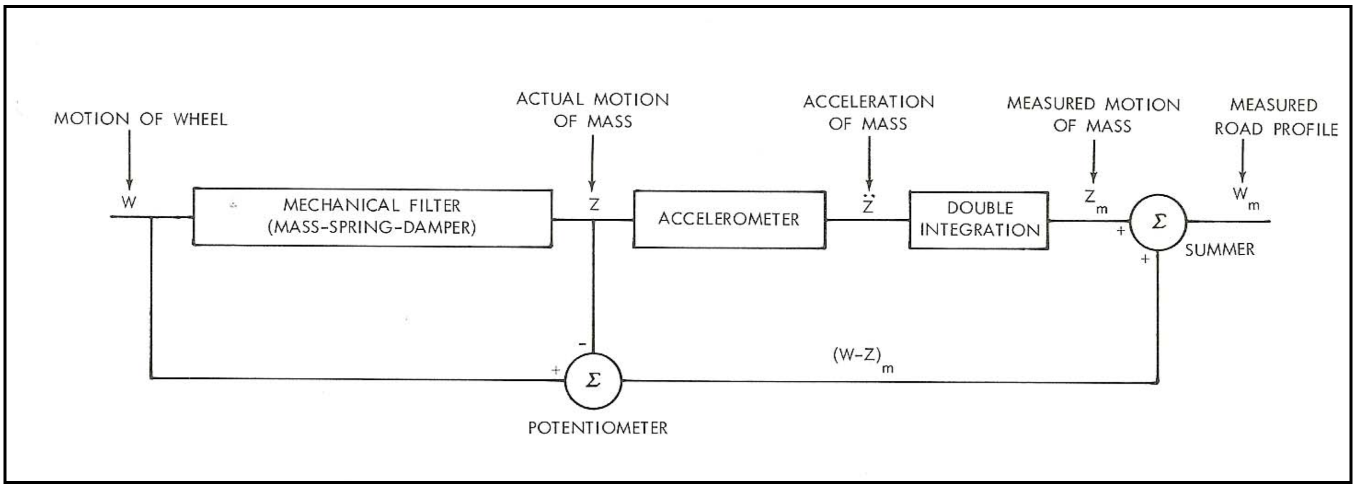

Figure 7. GMR Road Profilometer Measurement Process (*1*).

In 1983, Spangler obtained a patent for a digital version of this process where the analog sensor readings are sampled with respect to distance traveled. A real-time computer program was developed that would compute profile from the sampled signals.

The South Dakota Method

During 1981 and 1982, David Huft of the South Dakota Department of Transportation developed a variation of the profiling procedure using a time-based inertial profiling algorithm. For the Huft method, the analog voltages proportional to the vehicle mass acceleration, $\ddot{Z}_m$, and road-body displacement (W-M) is sampled with respect to time (originally at 1000 Hz). The mass acceleration is then integrated with respect to time and added to the time sampled road-body displacements. The closest time based profile value is then synchronized with the appropriate discrete distance reading, yielding the road profile. Both the Spangler and Huft methods also use a filtering process to attenuate the low frequencies or long wavelengths measured by the accelerometer where the Spangler method used a three pole filter and the Huft method used a single pole Butterworth filter. The Huft method then would post process the profile with a two pole distance based filter. SDDOT subsequently began using the Road Profiler to conduct annual statewide roughness surveys. The Huft or South Dakota method used a noncontact ultrasonic ranging sensor to measure the distance between the test vehicle and the pavement surface (see reference *3* for a description and evaluation of the original South Dakota Profiler). In 1985, a third ultrasonic sensor, located in the center of the vehicle was added for making rut measurements. Because of the success of this system and the Federal mandate to collect reliable roughness measurements for the Highway Performance Monitoring System (HPMS), SDDOT began providing technical assistance to other states interested in building similar equipment and organized the Road Profiler Users Conference. This conference provided personnel from the various states with profilers a common time and place where they could discuss their experiences and problems in constructing and using these profilers.

Because South Dakota did not patent this method, the result was the wide spread usage of road profiling technology. International Cybernetics Corporation was one of the first companies to market a commercial version of the South Dakota Profiler and was later followed by other companies.

Project Profiling Model

One of the tasks planned for the research effort is to develop a means by which the various profiling methods can be investigated for applications requiring procedures that will meet the requirements of multiple locations and portable usage. During the project, a general profiling model (Figure 8) to test the various methods and their variations has been under development. However, this effort has been hampered by not having actual raw sensor data from the portable instrument module for testing and comparison to reference profile values. As a result, research efforts were redirected on moving up the construction of the portable instrumentation package so it could be used to collect raw sensor data. Reference data from two road sections on SH6 and SH47 have recently been profiled by TTI using the walking profiler and rod and level. Additionally, a third section on SH130 in Austin is available. A later section discusses the initial prototype portable instrument developed during the first year, which has recently undergone testing on the TTI profiling vehicle.

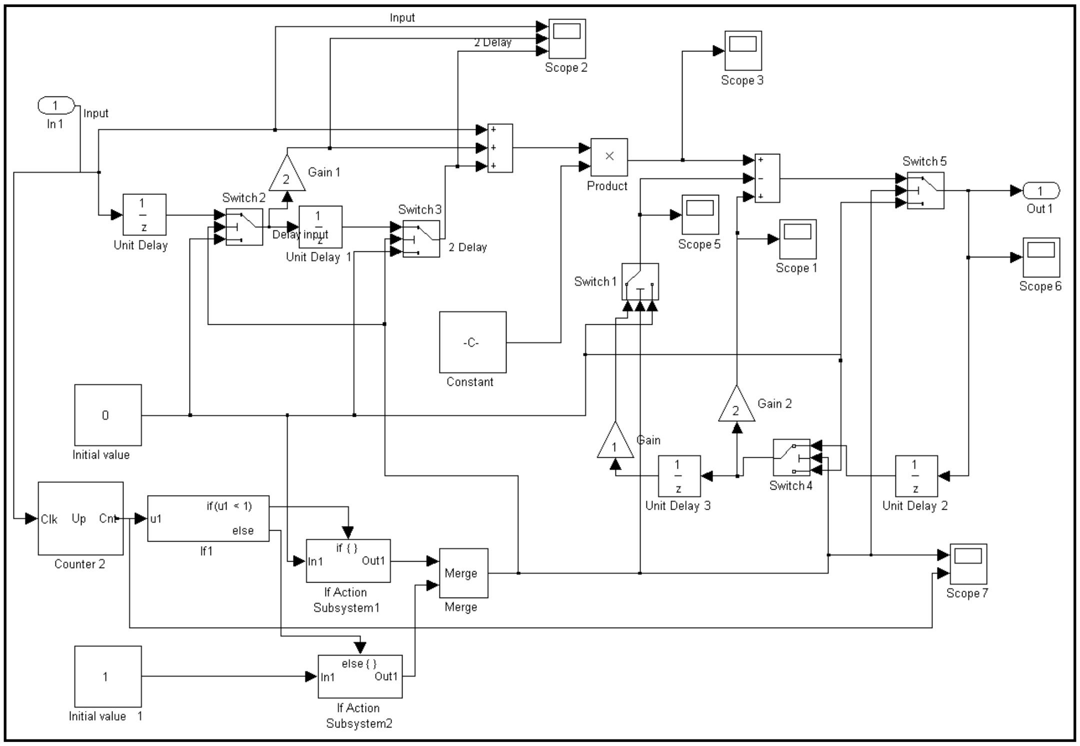

Figure 8. Matlab Profiling Model.

Model simulations will be used to perfect the profiling method during the second year of the project. As discussed earlier, there are three sensors needed for accurate profile data: laser, accelerometer, and distance encoder. The orientation of the body-motion and road-body displacement sensors with respect to each other as well as the accuracy and synchronization of the distance measurements are critical for accurate profile measurements. Additionally, proper positioning, location, and portability of the accelerometer-laser instrument package must be such that accurate acceleration measurements can be made of the vertical vehicle motion and road-body displacements. For example, in the original KJ Law profiler, the accelerometer-laser sensors were located on each wheel path in the center of the vehicle. This location had the added advantage of more accurately measuring the perpendicular body movement. Because of the more difficult problems of placing the sensors at this location and the need to collect rut information, the instrument package was later moved to the front of the vehicle and housed in a rut bar. This setup is used on most of today's road profilers. The instrument package and its location on today's high speed and light weight profilers are typically permanently fixed to a specific vehicle. The portable profiling package however can be attached to either the front or rear of the vehicle.

