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16. Abstract

This report provides a summary of work performed on Texas Department of Transportation (TxDOT) Research Project 0-6004. The project was initiated to develop a single path, easy to use, portable profiler. Such a device was developed. The profiler measurements from the device provide TxDOT an instrument that can easily be mounted or removed from the front or rear bumper of typical TxDOT vehicles. The Profile generated is compatible with existing TxDOT formats. Two separate certification tests were successfully conducted on both a full-size TTI pickup truck and a TxDOT full-size van at the inertial profiler certification track located at the Texas A&M Riverside Campus. The project was 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.

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A PORTABLE PROFILER FOR PAVEMENT PROFILE MEASUREMENTS – FINAL REPORT

by

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and the
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TABLE OF CONTENTS

ACKNOWLEDGMENTS vi
TABLE OF CONTENTS vii
LIST OF TABLES viii
LIST OF FIGURES ix
BACKGROUND AND OBJECTIVES 1
    Introduction 1
    Pavement Profiling Methods 1
PORTABLE PROFILER 2
    Profiler Components: 2
    Instrument Module 3
SOFTWARE DEVELOPMENT 7
    UTA Profiling Method 9
    Phase Removal Techniques 10
    UTA Profiler Program 11
INITIAL TESTING OF PROTOTYPE PROFILER MODULE 15
INVESTIGATION OF ALTERNATIVES FOR MOUNTING PORTABLE PROFILER MODULE 21
CERTIFICATION TESTING OF PORTABLE PROFILER SYSTEM 26
PORTABLE PROFILER COMPARISONS 32
REPORT SUMMARY 35
REFERENCES 37
APPENDIX A 39
    INSTALLATING AND USING THE PORTABLE PROFILER 39

LIST OF TABLES

Table 1. Instrument Module Components. 4
Table 2. Cross-Correlations between IRI-Filtered Reference Profiles. 17
Table 3. IRIs Computed from Unfiltered Reference Profiles. 17
Table 4. Repeatability of Profile Measurements from Test Module. 20
Table 5. Repeatability of IRIs from Test Module Profile Measurements. 20
Table 6. Accuracy of Profile Measurements from Test Module. 20
Table 7. Accuracy of IRIs from Test Module Profile Measurements. 20
Table 8. Profile Repeatability with Suction Cup Mounts. 25
Table 9. IRI Repeatability with Suction Cup Mounts. 25
Table 10. Profile Accuracy with Suction Cup Mounts. 25
Table 11. IRI Accuracy with Suction Cup Mounts. 25
Table 12. Profile Repeatability from Certification Tests. 31
Table 13. IRI Repeatability from Certification Tests. 31
Table 14. Profile Accuracy from Certification Tests. 31
Table 15. IRI Accuracy from Certification Tests. 31
Table 16. Projects Tested for Comparative Evaluation of Portable Profilers. 33
Table 17. 95 Percent Confidence Intervals of IRI Differences. 35

LIST OF FIGURES

Figure 1. LMI's Selcom Road Lasers (from LMI sales literature). 3
Figure 2. Distance Measuring Assembly Used on TTI Profiler....4
Figure 3. Block Diagram of Portable Profiler Design. 5
Figure 4. Printed Circuit Board for Portable Profiler Signal Interface 6
Figure 5. Signal Interface Board Schematic 7
Figure 6. Profiler Instrument Package. 8
Figure 7. Connecting the Profiler Instrument Module....9
Figure 8. UTA Profile Computation Process....10
Figure 9. Results of Applying a Reverse Filter to a Filtered Signal 11
Figure 10. Part A of UTA-Profiler Program Flow Diagram....13
Figure 11. Part B of UTA-Profiler Program Flow Diagram....14
Figure 12. Unfiltered Reference Profiles on SH6 CRCP Section. 15
Figure 13. Unfiltered Reference Profiles on SH47 Hot-Mix Asphalt Section. 16
Figure 14. Prototype Profiler Module Mounted in Front of Test Vehicle. 18
Figure 15. Repeatability of Inertial Profile Measurements on SH6 Test Segment. 19
Figure 16. Repeatability of Inertial Profile Measurements on SH47 Test Segment. 19
Figure 17. Profiler Module Mounted at Side of Test Vehicle using Suction Cups....22
Figure 18. Profiler Module Mounted at Rear of Test Vehicle using Suction Cups. 23
Figure 19. Profile Repeatability on SH6 Section with Suction Cup Mounting System....24
Figure 20. Profile Repeatability on SH47 Section with Suction Cup Mounting System....24
Figure 21. Portable Profiler System on TTI Full-Size Truck....27
Figure 22. Portable Profiler System on TxDOT Full-Size Van. 28
Figure 23. Profile Repeatability on Smooth Section (TTI Full-Size Truck)....29
Figure 24. Profile Repeatability on Smooth Section (TxDOT Full-Size Van). 29
Figure 25. Profile Repeatability on Medium Smooth Section (TTI Full-Size Truck). 30
Figure 26. Profile Repeatability on Medium Smooth Section (TxDOT Full-Size Van)....30
Figure 27. Test Setup for Comparative Evaluation of Portable Profilers. 33
Figure 28. Comparison of Portable Profiler IRIs on SH6 CRCP Project. 33
Figure 29. Comparison of Portable Profiler IRIs on SH6 PFC Project....34
Figure 30. Comparison of Portable Profiler IRIs on SH21 Project (Type C Surface). 34
Figure 31. Comparison of Portable Profiler IRIs on SH47 Project (Type D Surface). 35

BACKGROUND AND OBJECTIVES

Introduction

TxDOT Research Project 0-6004 was initiated to develop a single path, easy to use, portable profiler. The project was 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. During the project such a device was developed, tested, and profile from the device verified. The profiler module provides 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 compatible with existing TxDOT formats. This report provides a description of the portable profiler developed for the project, including its design and initial testing, comparison runs, and verification. The report includes descriptions of the sensors used, the portable profiler construction and use. An appendix includes operational instruction and other information for mounting and using the device. Interim project report, 'Project 0-6004, Development of a Portable Profiler Interim Report' was published in May of 2009. The research plan as well as other project information was documented in the interim project.

Pavement Profiling Methods

Two generally known profiling methods or derivations of these methods are commonly used by today's profilers. Further details of these methods are described in the interim report mentioned above. The first method was developed by Elson Spangler and William Kelly in the early 1960s. The method 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 $(W\text{-}M)_m$ with respect to the road is determined by a laser mounted with the laser measurement beam perpendicular to the road surface. 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

The second method, a variation of the first method, was developed by David Huft of the South Dakota Department of Transportation (SDDOT). This method use a similar procedure but with a time-based profiling algorithm. For the Huft method, the vehicle mass acceleration, $\ddot{Z}_m$, and road-body displacement (W-M) are sampled with respect to time. The mass acceleration is then integrated with respect to time and added to the time sampled road-body displacements. Both the Spangler and Huft

methods use a filtering process to attenuate the low frequencies or long wavelengths measured by the accelerometer. Because of the success of this system 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. South Dakota did not patent this method, resulting in wide spread usage of this road profiling technology.
The portable profiler developed and described in this report uses a slight variation of the South Dakota method and is described in more detail later in the report. The major components used in the portable profiler are described next.

PORTABLE PROFILER

Profiler Components:

The portable profiler computes road surface profile with the measurements from the following three sensors:

- 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.

A fourth sensor, an infrared start sensor, is used for automated and precise starting of profile measurements useful for profile verification with known or reference profile and repeatability studies.

The portable profiler developed in this project uses an LMI SLS 5000 laser (Figure 1) for the road-body displacement measurements. A ± 4g Columbia Research SA107BHP accelerometer is used for measuring the vehicle body acceleration measurements. Synchronizing the computed profiles to distance traveled is required for pavement profiler applications. An Accu-Coder 260 encoder is used for this purpose. A portable distance mounting assembly (See Figure 2) was constructed at TTI on the project for easy attachment of the encoder to the measuring vehicle.

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

Instrument Module

A portable instrument module using the sensor components was designed and constructed. The sensors along with power, filter, and other required components in the module are listed in Table 1. Figure 3 provides a block diagram of the relationship between the components. Except for the distance encoder which is attached to the vehicle wheel, all sensors, power, and signal conditioning are housed inside the profiler instrument module that is placed on the front or rear bumper of the profiler vehicle. During measurements, the data collected from these sensors, are converted to digital values and then sent to a notebook PC located in the vehicle for computing profile. All communications between the sensors and PC is done so via a USB cable. A printed circuit board was designed and constructed for the filter and other signal conditioning circuit. The board design and schematic are illustrated in figures 4 and 5 respectively. Figure 6 illustrates the layout of the sensor components discussed in the instrument module. The instrument module is attached to the power, PC (via the USB), distance encoder, and infrared start signal via 4 four connectors as illustrated in Figure 7.

The profiler is portable, small in size, and contains power, laser and accelerometer sensors, signal conditioning, and analog to digital interface components. The unit is designed to run off the vehicle's 12 volt power source.

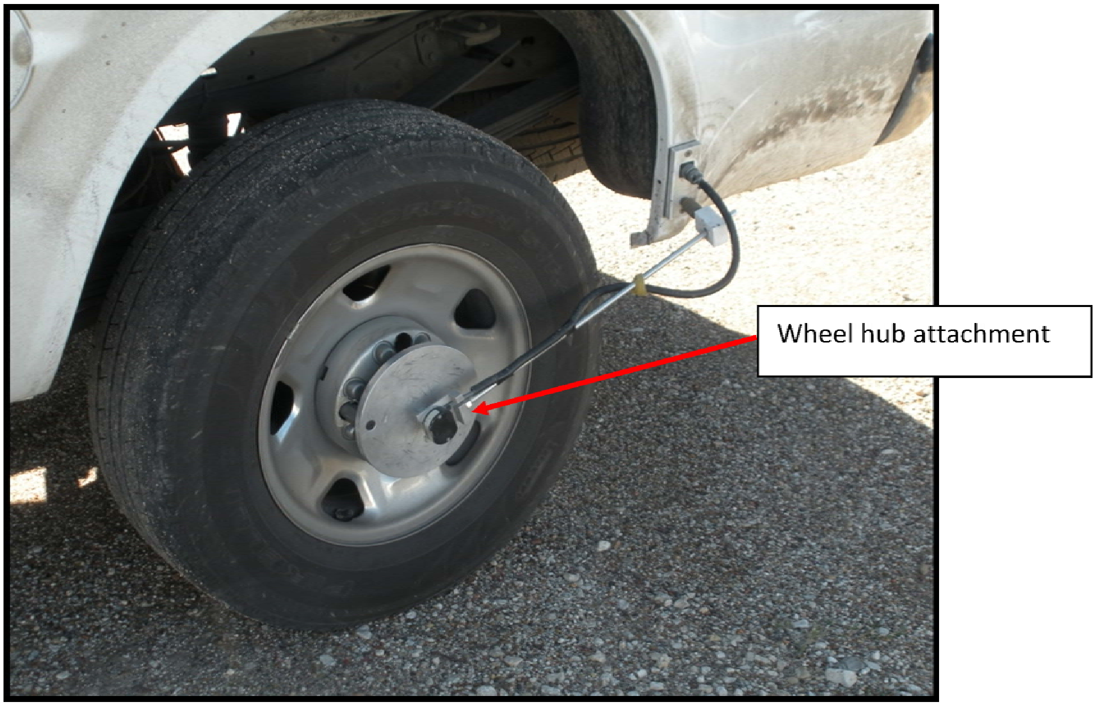

Figure 2. Distance Measuring Assembly Used on TTI Profiler.

Table 1. 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 bar was designed and developed for the instrument module. Alternate mounting procedures were investigated and discussed later in the section Investigation of Alternatives for Mounting Portable Profiler Module.

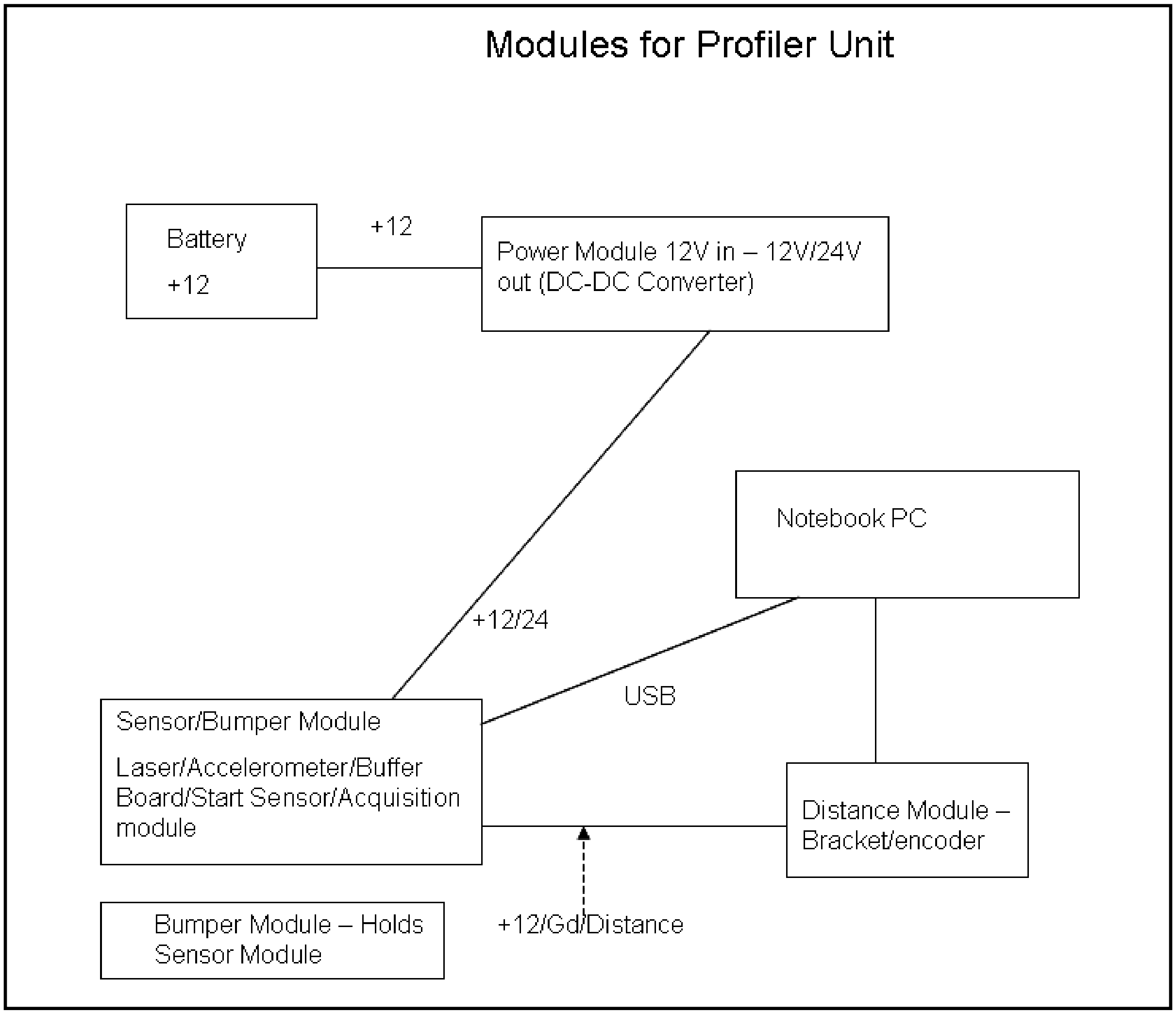

Figure 3 Block Diagram of Portable Profiler Design.