Investigating Different Locations for Accelerometer Placement

A set of previously collected acceleration data along with the associated inertial profile data was available at UTA. The data had been collected on another UTA internally funded project aimed at developing a portable IRI measuring procedure. Since one of the portable profiler design parameters is the location of an instrument package that includes a similar accelerometer used in this previous project, researchers again investigated the data. Further, since the method investigated was highly dependent on accurate vehicle body accelerations and similar computational procedures were used, the results were of interest to researchers. Thus, researchers analyzed the available data to determine how the position of the acceleration package would affect accurate vehicle body motion measurements. The experiment also provided a head to head comparison between accelerometer measurements from both the lower cost accelerometers and the SA107BHP.

For the previous study, a full size van was instrumented with three pairs of the less expensive accelerometers similar to the Analog Devices sensors where one sensor of each pair was filtered with a 50 Hz analog low pass filter while the other was unfiltered. Each of the three pairs of sensors was located in the front, rear, and on the back axle of the vehicle. Note that no sensors were placed on the front or rear bumpers of the test vehicle. A seventh sensor, the Columbia Research SA107BHP accelerometer was located at the back of the vehicle. A distance encoder and infrared start sensor were used to synchronize the accelerations obtained at discrete distance intervals. Table 1 summarizes the location of each sensor and the assigned A/D channel.

A total of seven one-mile sections, each consisting of five 0.1-mile test segment were selected. Each section was run five times, where a start tape signaled the beginning of each one-mile five section set. For the tests, the data were sampled by time, similar to the current method used in TxDOT's profilers and the average set of readings of each sensor was computed for each distance pulse. Raw sensor readings were then obtained on the five one-mile sections. Five repeat measurement runs were made on each section thus yielding a total of twenty-five 0.1-mile data files. The infrared start sensor was used to ensure the same start point for each measurement run. As indicated, one of the objectives of the experiment was to determine if a model could be developed to predict IRI from the accelerometer readings. The statistic used for correlating to IRI was the slope variance of the first derivative of a predicted profile. The computational procedures used to compute the estimated slope variance (denoted as WSV) included a digital integration and high pass filtering similar to the one used for computing profile. Three repeat runs were made on the five one-mile sections with an inertial profiler and the corresponding IRI computed for each of the one hundred and twenty five 0.1-mile runs (5 one mile sections × 5 tenth of a mile subsections × 3 repeat runs). The average IRI of each of the three repeat runs were then correlated to the average of each of the five WSV runs using a linear regression model of the form $IRI = Log(WSV+1)^{0.2}$.

No significant difference was noted between locations of the accelerometers and the two accelerometer types for the accelerometer placements considered in the experiment. The results are given in Table 2 and the corresponding IRI vs. WSV regression plots illustrated in Figures 9 to 15.

Table 1. Summary of Correlations between IRI and WSV.

Statistics	acc – 1	acc – 2	Acc - 3	acc - 4	acc – 5	acc – 6	acc – 7
RSQ	0.935228	0.95332	0.942967	0.935336	0.947338	0.941501	0.95025
STD ERR	0.342135	0.290448	0.321045	0.34185	0.308497	0.325144	0.299848

Table 2. Sensor Type and Location.

Accelerometer	Position
1 - (filtered 50Hz)	Under Axle
2 - (filtered 50Hz)	Back of Van
3 - (filtered 50Hz)	Front of Van
4 - (unfiltered)	Under Axle
5 - (unfiltered)	Back of Van
6 - (unfiltered)	Front of Van
7 – Columbia Research	Back of Van

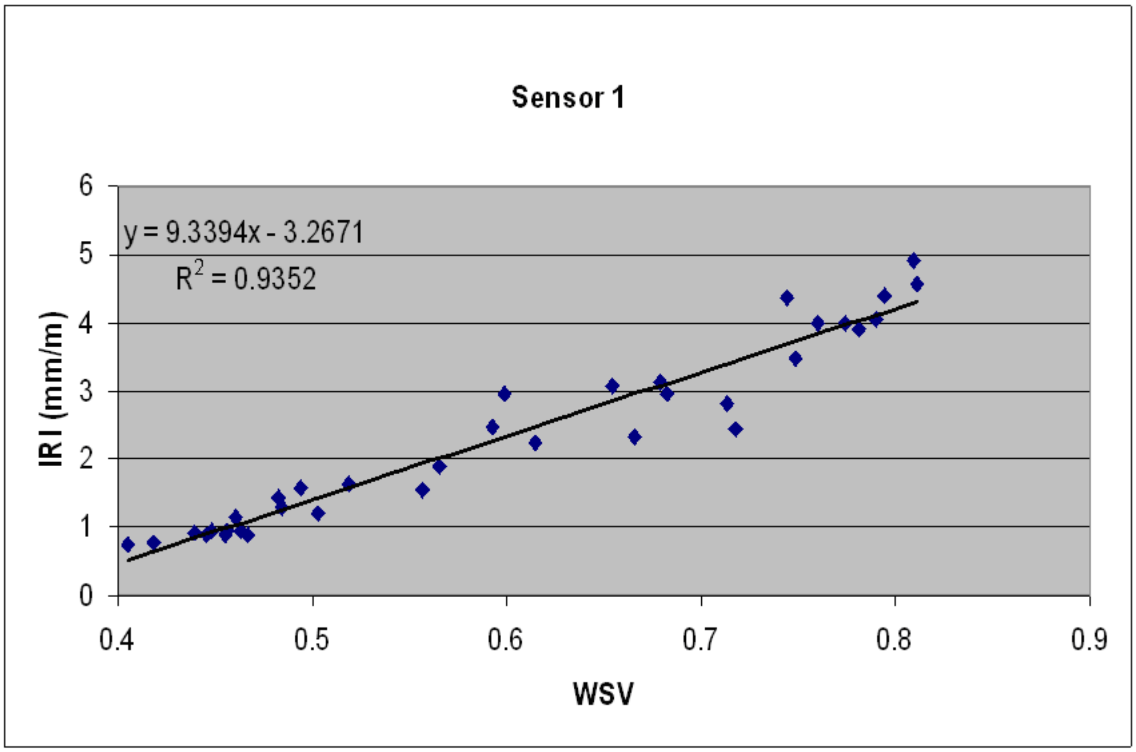

Figure 9. Plot of Correlation between IRI and WSV – Sensor Placement 1.

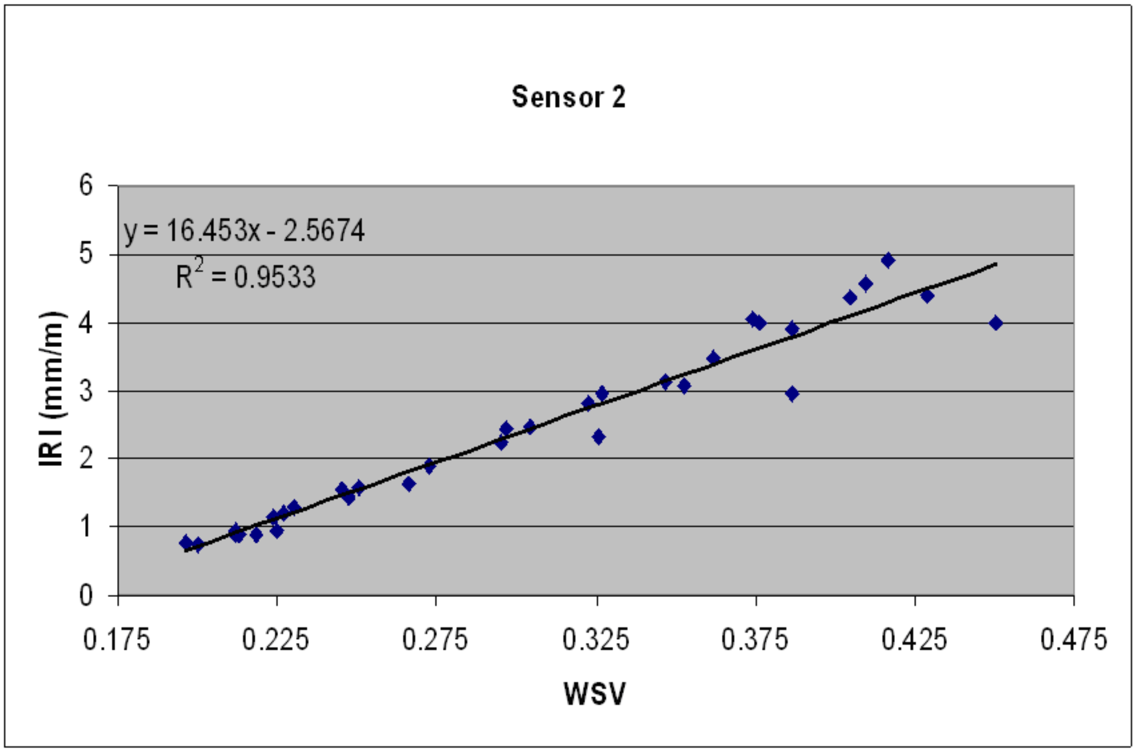

Figure 10. Plot of Correlation between IRI and WSV – Sensor Placement 2.