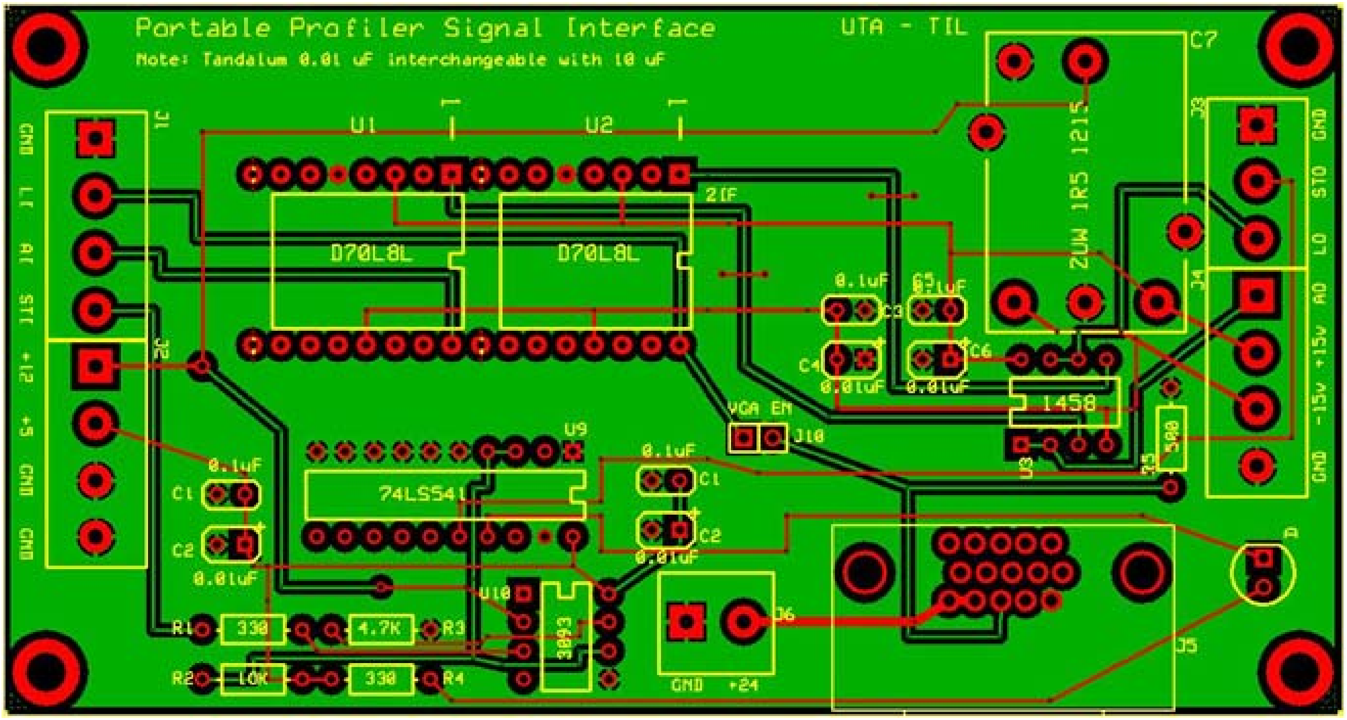

Figure 4 Printed Circuit Board for Portable Profiler Signal Interface

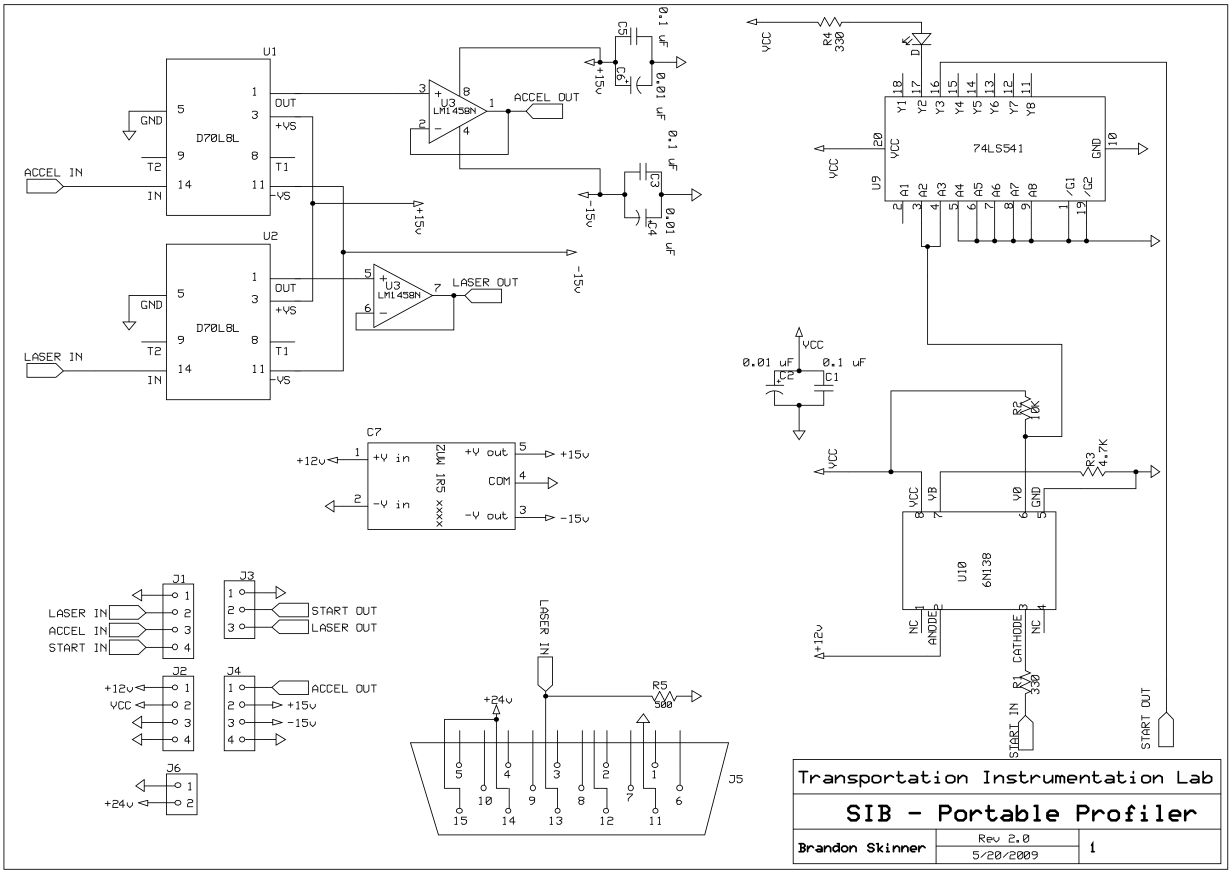

Figure 5 Signal Interface Board Schematic

SOFTWARE DEVELOPMENT

The profiler software or software module is a modified version of the UTA Ride Console program. Ride Console was developed on an unrelated project at UTA and has been used for a number of years on TxDOT's and TTI's profilers for both data collection and certification efforts. Several changes were made to the program for the portable profiler operations. Instructions for running the program are described later in this report. Both the source code and execute modules were made available to TxDOT.

The portable software runs under Windows XP on a notebook PC. The package provides an output format consistent with the TxDOT VNET protocol and has been tested on both TxDOT and TTI profilers to provide data that complies with the profiler certification requirements given in TxDOT Test

Method Tex-1001S. The profile generated from the portable profiler has been used with both TxDOT's Ride Quality software and the FHWA software PROVAL.

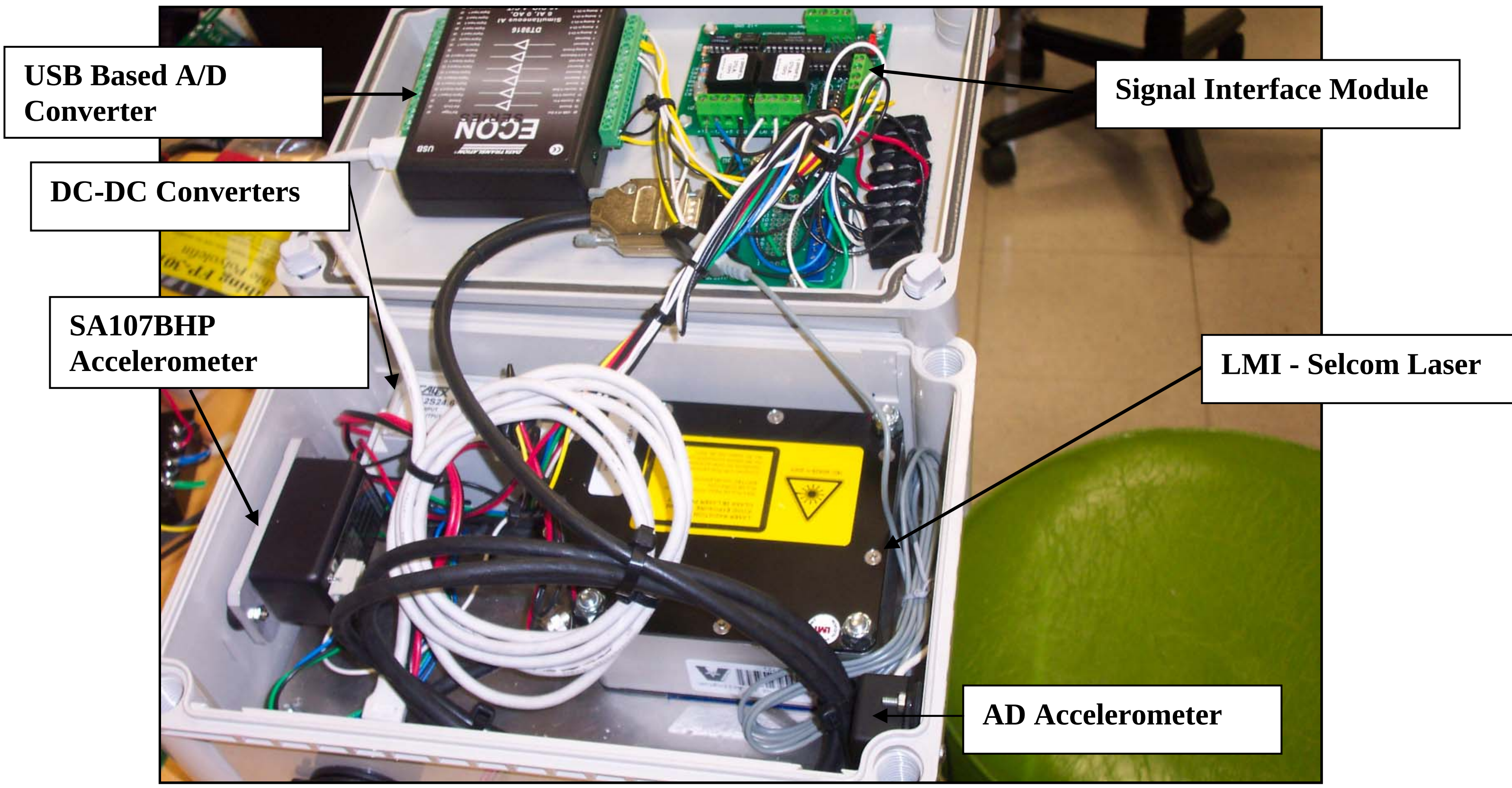

Figure 6 Profiler Instrument Package.

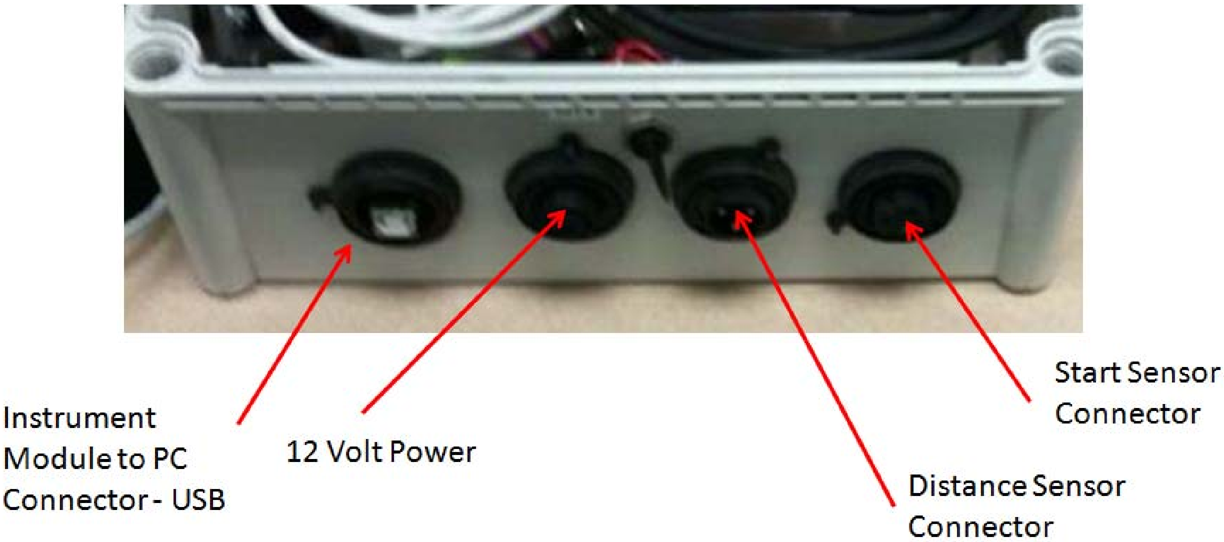

Figure 7 Connecting the Profiler Instrument Module

UTA Profiling Method

As previously discussed, the profiling method used is similar to the South Dakota profiling method. That is both the UTA and South Dakota methods use a time-based profiling algorithm. There are three sensors typically used for computing profile: a laser, an accelerometer, and a distance encoder. The orientation of the sensors measuring the body-motion and road-body displacement 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 from the vehicle motion and road-body displacements. The vehicle mass or body acceleration, $\ddot{Z}$, and road-body displacement (W-M) are sampled with respect to time. The body acceleration is then integrated with respect to time and added to the time sampled road-body displacements. A filtering process is used to attenuate the low frequencies or long wavelengths measured by the accelerometer. The UTA method implements a four pole IIR Butterworth cascaded filter, where the first two poles are combined with a recursive time integration process. The coefficients for the Butterworth filter are computed for each time & distance displacements using the bilinear transform. This output is then fed into the second cascaded part of the two pole filter. The laser displacement readings are added to the twice integrated accelerometer readings, W-M, during the filtering process resulting in the profile, or W. The completed process is summarized in the Figure 8.

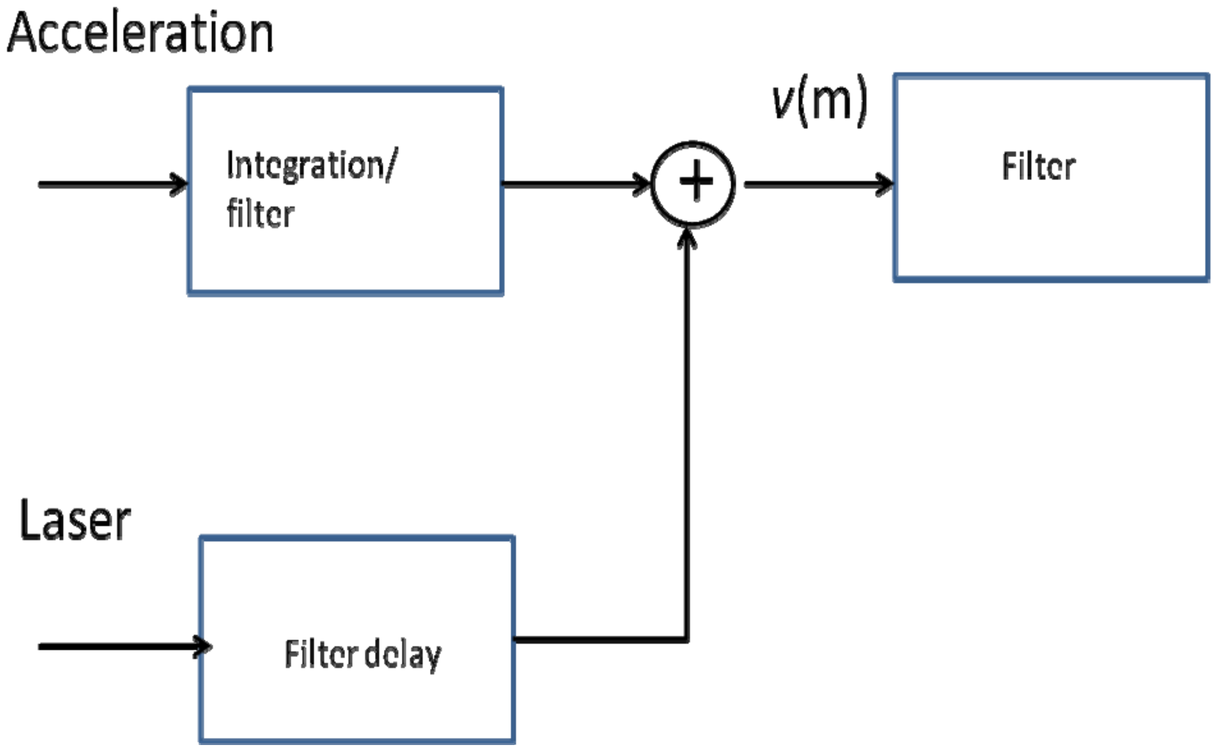

Figure 8 UTA Profile Computation Process

Phase Removal Techniques

As a signal is filtered, both the amplitudes as well as the phase of the frequencies in the stop and transition bands are affected by the filter. If the filter is a linear phase filter, the phase response of the signals is a linear function of frequency. For nonlinear phase filters the fact that the response is not a linear function of the frequency can result in some undesirable characteristics. The UTA profiling procedure uses a Butterworth Infinite Impulse Response (IIR) filter, resulting in a nonlinear phase change during the filtering processing. The nonlinear phase effect results in a distance delay of the frequencies in the profile signal in the stop and transition bands, as well as many of the frequencies in the pass band. A simple illustration of the results of such a nonlinear delay on the frequencies comprising a profile signal, is that the location of some objects, such as bumps or hills, are oriented differently from one another than from their original position. Accounting for such movements in linear phase filters is easily adjusted for as the frequencies comprising a profile signal are simply delayed but maintain their same orientation with respect to each other as in the original unfiltered signal. The effects of the nonlinear phase can also be adjusted by applying the same nonlinear filter used on the original the reverse direction. Figure 9 illustrates and example where the original unfiltered signal is shown in dark blue, the forward filtered signal, shown in light blue, followed by the reverse filter, shown in red. It is easy to note the relationship of the signal peaks in the forward filtered data is not at the same position as in the original data. Notice however, after applying the reverse filter that the peaks are moved to match the original signal, with only the amplitude affected.

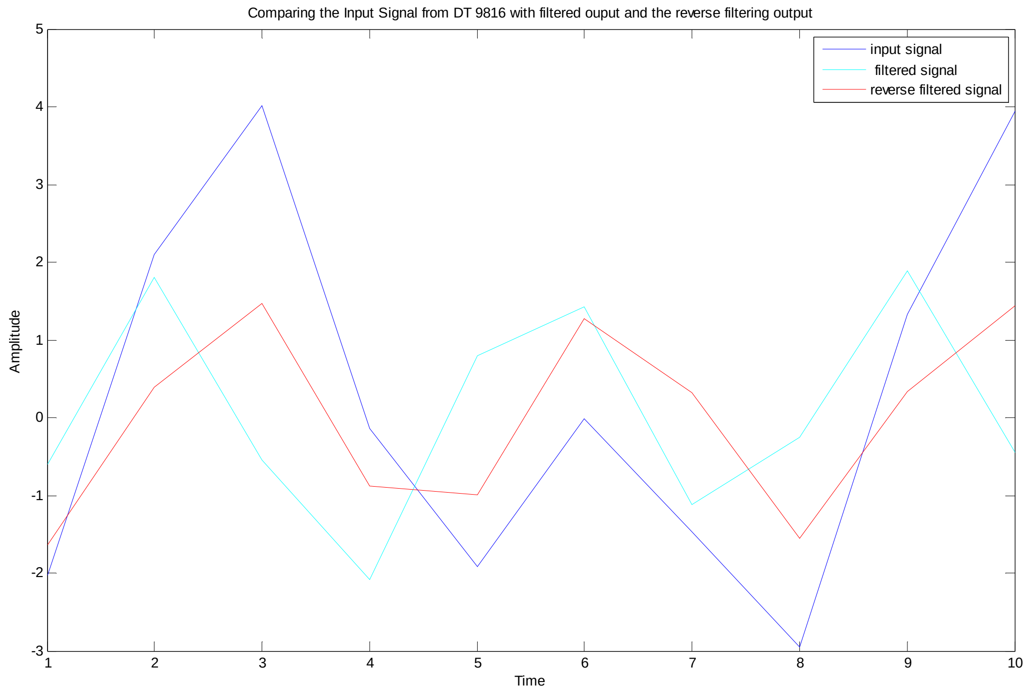

Figure 9 Results of Applying a Reverse Filter to a Filtered Signal

Thus, following the profile computation, a reverse filter should typically be applied to the profile data for project level applications. A separate software package was provided TxDOT for correcting the forward filtered profile data. TxDOT has also recently been supplied a later versions of the profiler software that automatically provides this correction as part of the profiling process.

UTA Profiler Program

As noted above, a C program was written for computing profile from the raw sensors readings obtained from the instrument module discussed earlier. This program, designed to run in real-time, directly interfaces with the Data Translation 9816, located in the instrument module, via the USB port. The program then averages the time digitized sensors readings over each distance interval and computes the profile in accordance to the profile computation method described in the previous section. A flow diagram of the program is illustrated in Figures 10 and 11. Following each computed profile value computed, the data is stored to a disk in accordance to the TxDOT VNet protocol. Typical profiles generated are illustrated in the section, INITIAL TESTING OF PROTOTYPE PROFILER MODULE. The Profile may then be used for post processing. The initial version of the software used a separate program for reverse filtering to correct for the non-linear phase characteristics of the IIR filter used in the profile computational methods. As noted in the previous section later versions, not associated with this project, provide a version of the program that automatically provides the adjusted phase characteristics performed in the reverse filter program. Further details on the program and on using the program are included in the Appendix.

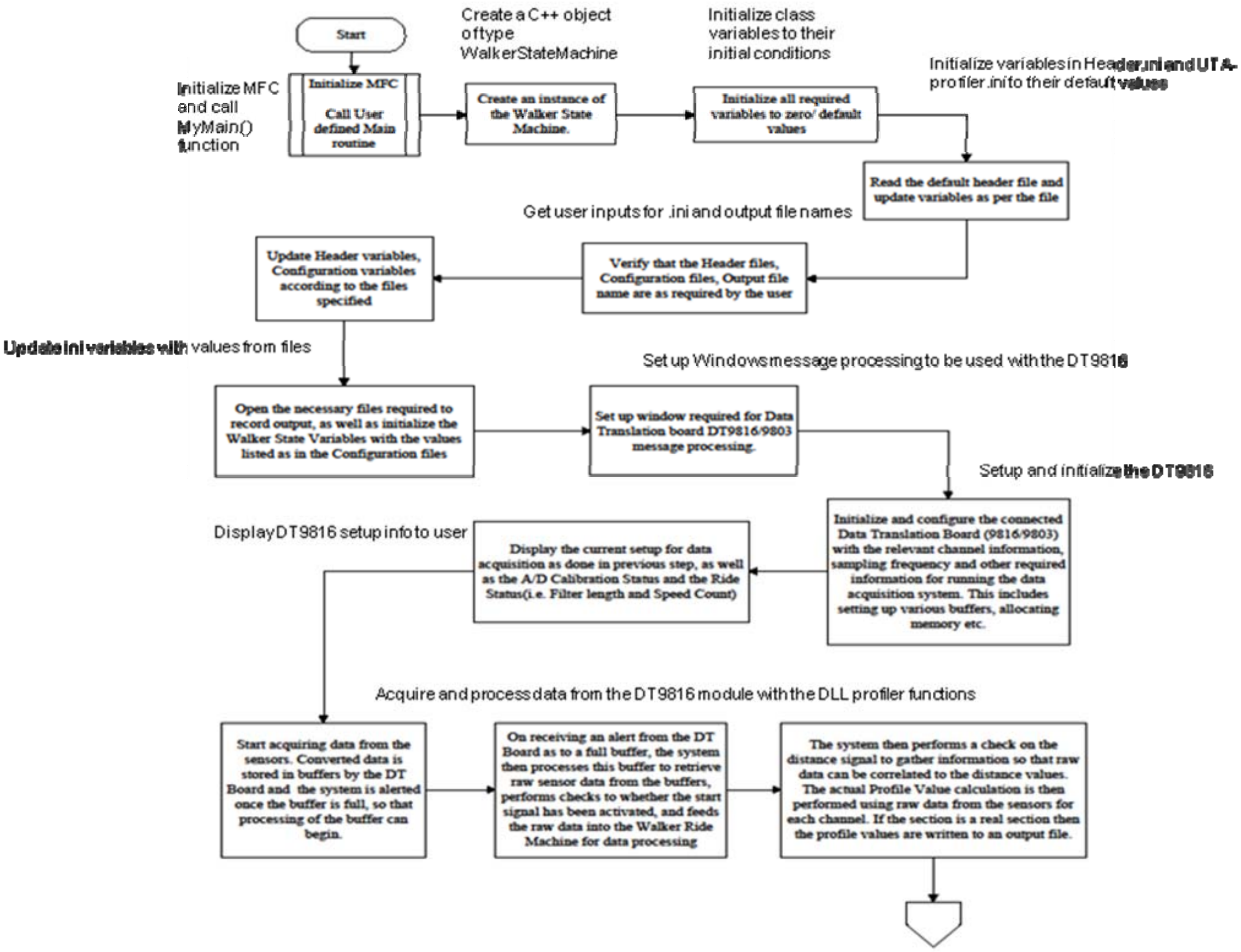

Figure 10, Part A of UTA-Profiler Program Flow Diagram

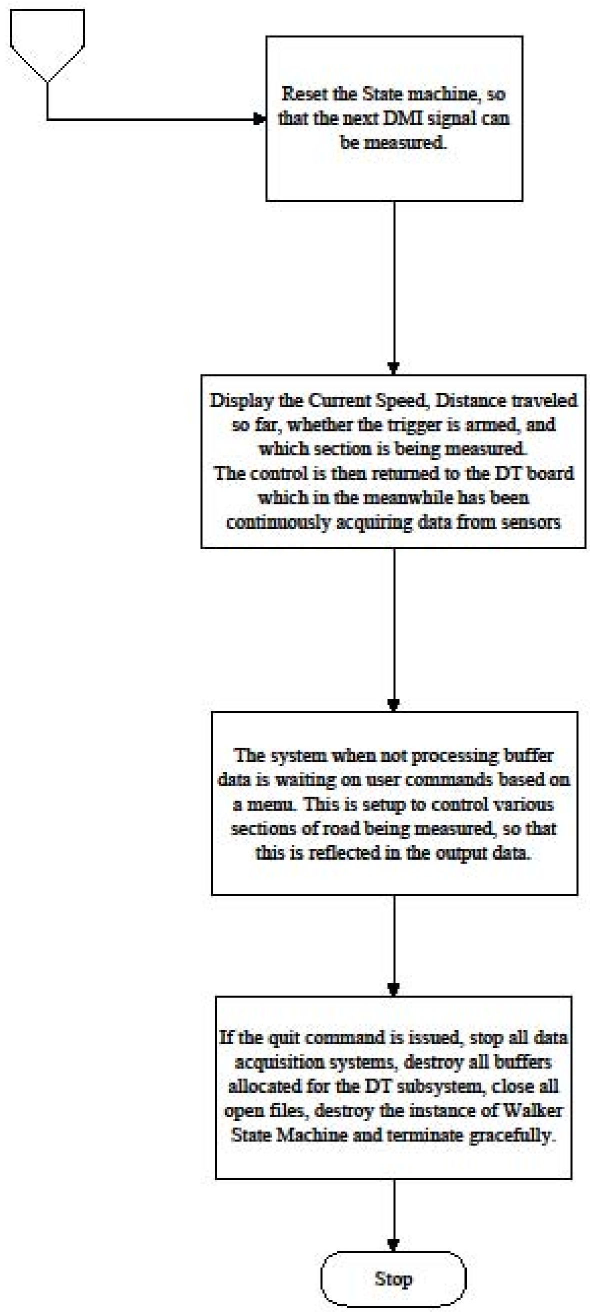

Figure 11, Part B of UTA-Profiler Program Flow Diagram

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 6 of this final 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 12 and 13 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.