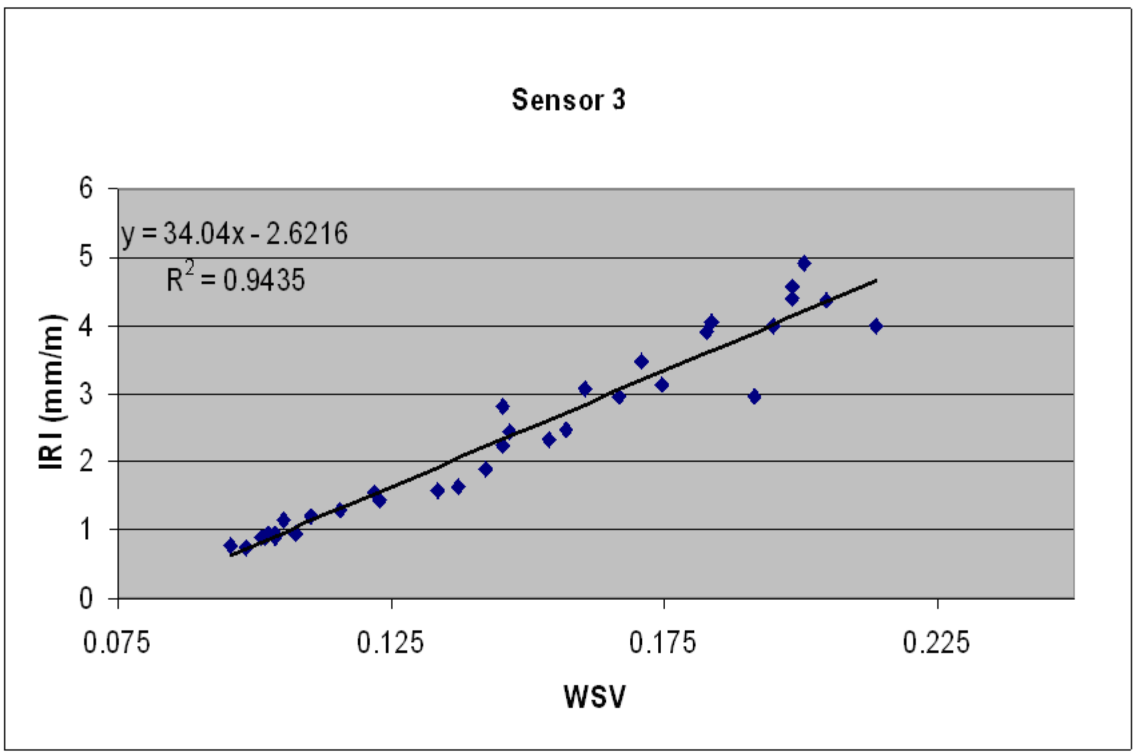

Figure 11. Plot of Correlation between IRI and WSV – Sensor Placement 3.

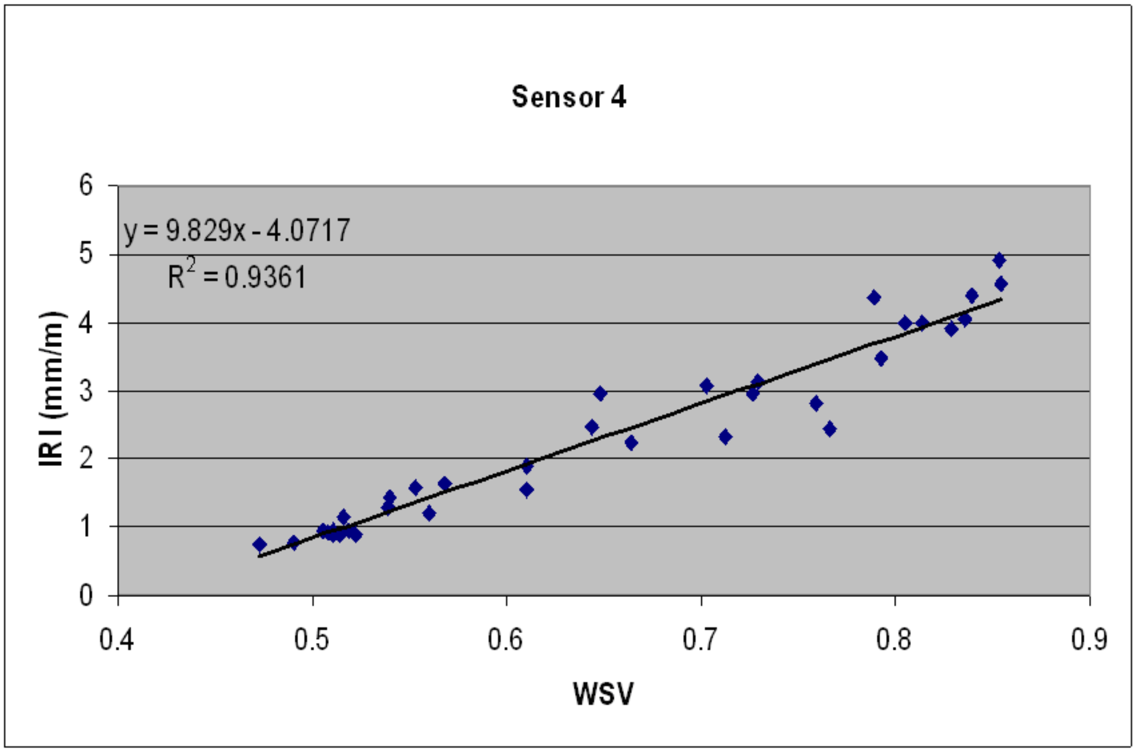

Figure 12. Plot of Correlation between IRI and WSV – Sensor Placement 4.

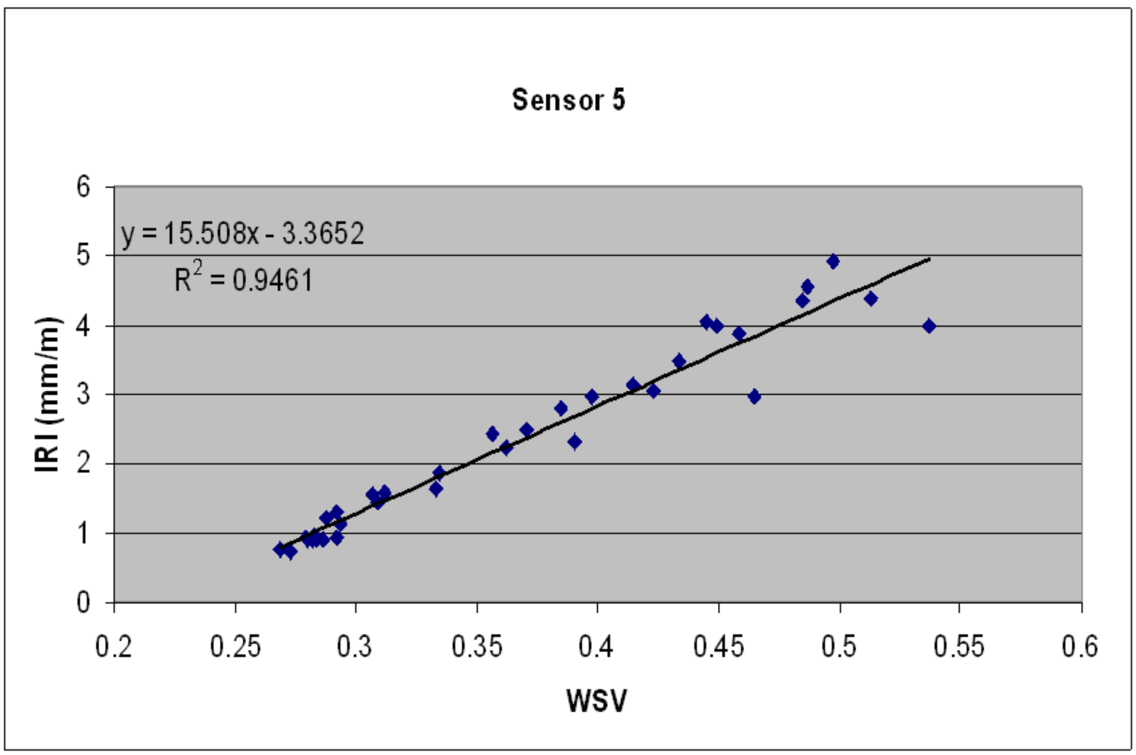

Figure 13. Plot of Correlation between IRI and WSV – Sensor Placement 5.