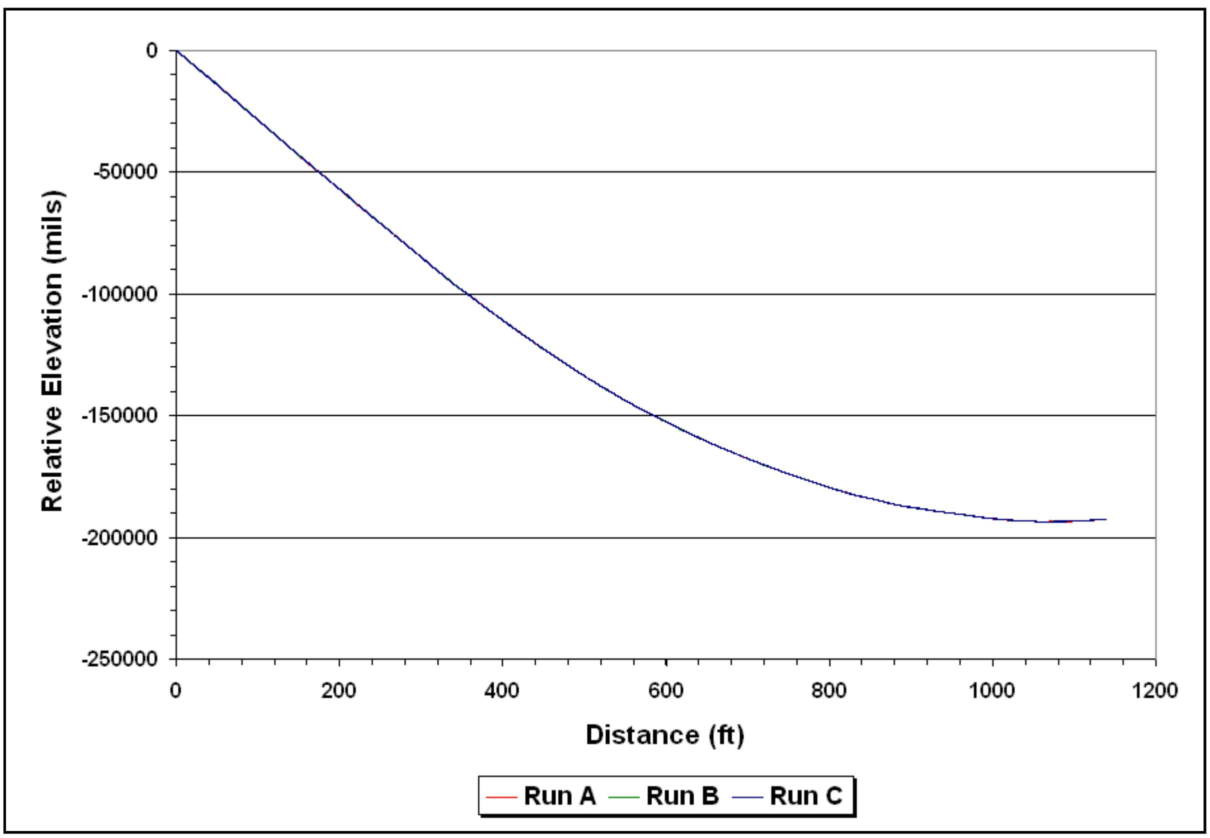

Figure 12. Unfiltered Reference Profiles on SH6 CRCP Section.

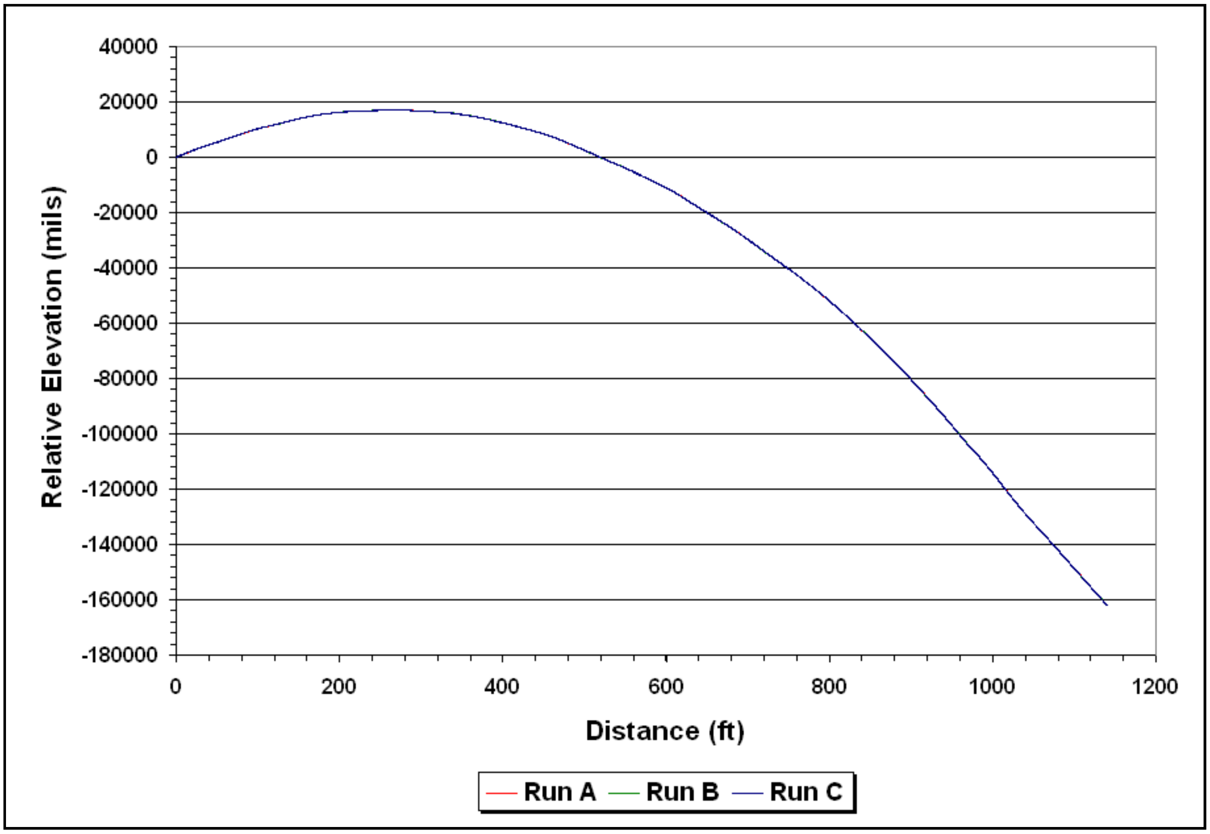

Figure 13. Unfiltered Reference Profiles on SH47 Hot-Mix Asphalt Section.

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 (Chang, et al., 2007). Table 2 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 3 shows the IRIs determined from the unfiltered reference profiles on the 528-ft test segments established along SH6 and SH47.

Table 2. 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 3. 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 14. 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 15 and 16 show the repeat profile measurements on the test segments while Tables 4 to 7 summarize the test statistics from this evaluation. The results are quite encouraging. The prototype profiler module met all test criteria prescribed in Tex-1001S. Subsequent to these initial tests, UTA researchers made additional modifications to the filtering algorithm of the inertial profiler software. Specifically, a change was made to correct for the nonlinear phase of the Butterworth filter through the addition of a post-processing step to reverse filter the data. Subsequent verification tests presented later in this document were conducted using the modified inertial profiler software. In the following, researchers document efforts made to investigate alternatives for mounting the portable profiler module onto a test vehicle.

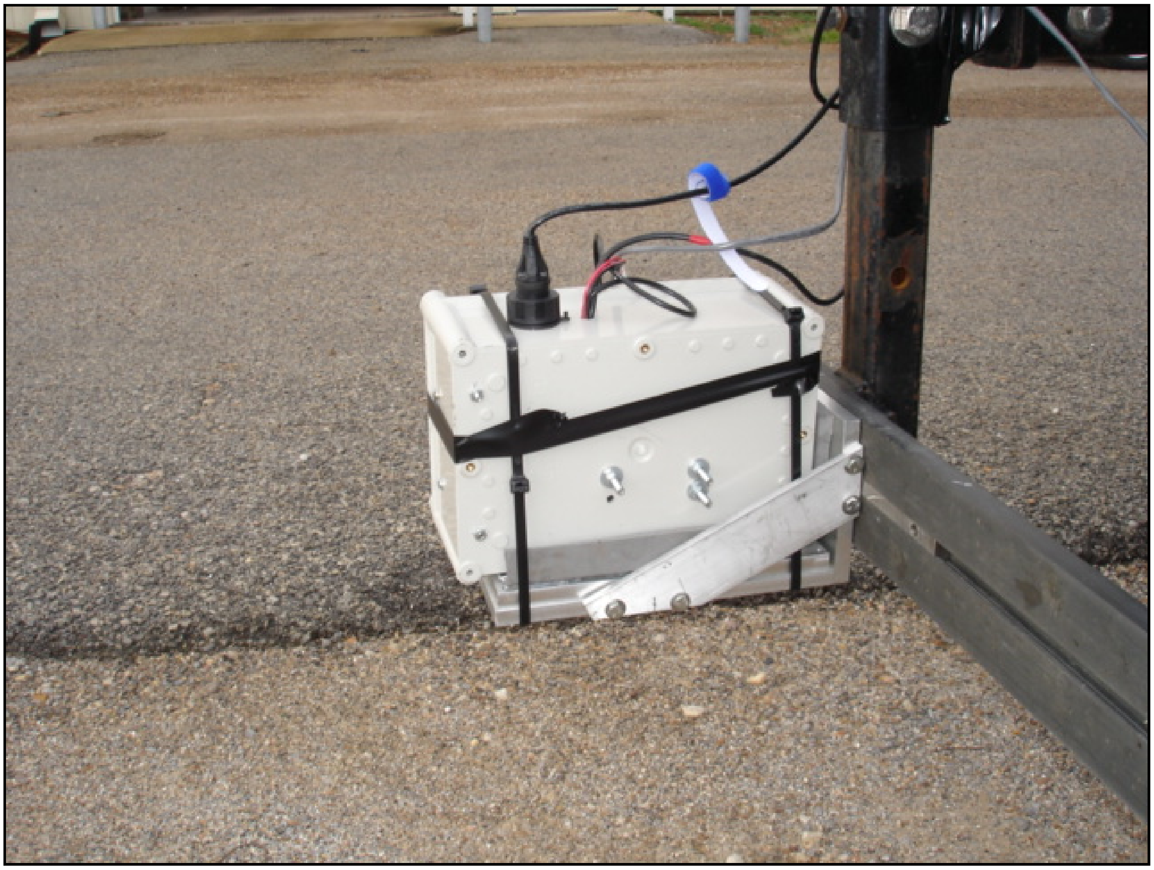
Figure 14. Prototype Profiler Module Mounted in Front of Test Vehicle.

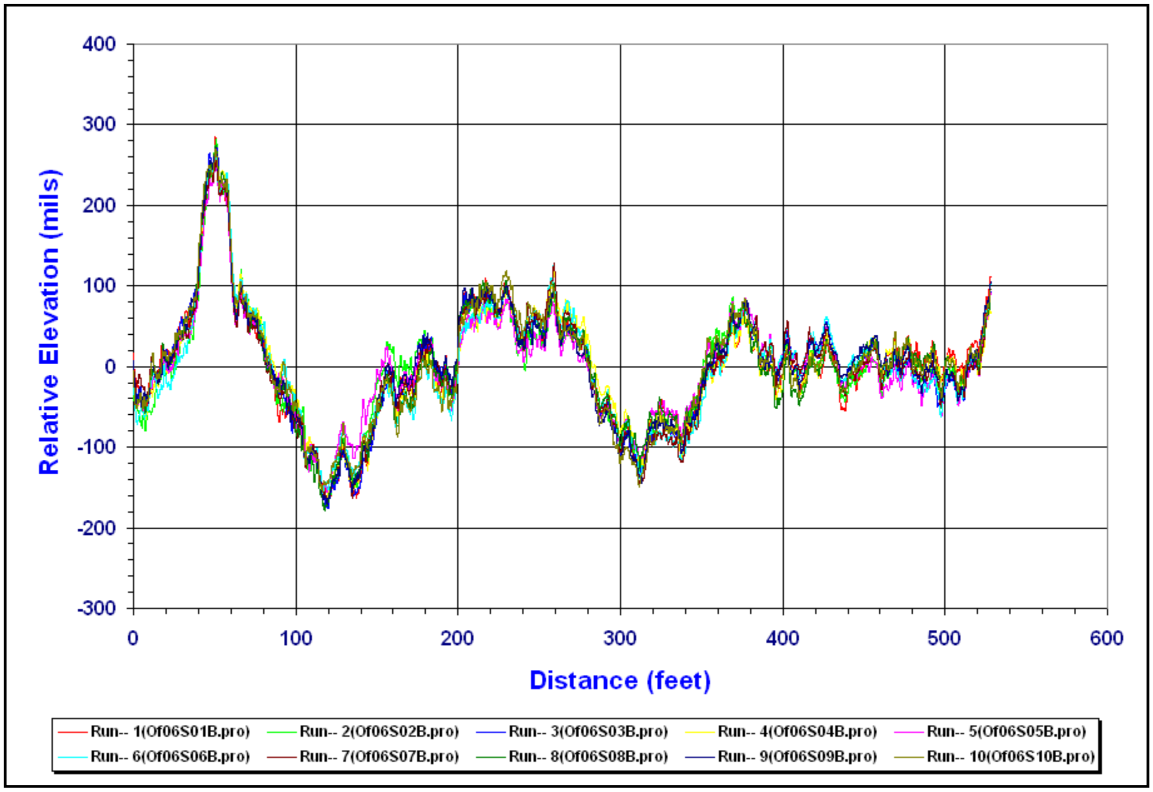

Figure 15. Repeatability of Inertial Profile Measurements on SH6 Test Segment.

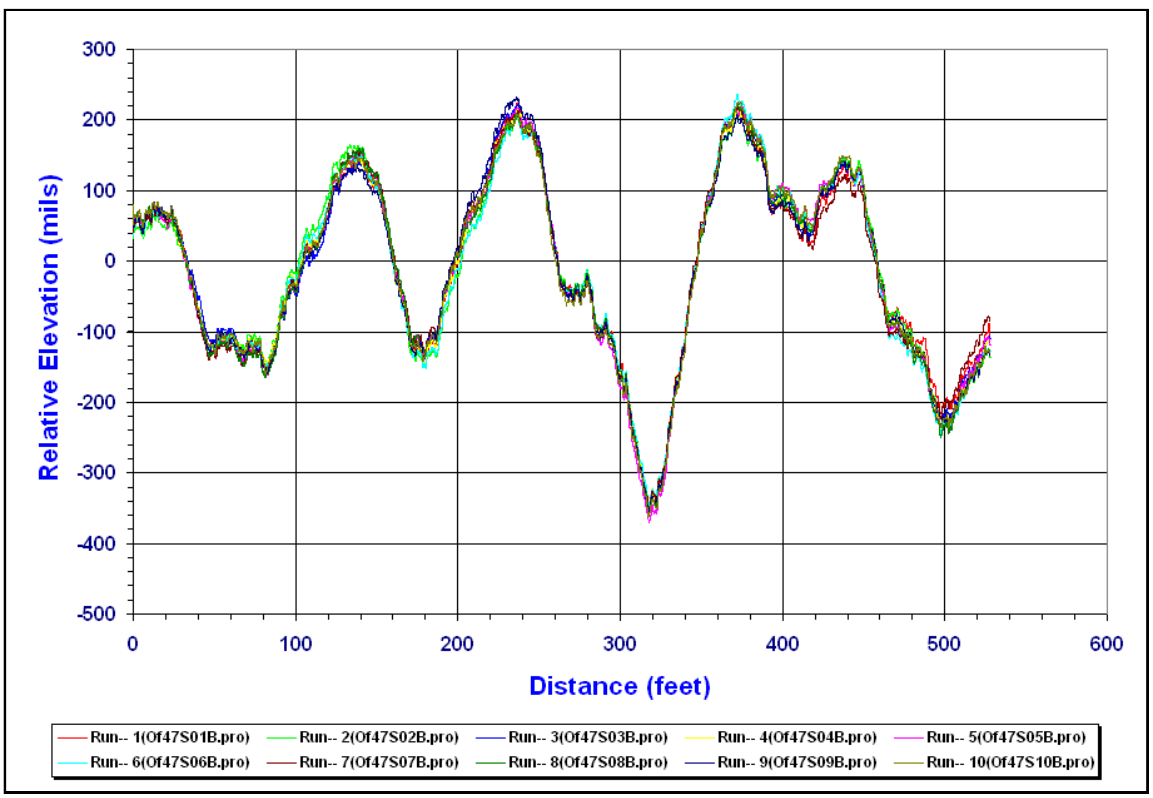

Figure 16. Repeatability of Inertial Profile Measurements on SH47 Test Segment.

Table 4. Repeatability of Profile Measurements from Test Module.

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

Table 5. Repeatability of IRIs from Test Module Profile Measurements.

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

Table 6. Accuracy of Profile Measurements from Test Module.

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

Table 7. 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

INVESTIGATION OF ALTERNATIVES FOR MOUNTING PORTABLE PROFILER MODULE

For the initial tests conducted on the portable profiler module, researchers mounted the module onto a bar tow-hitched to the front of the test vehicle as shown in Figure 14. These tests were conducted on the same mounting hardware used on TTI's inertial profiler where the laser/accelerometer modules are mounted on the same bar shown in the figure. The bar is slotted to provide flexibility in positioning the sensors along the transverse direction for measurement of longitudinal profiles as well as permitting multiple sensors to be used for multiple profile measurements. During this project, researchers also considered other alternatives for mounting the inertial profiler module in a way that would enhance the portability of the system for use on different vehicles. Among the clamp-on or snap-on designs considered, the research supervisor purchased the suction cup system shown in Figure 17. This picture shows the portable profiler module mounted on the side of the vehicle in-between the axles. Another picture (Figure 18) shows a setup where the profiler module is mounted at the back of the vehicle using the suction cups. TTI researchers collected data on the SH6 and SH47 sections to check the performance of the prototype portable profiler module with the instrument mounted onto the test vehicle using the suction cups. On SH6, researchers had to mount the profiler module on the right side of the vehicle to avoid tracking the rumble strips adjacent to the shoulder stripe. For these measurements, the test vehicle straddled the outside lane and the shoulder on each run, to collect data along the middle of the section along the same path as the reference profiles. On SH47, the profiler module was positioned at the back of the vehicle as illustrated in Figure 19, with the box oriented so that the laser tracked the middle of the section where researchers collected reference profile measurements.

Figures 19 and 20 show, respectively, the profile repeatability on the SH6 and SH47 sections, while Tables 8 to 11 summarize the test statistics from this evaluation where the profiler module was mounted using the suction cups. Although the test results satisfy Tex-1001S requirements, the profile and IRI repeatability statistics are not as good compared to those obtained when a tow-hitch is used. In view of this finding and the experience with using the suction cups, the decision was made to fabricate the mounting hardware based on using a receiver hitch.

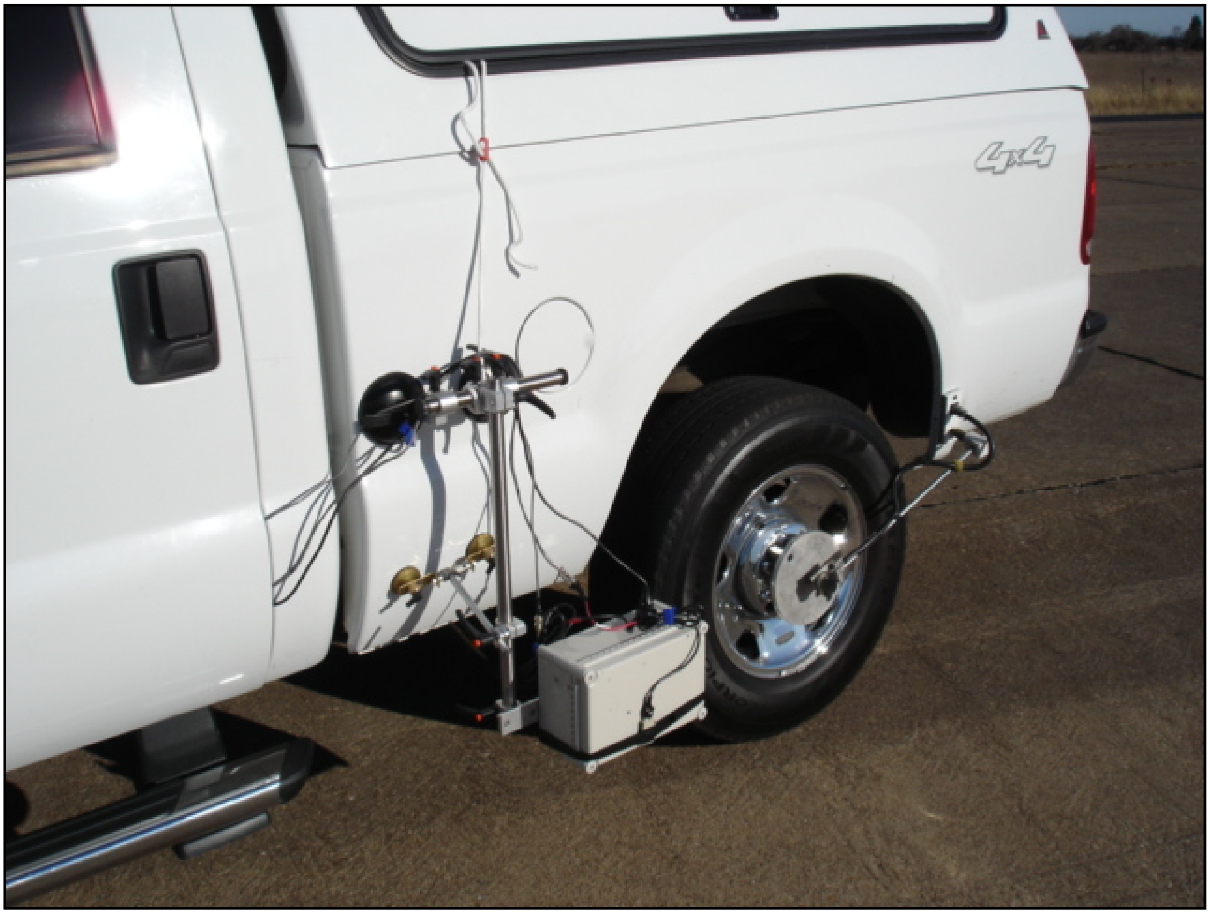

Figure 17. Profiler Module Mounted at Side of Test Vehicle using Suction Cups.

Figure 18. Profiler Module Mounted at Rear of Test Vehicle using Suction Cups.

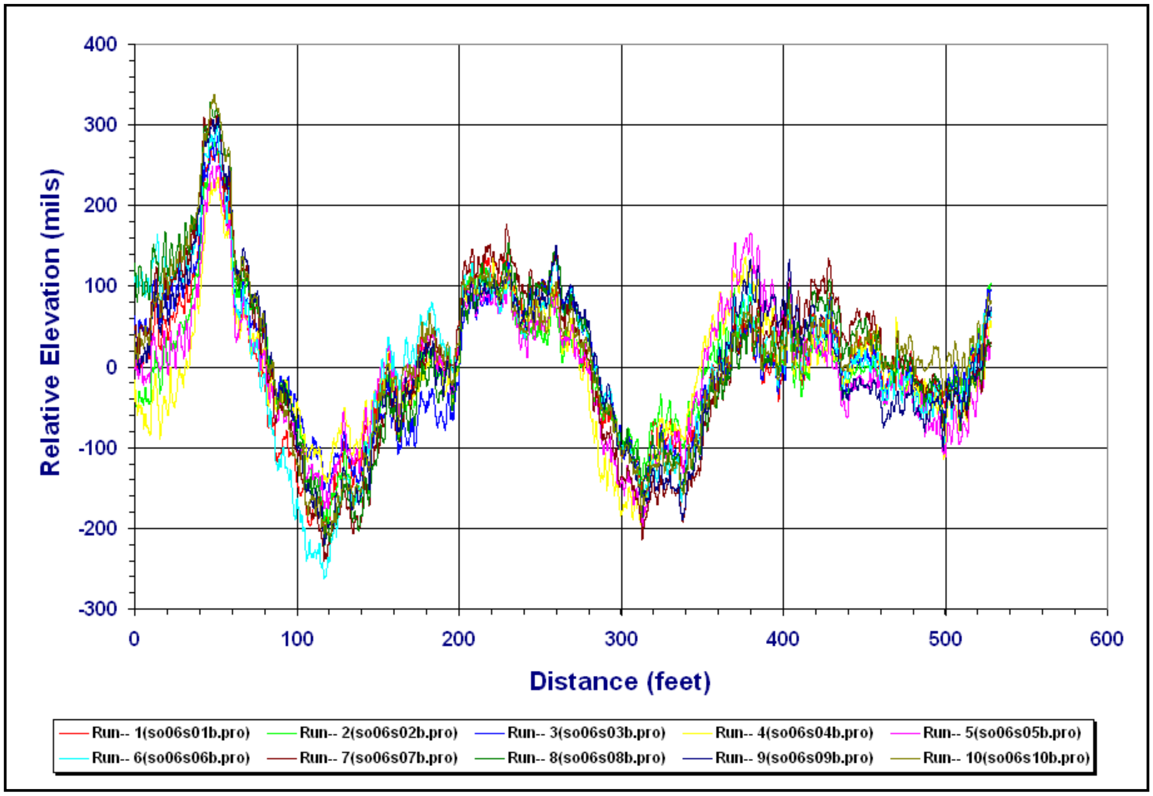

Figure 19. Profile Repeatability on SH6 Section with Suction Cup Mounting System.