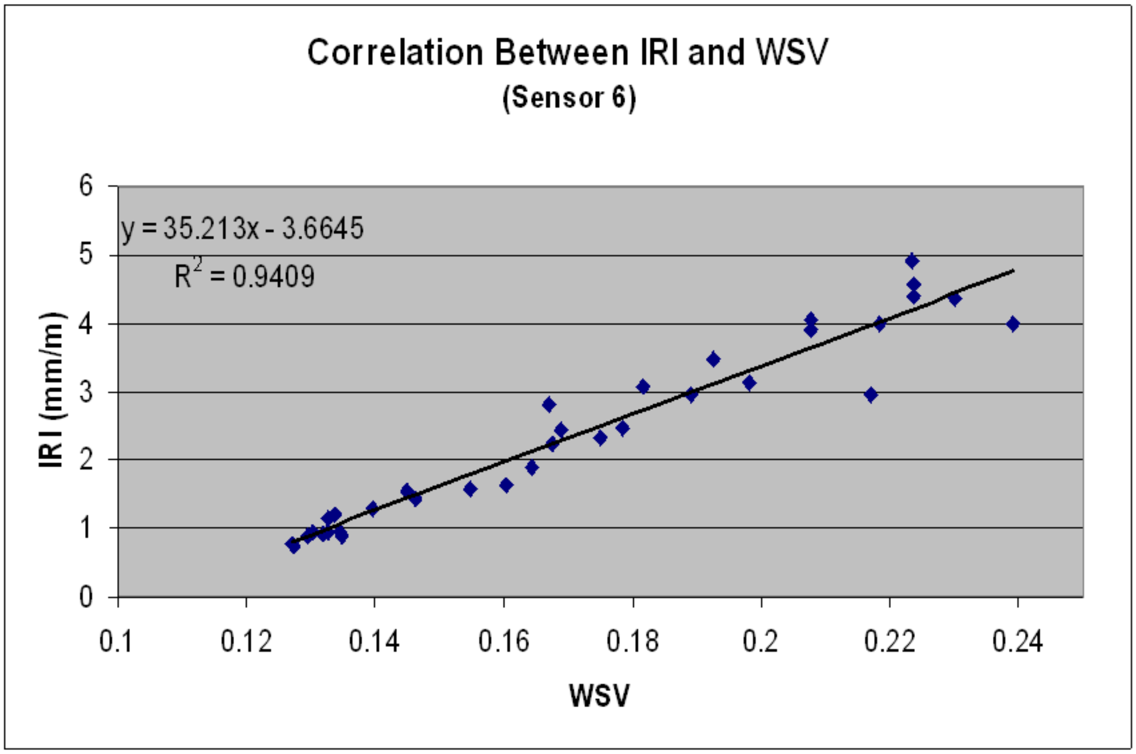

Figure 14. Plot of Correlation between IRI and WSV – Sensor Placement 6

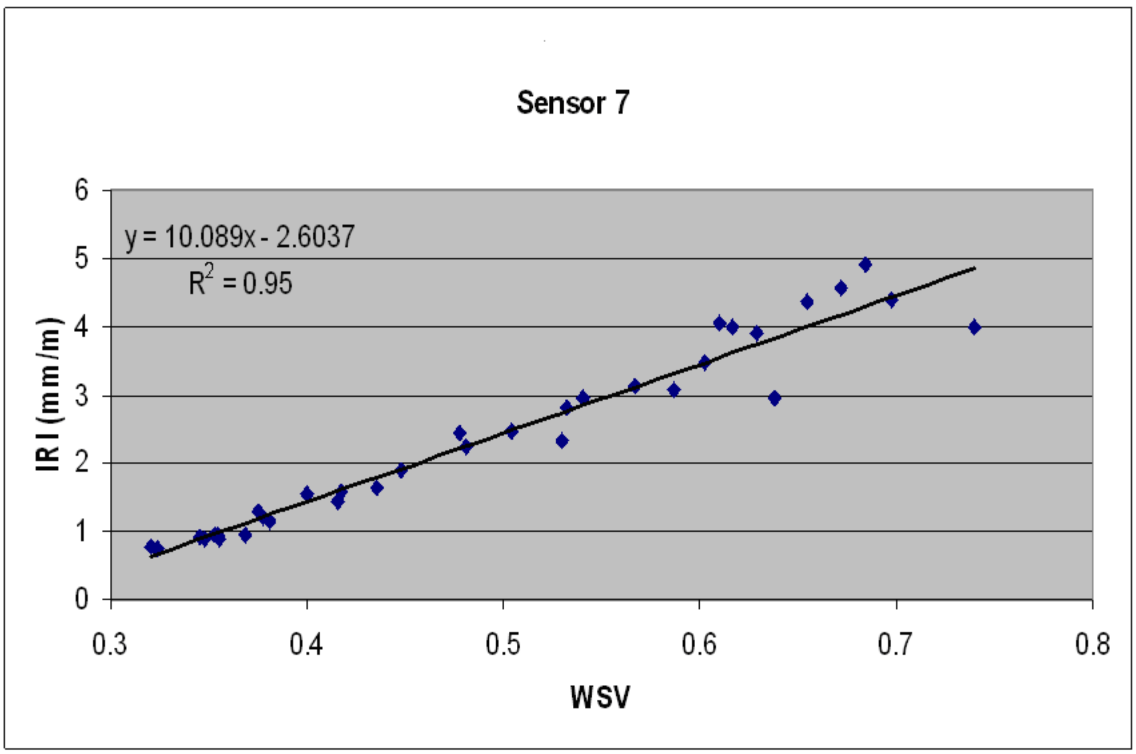

Figure 15. Plot of Correlation between IRI and WSV – Sensor Placement 7.

As indicated, researchers observed no significant differences in the results for the sensor placements and accelerometer types considered in the experiment. In this evaluation, the two computation procedures were different in that they did not combine laser readings and accelerometer measurements to measure profile. Also, the sensors were not located on the front and rear bumpers. However, the results did seem to indicate that measurements of the vertical vehicle body movement could be accomplished in the locations investigated, and perhaps with the less expensive accelerometers. However, without actually testing in a profiler, actual performance is unknown. The instrument module used for the portable profiler and described later in this report accommodates both the Analog Devices (AD) and Columbia Research Labs accelerometers so data from both sensors can be obtained for comparisons.

PORTABLE INSTRUMENT MODULE

Instrument Module

A prototype instrument module has been designed and is currently being tested. Figure 16 shows a block diagram of the design concept. The plan is to house all sensors, power, and signal conditioning components inside a module that will be placed on the bumper of the profiler vehicle. The data will be collected from these sensors, converted to digital values and then sent to a notebook PC located in the vehicle. Communications between the sensors and PC will be via a USB cable. The design is very portable, small in size, and contains all laser, accelerometer, power, signal conditioning, and analog to digital components. The instrument package is designed to run off the vehicle's 12 volt power source. Table 3 identifies the sensors and other components in the instrument module while Figure 18 provides the connections between the components. The constructed prototype module is shown in Figure 17. A block diagram of the components for the instrument is provided in Figure 16.

Table 3. Instrument Module Components.

ITEM NO.	COMPONENT
1	USB Connector Mount – DT 9816 to PC
2	Filter Module – SIM Board
3	DT 9816 Data Translation A/D Module
4	DC-DC Converter – 12v to 24v
5	DC-DC Converter – 12v to 5v, ±15v
6	SLS 5000 Laser
7	4g Accelerometer
8	Laser Connector Breakout
9	Power
10	R1 – 500 ohms

A portable mounting apparatus has been obtained for initial testing which can easily be attached to most vehicles (see Figure 19). This apparatus is very flexible and may be attached to the front, rear, or side of most vehicles. During the second year of this project, researchers will investigate the feasibility of using this mounting apparatus and will recommend improvements or other options as warranted. Researchers will also consider mounting systems used by other portable profiler manufacturers.

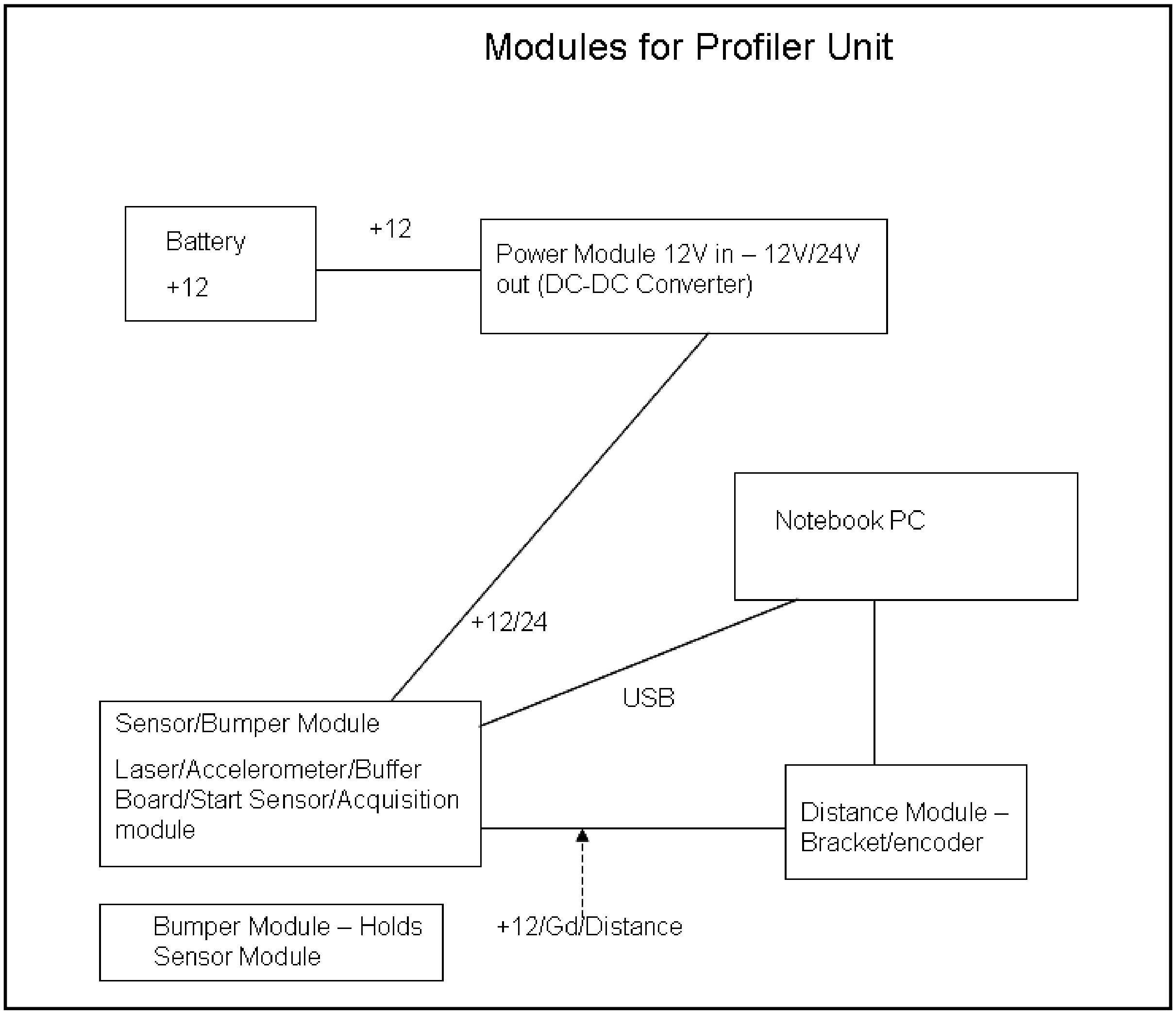

Figure 16. Block Diagram of Portable Profiler Design.

Development of Software Module

The software module in the notebook PC will be a modified version of Ride Console, a program developed on an unrelated project at UTA and which is currently being used in both TxDOT's and TTI's profilers. This package provides an output format consistent with the TxDOT VNET protocol and has been tested in both TxDOT and TTI profilers to provide data that complies with the profiler certification requirements given in TxDOT Test Method Tex-1001S. The modifications that might be necessary will be to accommodate portability issues. More details on this software will be provided in the final project report.

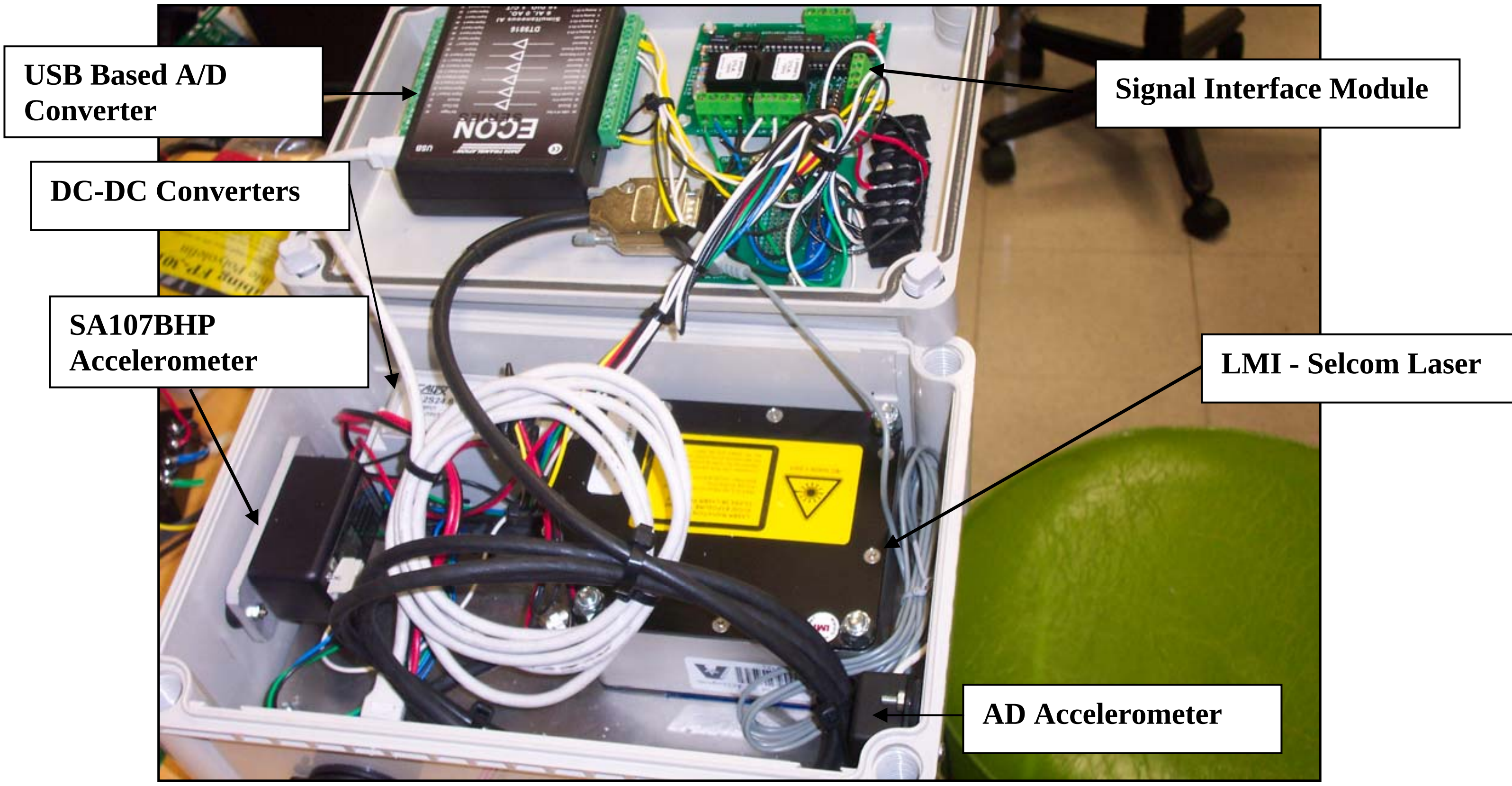

Figure 17. Profiler Instrument Package.