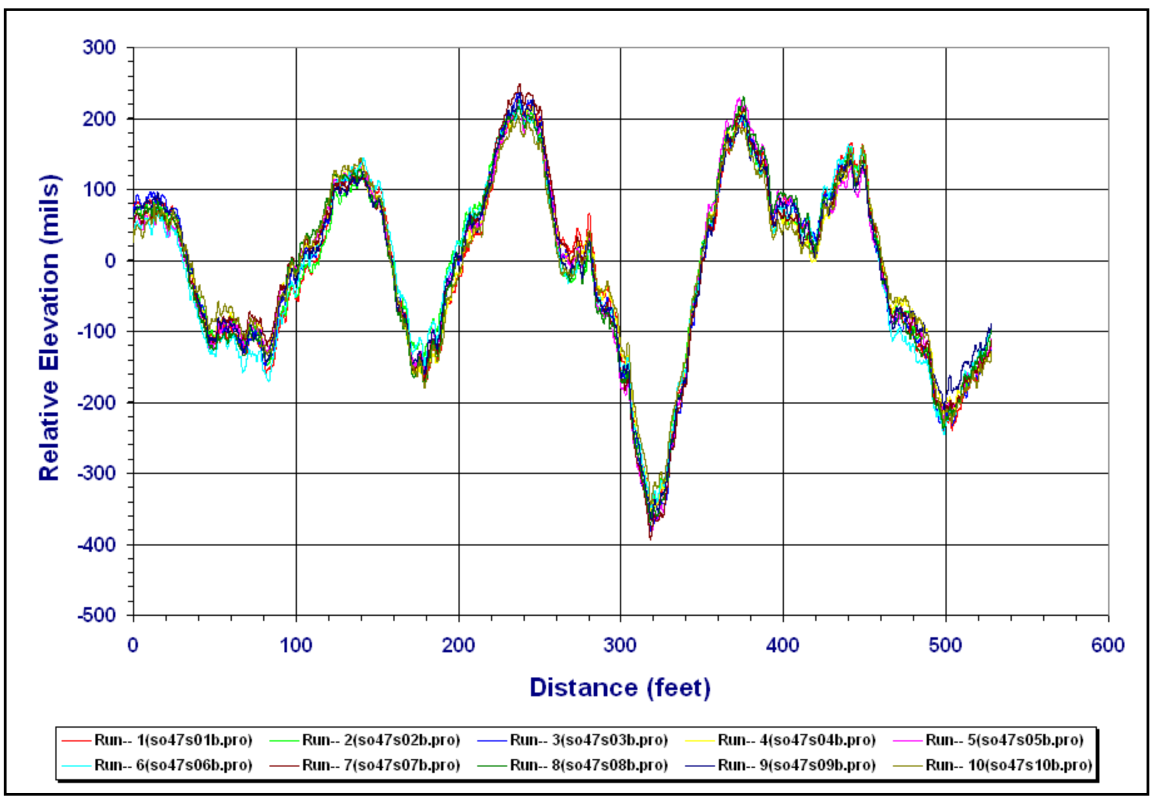

Figure 20. Profile Repeatability on SH47 Section with Suction Cup Mounting System.

Table 8. Profile Repeatability with Suction Cup Mounts.

Section	Average Standard Deviation (mils)
SH6	29
SH47	13

Table 9. IRI Repeatability with Suction Cup Mounts.

Section	Standard Deviation (inches/mile)
SH6	2.88
SH47	2.44

Table 10. Profile Accuracy with Suction Cup Mounts.

Section	Average Difference (mils)	Average Absolute Difference (mils)
SH6	2	25
SH47	1	16

Table 11. IRI Accuracy with Suction Cup Mounts.

Section	Difference between Averages of Test and Reference IRIs (inches/mile)
SH6	5.45
SH47	6.39

From their experience, researchers offer the following comments about the suction cups:

- Initially, setup took longer since positioning the profiler module required working with the suction cups and the support bars to make adjustments in order to level the module or to go around an obstruction (such as the rear bumper). However, with experience on a particular vehicle, setup can evolve into a routine process, in the authors' opinion.
- The truck used for testing (and most passenger vehicles for that matter) had curved surfaces that were hollow on the inside. Researchers had to pick spots on the vehicle body that were flat enough to use the suction cups. Moreover, as one pushes down on the cups to apply the suction, the surface (which is hollow on the inside) would at times "give" depending on the pressure one applies to the cups. In this instance, the suction can be released as the surface pops back up.

- Because of the possibility that suction might be released at one or more cups during a test, researchers tethered the entire system to the vehicle to prevent damage to the profiler module and to other vehicles from parts that fly off. This precautionary measure justified itself in one instance when the entire system popped loose during tests on the SH6 section. With mounting hardware that uses a receiver hitch, the assembly is fastened together with bolts that provide secure connections.

In view of the test results and the above experience with the suction cups, the decision was made to fabricate the mounting assembly based on using a receiver hitch. Figure 21 shows the components of this mounting assembly along with the portable profiler module as laid out inside the foam-padded portable profiler transport case. Tools and fasteners (bolts, washers and nuts) for installation are also stored inside the carrying case. Appendix A provides setup instructions. Researchers conducted subsequent tests of the portable profiler module using the mounting assembly shown in Figure 21. The succeeding sections present the results from these tests.

CERTIFICATION TESTING OF PORTABLE PROFILER SYSTEM

Researchers tested the portable profiler system on the inertial profiler certification track located at the Texas A&M Riverside Campus. Two separate certification tests were conducted. On one test, researchers installed the portable profiler on a full-size pickup truck while on the other test, a TxDOT full-size van was used. In both tests, the portable profiler was mounted at the rear of the test vehicle as shown in Figures 22 and 23. Researchers and TxDOT monitoring committee members expect that this rear installation would be how TxDOT staff will setup the portable profiler in practice.

TTI and TxDOT staff made 10 runs on each test vehicle and submitted profile data on two designated sections of the track. Data were collected using a notebook computer connected to the profiler module via a USB cable. A power cable connected to the vehicle’s cigarette lighter supplied power to the profiler module.

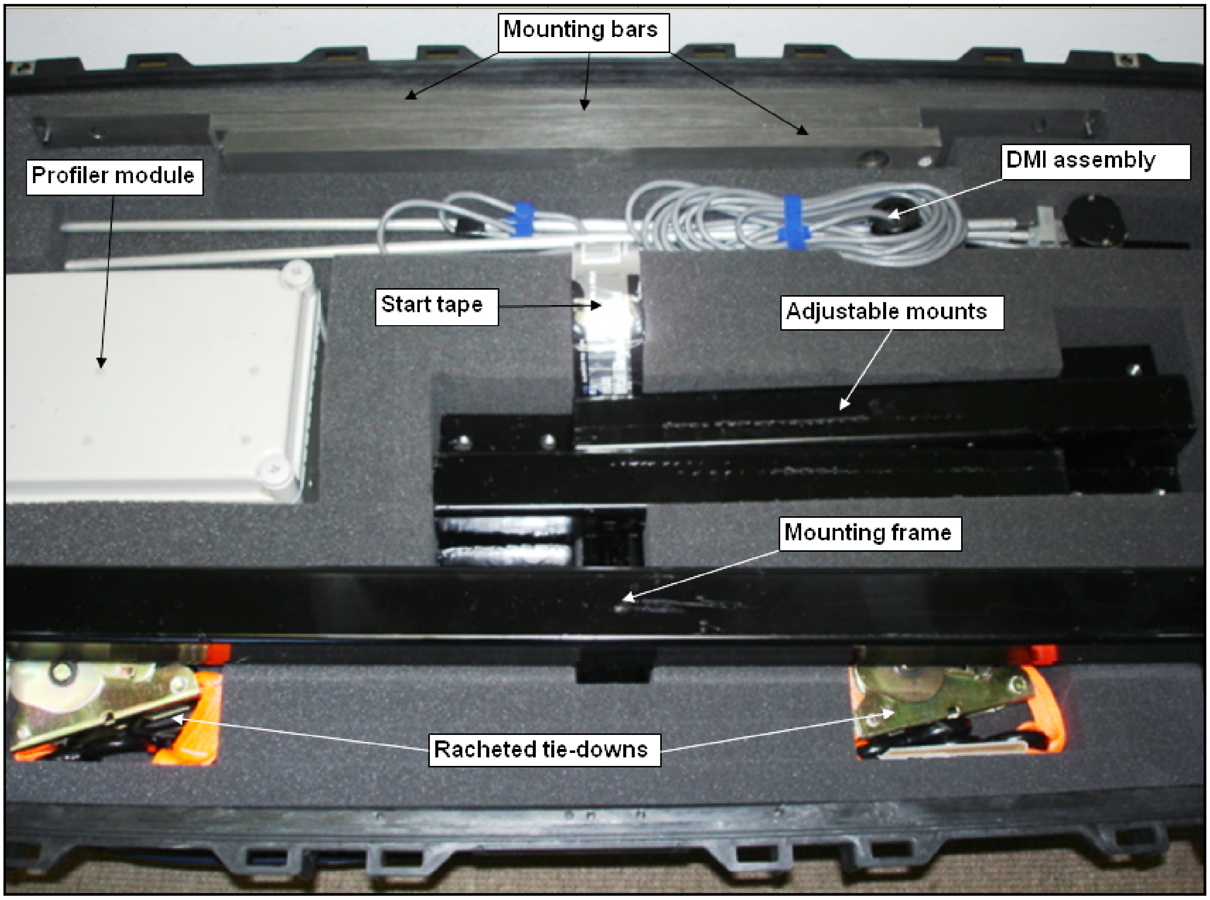

Figure 21. Components of Portable Profiler System.

Figure 21. Portable Profiler System on TTI Full-Size Truck.

Figure 22. Portable Profiler System on TxDOT Full-Size Van.

Researchers then evaluated the repeatability and accuracy of the profiles and IRI statistics based on TxDOT Test Method Tex-1001S. Figures 23 to 25 illustrate the profile repeatability achieved on the trucks used for testing while Table 12 summarizes the profile repeatability statistics. Researchers note the following observations:

- The results show that the portable profiler system met the ASTM E-950 Class I requirement on both test vehicles.
- For a given test vehicle, the profile repeatability (as measured by the average of the standard deviations of repeat profile measurements) showed consistency across the sections tested. For profiles collected with the TxDOT van, Table 12 shows the average standard deviation to be 15 mils on both test sections while for the TTI truck, the average standard deviations are 11 and 12 mils, respectively, on the smooth and medium smooth sections.
- The repeatability statistics are also quite comparable between the two test vehicles.

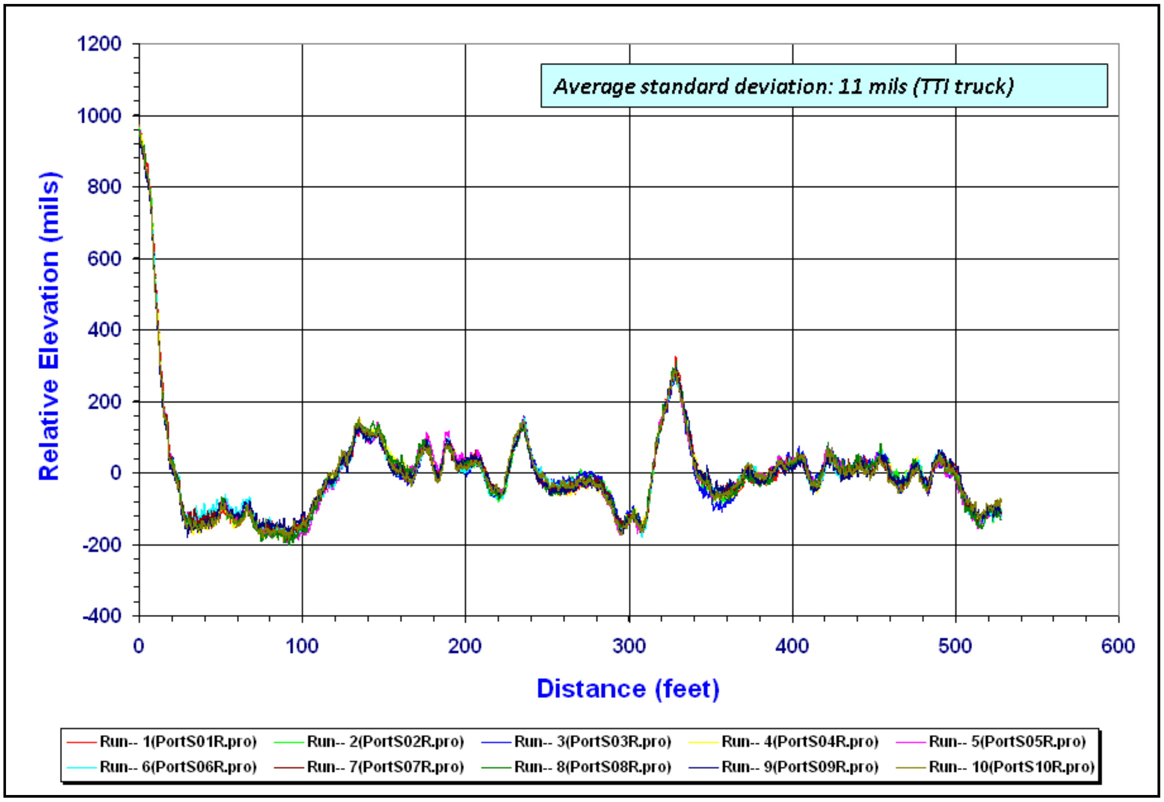

Figure 23. Profile Repeatability on Smooth Section (TTI Full-Size Truck).

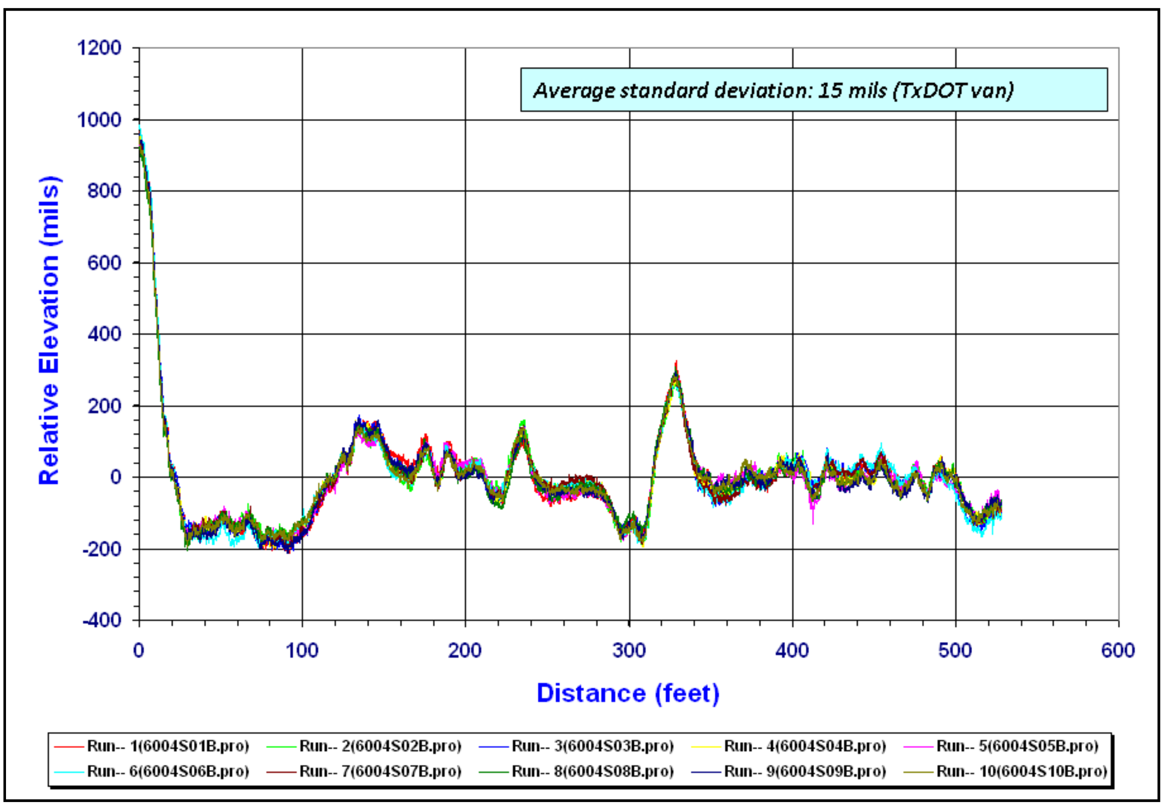

Figure 24. Profile Repeatability on Smooth Section (TxDOT Full-Size Van).