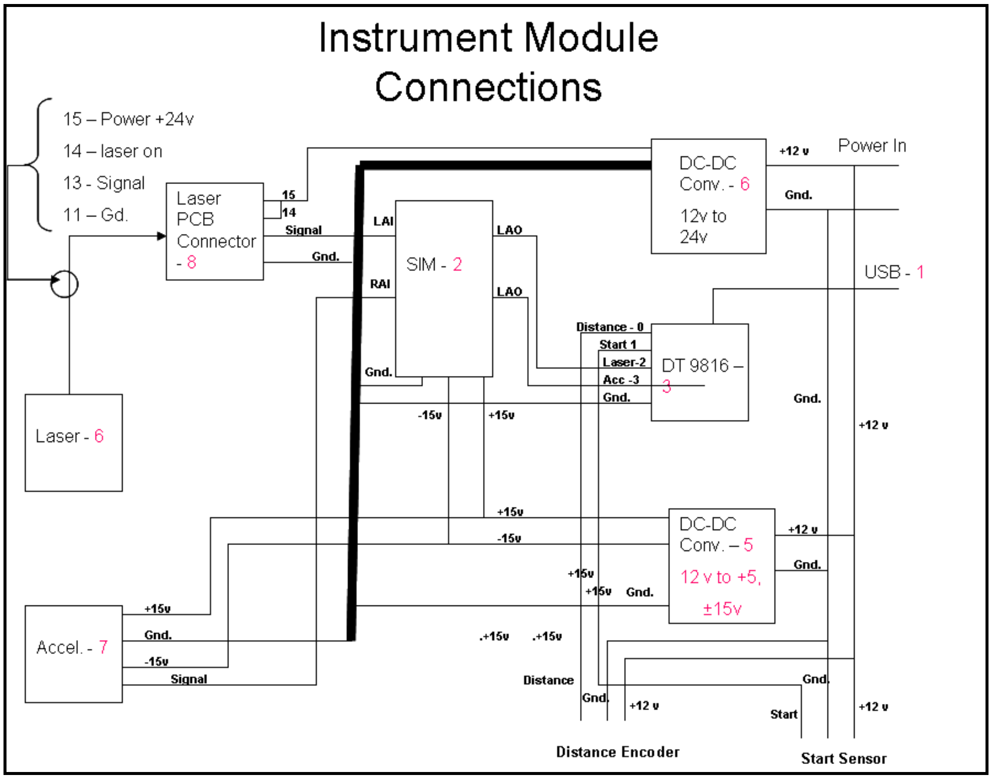

Figure 18. Instrument Module Connections.

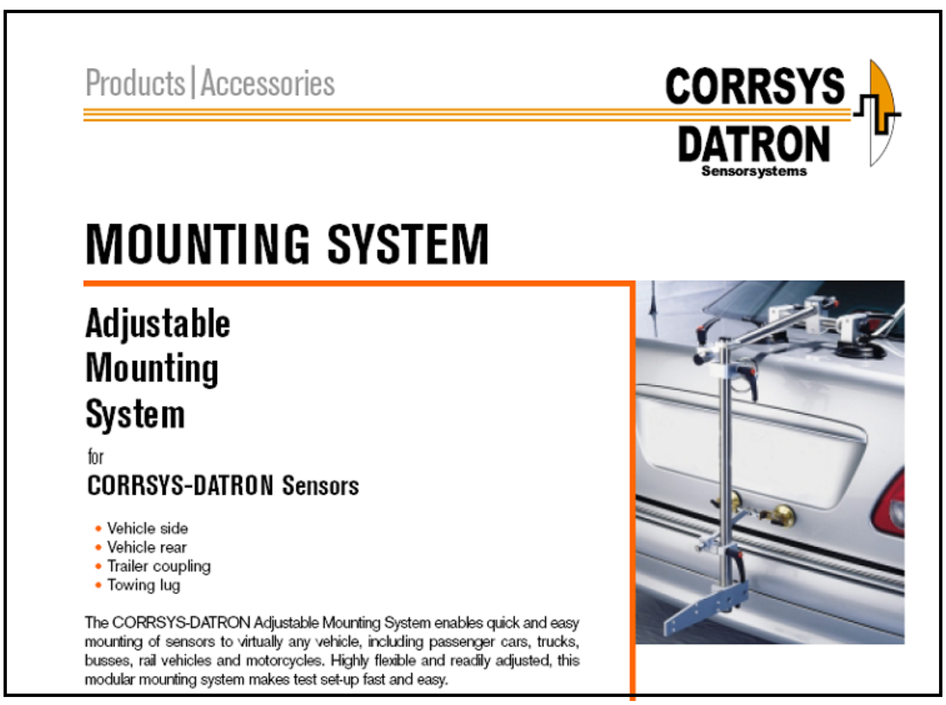

Figure 19. Option for Mounting Instrument Module to Test Vehicle.

INITIAL TESTING OF PROTOTYPE PROFILER MODULE

Researchers established two test sections on SH47 in Bryan and SH6 south of College Station to check the performance of the prototype profiler module illustrated in Figure 17 of this interim report. The section on SH47 is hot-mix asphalt while the one on SH6 is continuously reinforced concrete pavement. Each section is located along the shoulder adjacent to the northbound outside lane of the given highway. On each section, researchers collected reference profile measurements along the middle of the section using the Walking Profiler and rod and level. Researchers collected reference profile elevations over a distance of 1140 ft on each section in accordance with TxDOT Test Method Tex-1001S. These measurements produced reference profiles at 2.375-inch intervals on each section. Figures 20 and 21 show the reference profile measurements collected on the sections. Researchers made three repeat measurements (runs A, B, and C) on each section as shown in these figures.

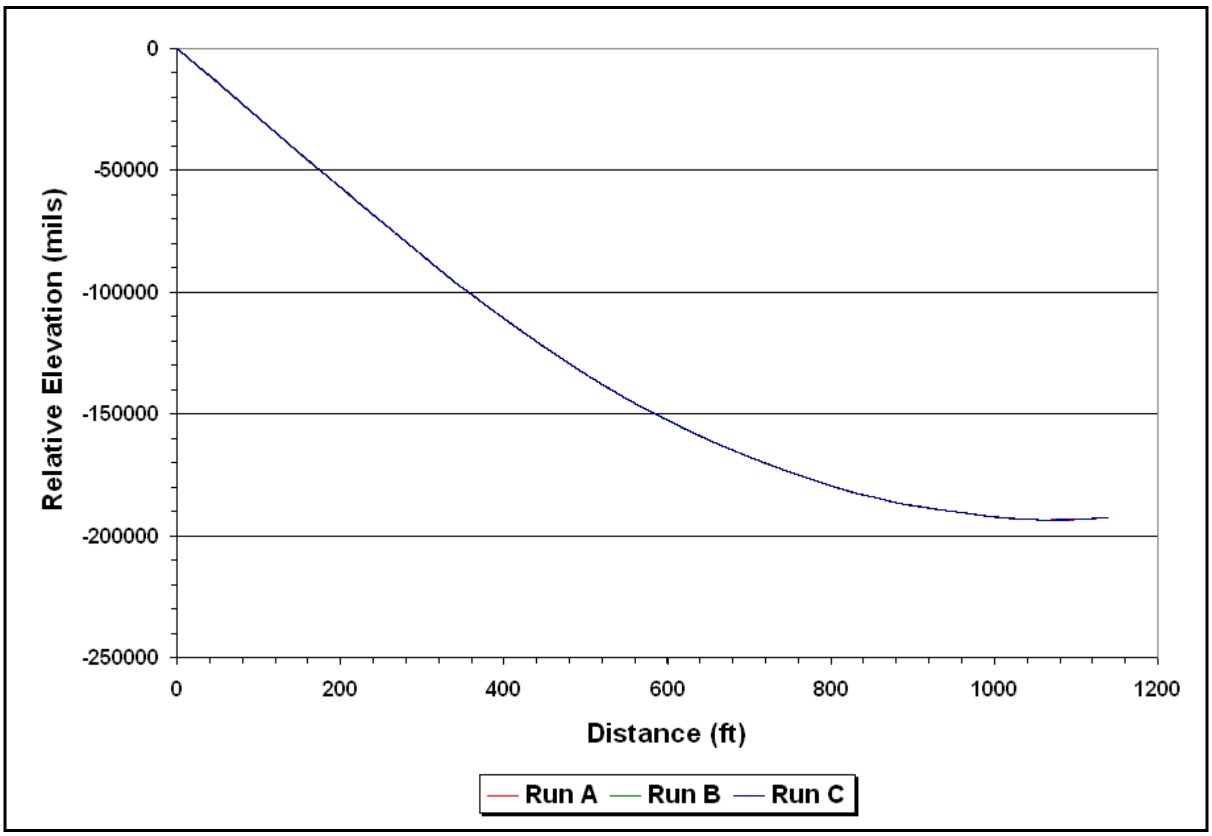

Figure 20. Unfiltered Reference Profiles on SH6 CRCP Section.

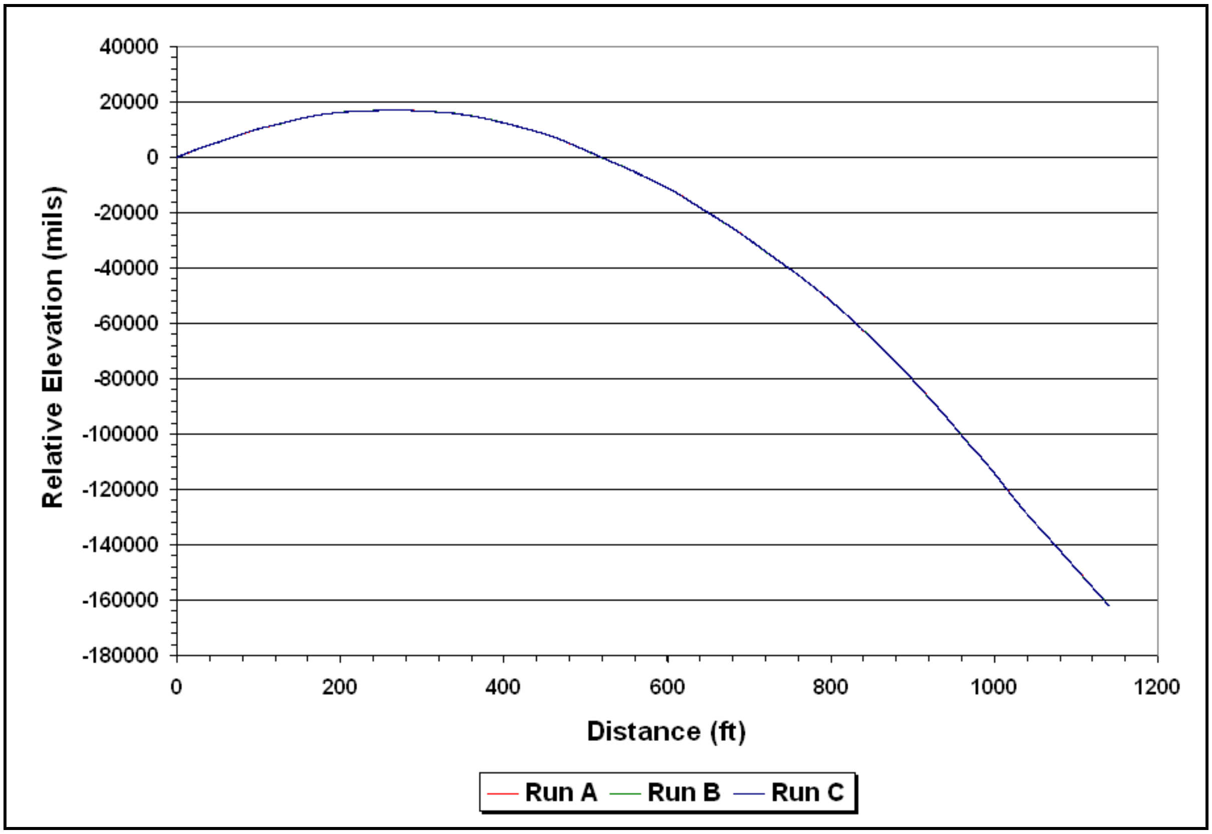

Figure 21. Unfiltered Reference Profiles on SH47 Hot-Mix Asphalt Section.

The 1140-ft distance over which researchers measured reference profiles provides sufficient lead-in and lead-out intervals for verifying the accuracy of inertial profile measurements based on the requirements given in Tex-1001S. Within this interval, researchers established a 528-ft test segment beginning 306 ft from the start of each section on which measurements with the prototype profiler module were collected. To gauge the repeatability of the reference profiles over each 528-ft test segment, researchers determined the cross-correlations between repeat measurements using the Federal Highway Administration's ProVAL software (*4*). Table 4 shows the cross-correlation coefficients from pairwise comparisons of replicate IRI-filtered reference profiles on the SH6 and SH47 sections. The cross-correlation coefficients are all above 90 percent indicating good repeatability between the IRI-filtered reference profiles. Moreover, the cross-correlation coefficients are consistent across the pairwise comparisons for a given segment. Table 5 shows the IRIs determined from the unfiltered reference profiles on the 528-ft test segments established along SH6 and SH47.

Table 4. Cross-Correlations between IRI-Filtered Reference Profiles.

Highway Segment	Pairwise Comparison	Cross-Correlation Coefficient (percent)
SH6 (CRCP)	A vs. B	91.1
	B vs. C	90.5
	A vs. C	91.6
SH47 (HMAC)	A vs. B	95.4
	B vs. C	95.9
	A vs. C	95.3

Table 5. IRIs Computed from Unfiltered Reference Profiles.

Highway Segment	Replicate Run	IRI (inches per mile)
SH6 (CRCP)	A	50.7
	B	51.7
	C	51.1
SH47 (HMAC)	A	39.0
	B	38.4
	C	38.4

Researchers mounted the prototype profiler module on the test vehicle as illustrated in Figure 22. Prior to testing, researchers ran laser, accelerometer, and distance calibrations to input into the configuration file of the modified Ride Console data collection program provided by UTA. Researchers then collected inertial profile measurements with the prototype module and processed the data to verify its performance based on the certification requirements specified in Tex-1001S. Figures 23 and 24 show the repeat profile measurements on the test segments while Tables 6 to 9 summarize the test statistics from this evaluation. The results are quite encouraging. The prototype profiler module met all test criteria prescribed in Tex-1001S. However, more tests should be conducted on other test vehicles to verify the portability of this module. Thus, more verification work is planned.

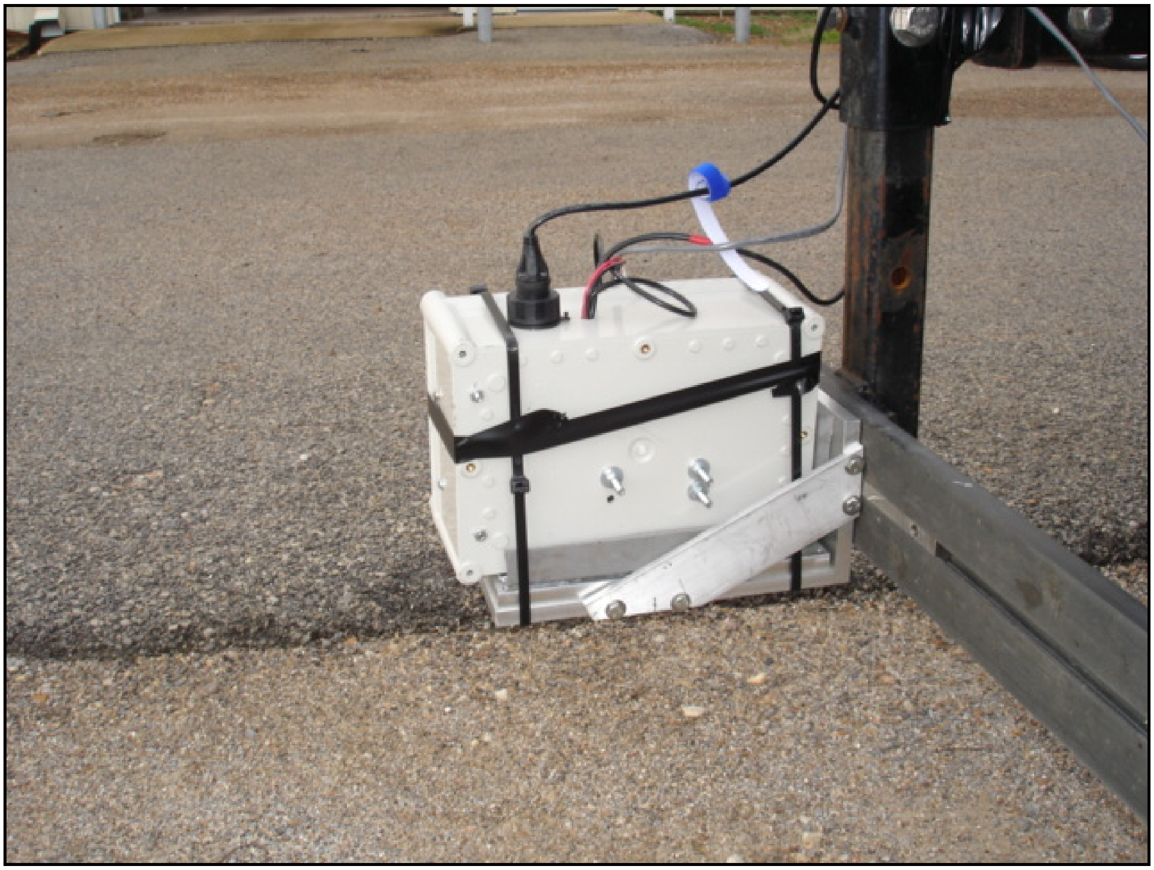

Figure 22. Prototype Profiler Module Mounted in Front of Test Vehicle.