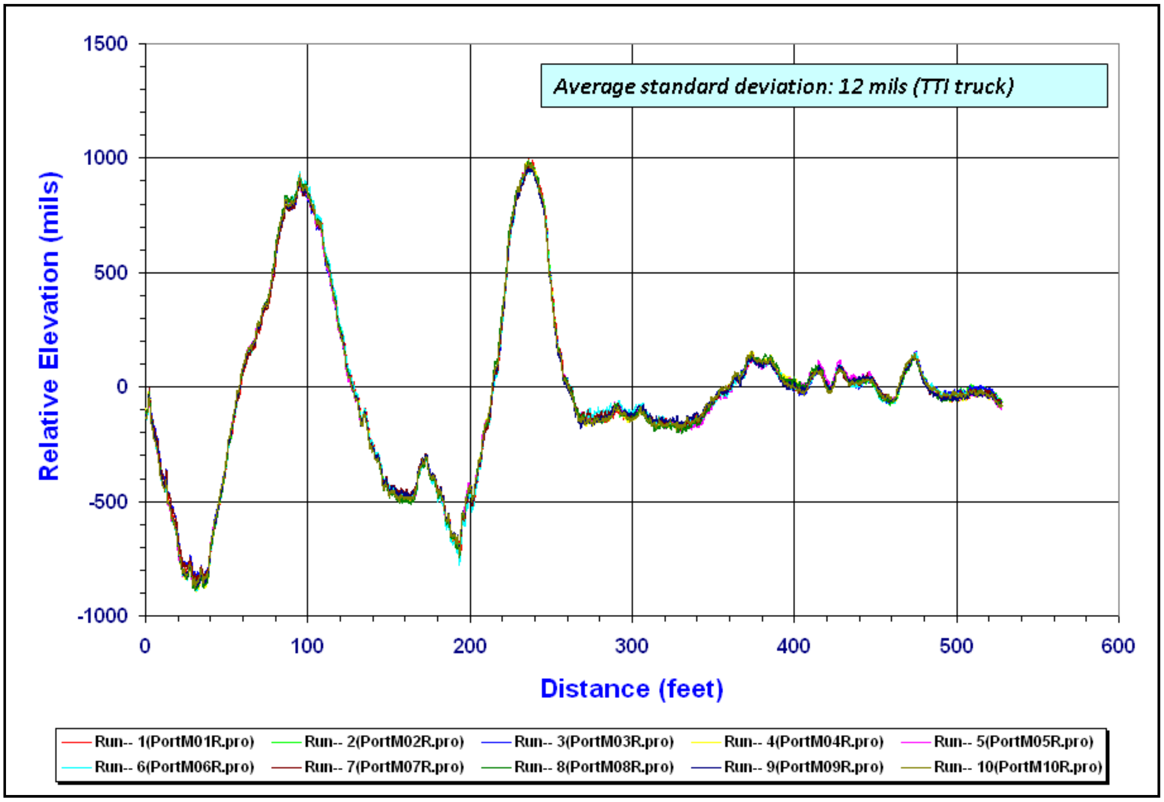

Figure 25. Profile Repeatability on Medium Smooth Section (TTI Full-Size Truck).

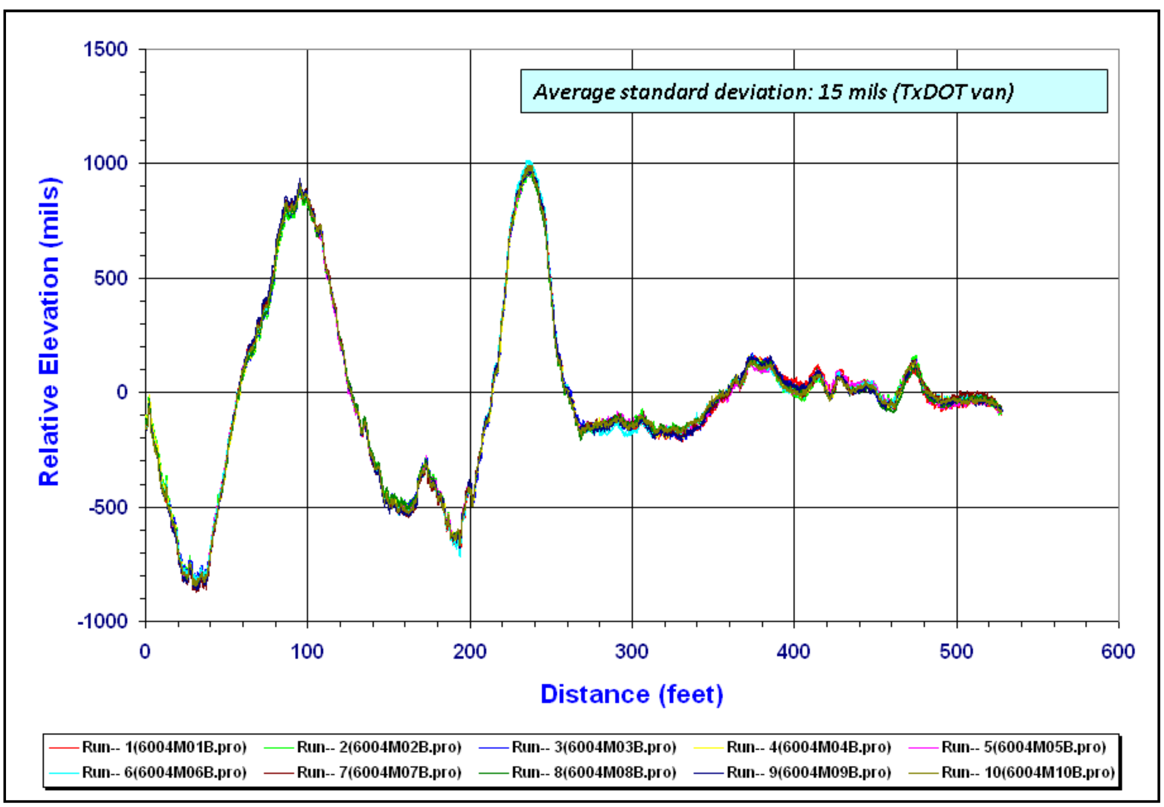

Figure 26. Profile Repeatability on Medium Smooth Section (TxDOT Full-Size Van).

Table 12. Profile Repeatability from Certification Tests.

Section	Average standard deviation (mils)	
	TxDOT Van	TTI Truck
Smooth	15	11
Medium-smooth	15	12

Tables 12 to 15 present the other statistics computed from the profiles collected during certification testing of the portable profiler system. Again, it is observed that the test statistics are very comparable between the two test vehicles. Overall, the results show that the portable profiler met Tex-1001S certification requirements on the two vehicles used for testing. In the authors' opinion, the portable profiler achieved good performance on both vehicles based on the statistics determined from the test data.

Table 13. IRI Repeatability from Certification Tests.

Section	IRI standard deviation (in/mile)	
	TxDOT Van	TTI Truck
Smooth	0.83	0.74
Medium-smooth	0.71	1.05

Table 14. Profile Accuracy from Certification Tests.

Section	Average difference (mils)		Average absolute difference (mils)	
	TxDOT Van	TTI Truck	TxDOT Van	TTI Truck
Smooth	-2	0	17	15
Medium-smooth	1	0	18	16

Table 15. IRI Accuracy from Certification Tests.

Section	IRI difference (in/mile)	
	TxDOT Van	TTI Truck
Smooth	4.98	4.55
Medium-smooth	1.59	1.88

PORTABLE PROFILER COMPARISONS

The portable profiler gives TxDOT engineers a tool they can use to monitor ride quality on their construction projects. Considering that quality assurance tests are conducted by contractors using their profilers on projects where Item 585 is specified in the plans, it is of interest to compare the portable profiler developed in this research project with another commercially available portable system. Consequently, researchers conducted another round of tests where concurrent measurements with two portable profiling systems were collected.

Figure 28 shows the test vehicle used for this comparative evaluation. As shown, the portable profiler was mounted at the rear of the TTI test vehicle while the other profiler (a portable unit from Ames Engineering) was mounted at the front. The Ames portable system was made available from another TxDOT project that was investigating texture effects on ride quality measurements. Both units had single-point conventional lasers for profile measurements.

TTI researchers positioned both portable units to measure profiles along the outside wheel path. Two separate notebook computers were used to collect data during testing. In addition, each portable profiler had its own start sensor to trigger data collection at the same start point on each project. Table 16 identifies the projects tested in this evaluation.

From the profiles collected, researchers computed the IRIs at 528-ft intervals and compared the resulting statistics from the two portable systems. Figures 28 to 31 show high correlations between the IRI statistics computed from both systems. Researchers also determined the 95 percent confidence intervals of the IRI differences where the IRI difference on each 528-ft section was evaluated as the portable profiler IRI minus the Ames profiler IRI. Table 17 presents the 95 percent confidence intervals of the IRI differences between the two systems. This table shows that the portable profiler generally gave IRIs that are higher than those determined from the Ames portable unit. While the differences are statistically significant, the confidence intervals are all within the 6 inches per mile tolerance for referee testing specified in Item 585. Thus, from a practical perspective, the IRI differences are not considered significant.

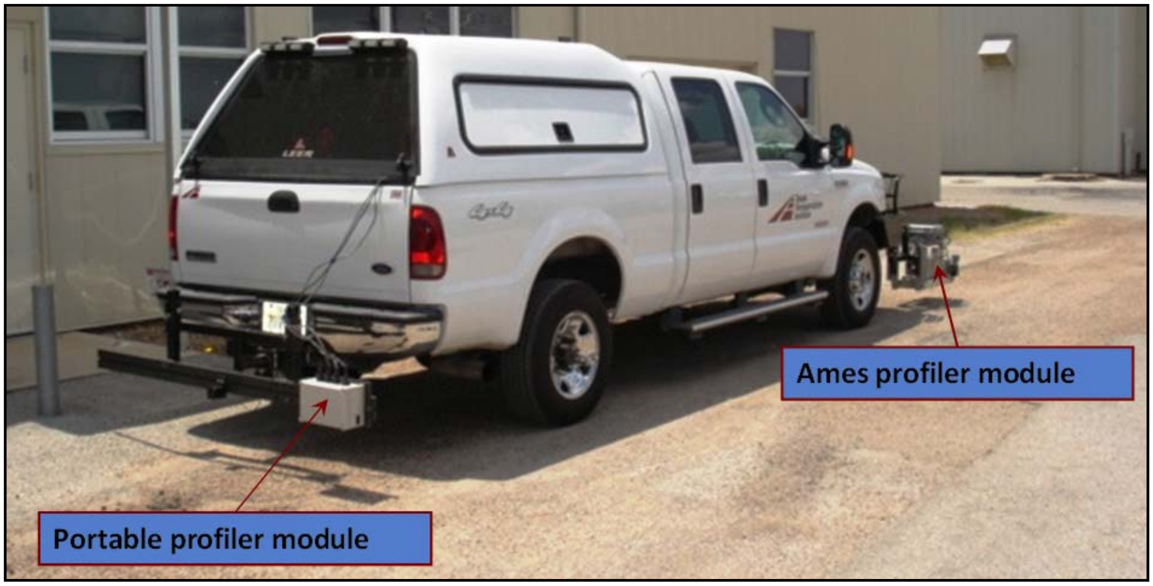

Figure 27. Test Setup for Comparative Evaluation of Portable Profilers.

Table 16. Projects Tested for Comparative Evaluation of Portable Profilers.