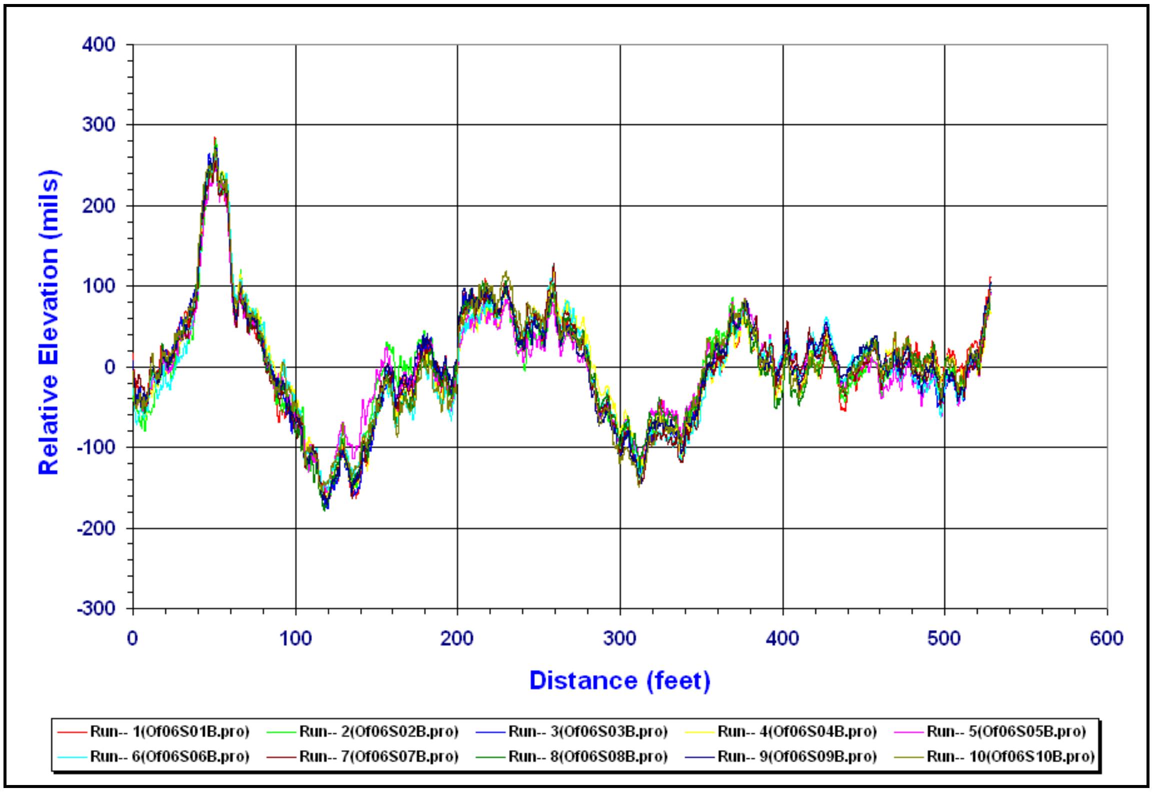

Figure 23. Repeatability of Inertial Profile Measurements on SH6 Test Segment.

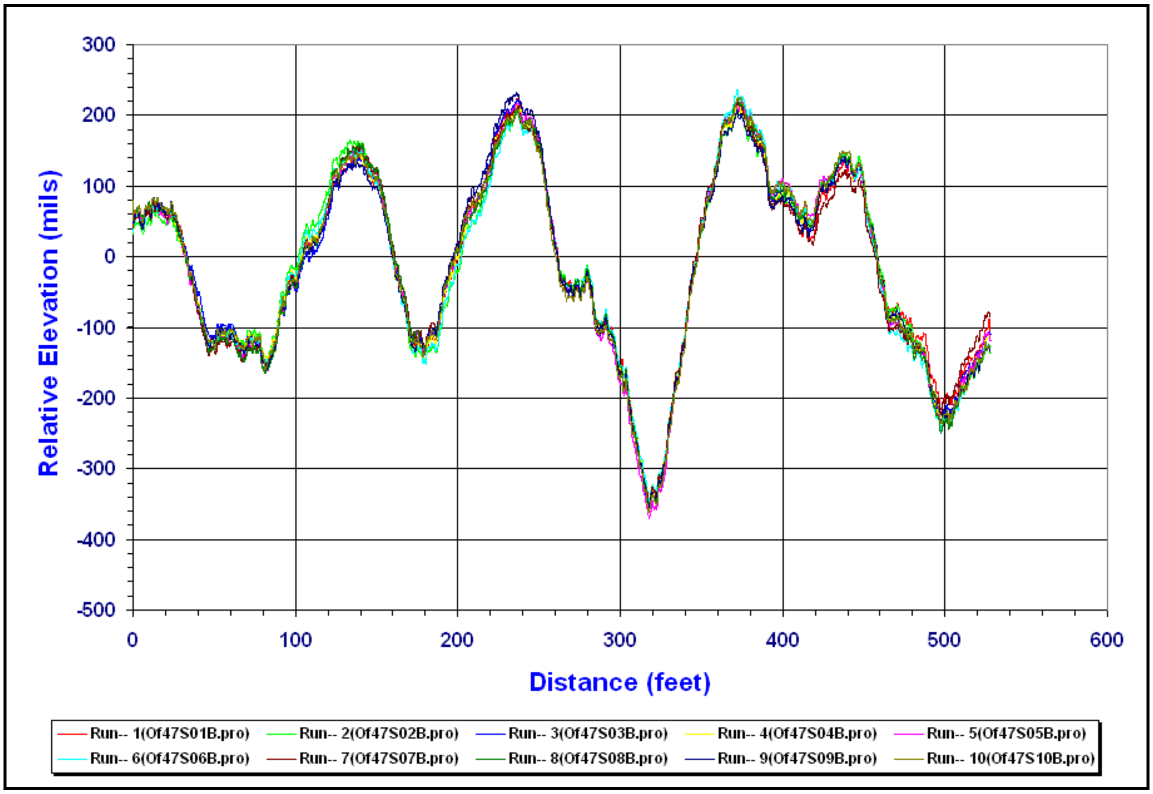

Figure 24. Repeatability of Inertial Profile Measurements on SH47 Test Segment.

Table 6. Repeatability of Profile Measurements from Test Module.

Section	Average Standard Deviation (mils)[1]
SH6	12
SH47	9

Table 7. Repeatability of IRIs from Test Module Profile Measurements.

Section	Standard Deviation (inches/mile)[2]
SH6	1.32
SH47	0.51

Table 8. Accuracy of Profile Measurements from Test Module.

Section	Average Difference (mils)[3]	Average Absolute Difference (mils)[4]
SH6	-1	11
SH47	0	18

Table 9. Accuracy of IRIs from Test Module Profile Measurements.

Section	Difference between Averages of Test and Reference IRIs (inches/mile)[5]
SH6	-5.23
SH47	-3.65

[1] Not to exceed 35 mils per TxDOT Test Method Tex-1001S
[2] Not to exceed 3.0 inches/mile per TxDOT Test Method Tex-1001S
[3] Must be within ±20 mils per TxDOT Test Method Tex-1001S
[4] Not to exceed 60 mils per TxDOT Test Method Tex-1001S
[5] Absolute difference not to exceed 12 inches/mile per TxDOT Test Method Tex-1001S

REPORT SUMMARY

This interim report has provided details on progress made during the first part of Project 0-6004, Development of a Portable Profiler. The project was initiated to develop a single path, easy to use, portable profiler that can provide profile data or IRI values. The desired profiler module is being designed and developed to provide TxDOT a unit that can easily be mounted or removed from the front or rear bumper of the typical TxDOT vehicles for profile measurements. The profile generated is to be compatible with existing TxDOT formats.

During this first year of the project, initial investigations and analysis of road profiling methods, and sensors used for these measurements have been performed. Laser, accelerometer, and other equipment have been obtained for constructing the portable instrument module. A candidate portable attachment apparatus was purchased. A prototype portable instrument module for profile measurements has been constructed and is currently being tested. Two road sections were established in Bryan/College Station on which researchers collected reference profile data. These sections were used in the initial testing of the prototype profiler module. The initial test results showed that the module provided profiles that met the certification requirements given in TxDOT Test Method Tex-1001S.

During the second year of the project, the issues of collecting high speed profile data from the portable instrument will be addressed. Module simulations will be investigated as needed for a robust profiling procedure. A major objective of these investigations is to come up with a certification-ready portable profiling system for testing at the profiler certification track located within the Texas A&M Riverside Campus. The desired outcome is a portable profiling system that has been demonstrated to meet TxDOT's Tex-1001S certification requirements.

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