Highway	Surface	No. of lane-miles tested
SH6	CRCP with conventional transverse tines	2.0
SH6	Permeable friction course (PFC)	2.0
SH21	Type C	1.6
SH47	Type D	2.0

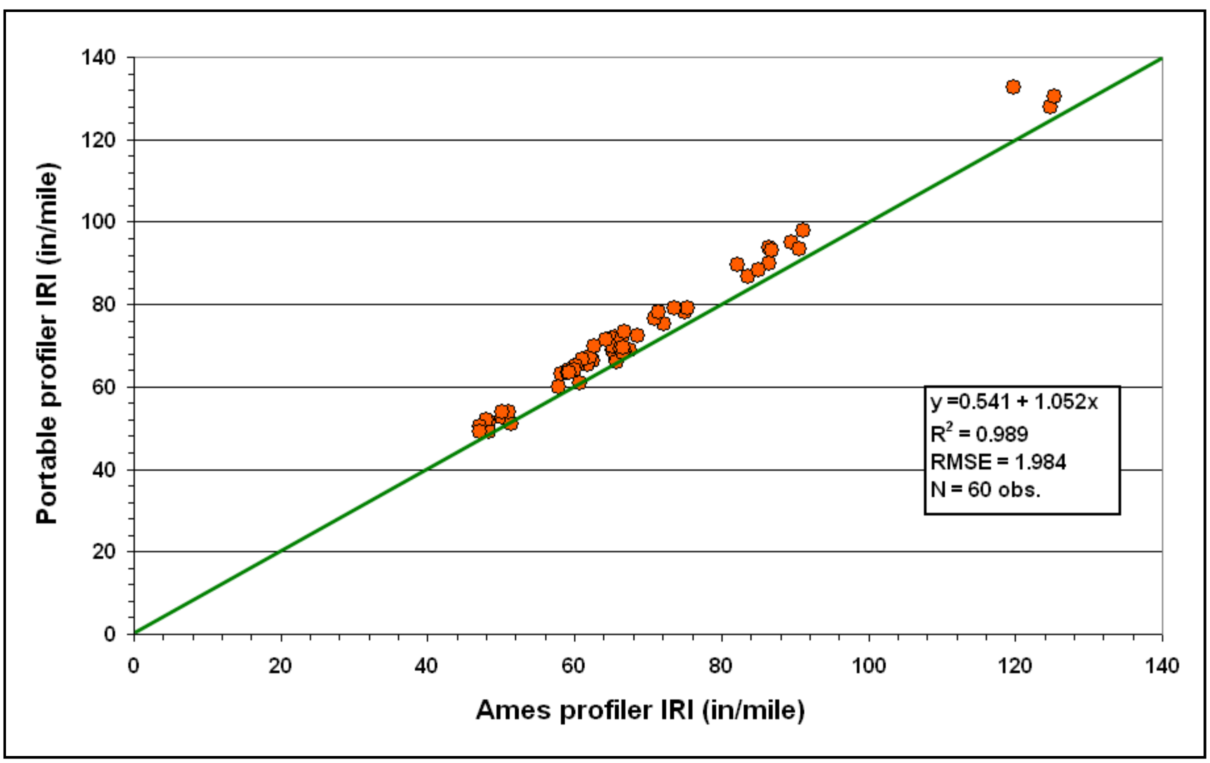

Figure 28. Comparison of Portable Profiler IRIs on SH6 CRCP Project.

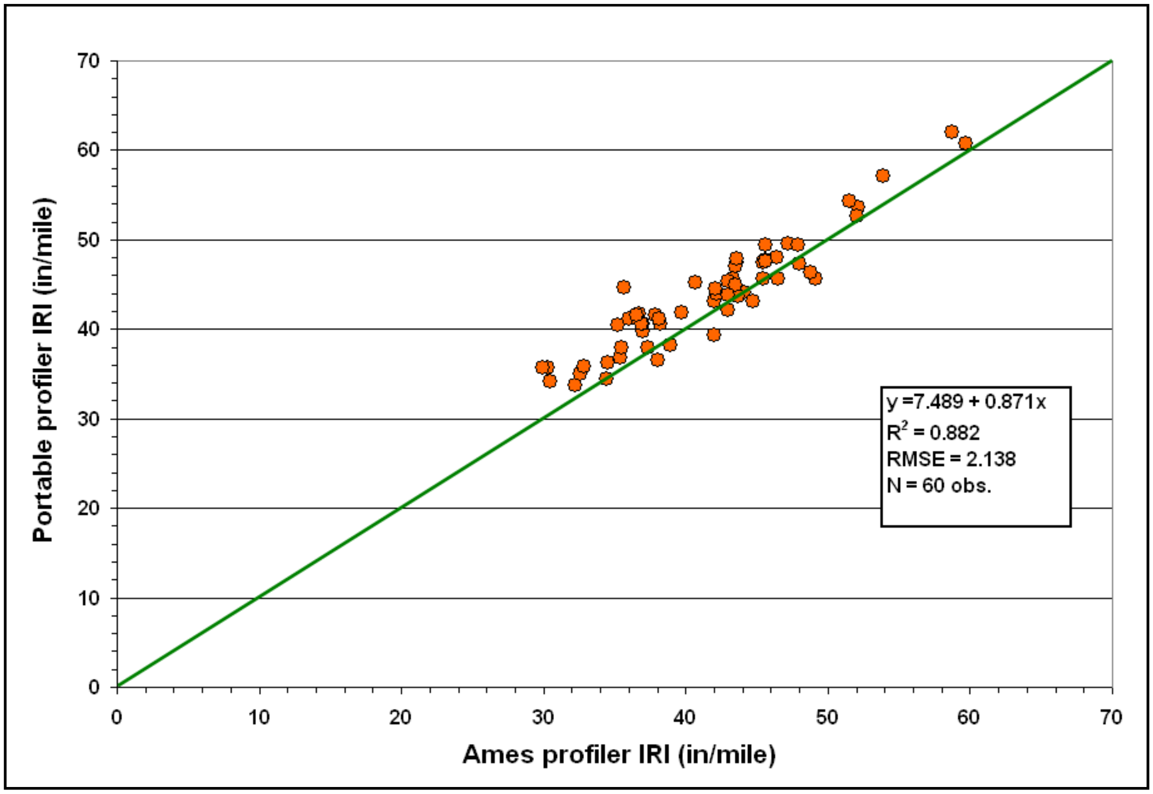

Figure 29. Comparison of Portable Profiler IRIs on SH6 PFC Project.

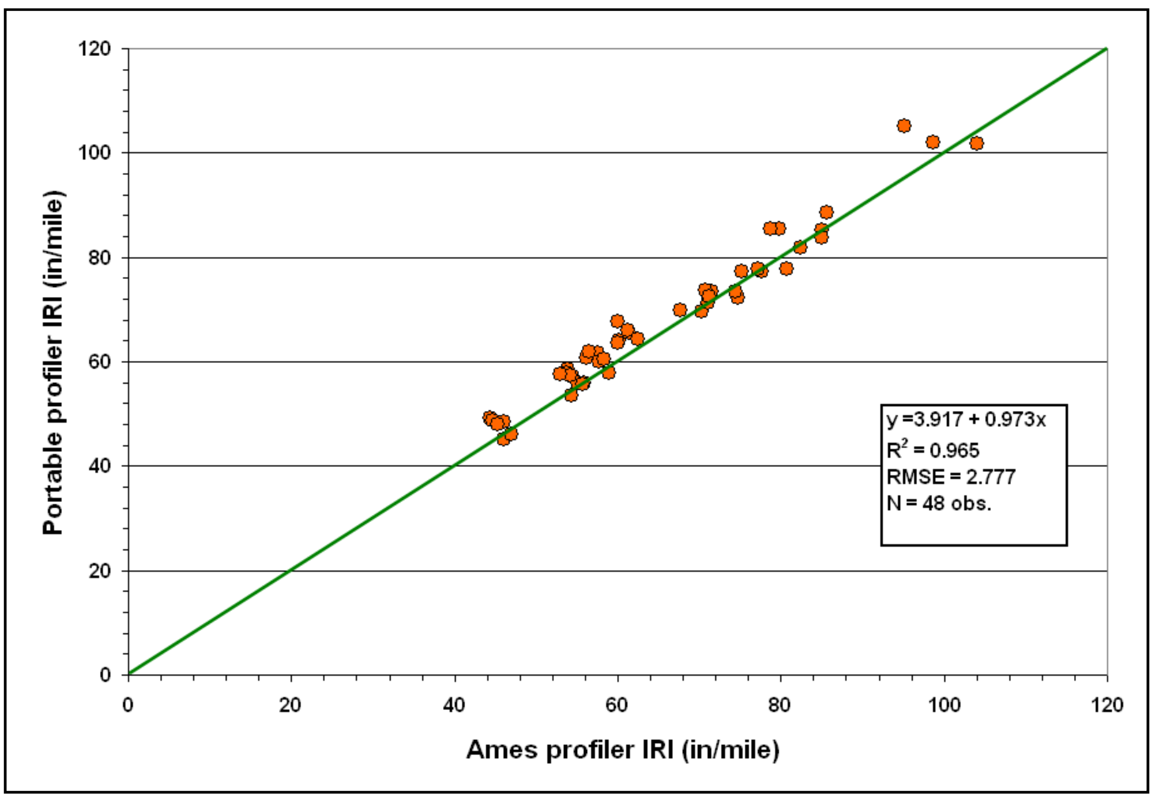

Figure 30. Comparison of Portable Profiler IRIs on SH21 Project (Type C Surface).

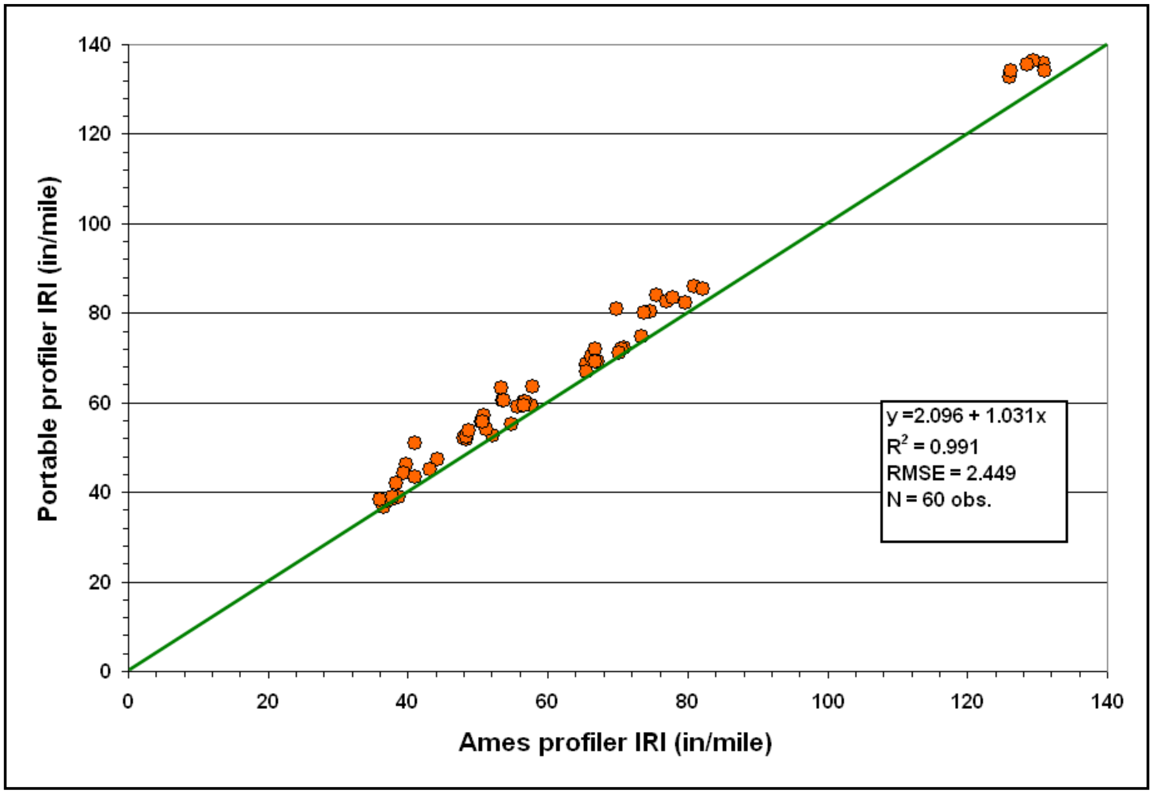

Figure 31. Comparison of Portable Profiler IRIs on SH47 Project (Type D Surface).

Table 17. 95 Percent Confidence Intervals of IRI Differences.

Highway	Surface	Confidence interval (in/mile)
SH6	CRCP with conventional transverse tines	3.54 to 4.64
SH6	PFC	1.50 to 2.68
SH21	Type C	1.35 to 2.96
SH47	Type D	3.42 to 4.74

REPORT SUMMARY

This report has provided details on the TxDOT Project 0-6004. The project was initiated to develop a single path, easy to use, portable profiler that can provide profile data or IRI values. The objectives have been met and discussed in this report. A portable profiling instrument, complete with software, mounting and instructions have been delivered to TxDOT. A summary of the results of the research are provided below.

1. A portable profiler has been developed and is available for immediate use.
2. An accompanying program has been developed.
3. A portable attachment that easily fits into commercially available receiver hitches has been fabricated.
4. A portable holder for the distance encoder was developed and tested.
5. The profile and measurement process is consistent with current TxDOT data collection procedures.
6. The portable profiler was certified on a TTI full size pickup and a TxDOT van.
7. The portable profiler is ready for implementation.

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2. Walker, Roger S., W. Ronald Hudson and Freddy L. Roberts, *Development of a System For High-Speed Measurement of Pavement Roughness, Final Report*, Research Report 73-5F, Center for Highway Research, The University of Texas at Austin, May 1971.
3. Huft, David L. *Description and Evaluation of the South Dakota Road Profiler,* FHWA-DP-89-072-002 November 1989.
4. Chang, G. K., J. C. Dick, and R. O. Rasmussen, *ProVAL: Profile Viewing and Analysis Software User's Guide (version 2.73)*. The Transtec Group, Incorporated, Austin, Tex., 2007.

APPENDIX A

INSTALLATING AND USING THE PORTABLE PROFILER

Table of Contents

Appendix A Installing and Using the Portable Profiler 39

Table of Contents 41

List of Figures 41

INTRODUCTION 43

USING THE UTA-Portable Profiler Program 43

Portable Profiler Installation Guide 57

Mounting the Portable Profiler Module 56

Distance Encoder Installation 65

List of Figures

Figure 1 Typical TxDOT Profiler Header.ini File	44
Figure 2 Typical UTA-Profiler.ini File	45
Figure 3 DT 9816-A Pin Assignments (See Data Translation http://www.datx.com/)	46
Figure 4 Connect Distance Input to Channel 0, Start Sensor to Channel 1	47
Figure 5 Entering Header.ini File Name/Location	48
Figure 6 Entering UTA-Profiler.ini File Name/Location	48
Figure 7 Entering Profile Output File Name/Location	49
Figure 8 Verifying Initialization and Header File Information	50
Figure 9 Verifying Initialization and Header File Information and Prepare for Data Collection	51
Figure 10 Verifying Initialization and Header File Information and Prepare for Data Collection	52
Figure 11 Selecting the Start Manually option	53
Figure 12 Selecting the Start (P)resection option	53
Figure 13 Selection the (A)rm sensor option	54
Figure 14 Selecting the (R)eal Section option	54
Figure 15 Selecting the St(o)p option	55
Figure 16 Installation Parts	56
Figure 17 Place Collar on Mounting Frame	56
Figure 18 Insert Frame into Receiver Hitch	57
Figure 19 Secure Mounting Frame	57
Figure 20 Adjust Mount	58
Figure 21 Adjust Height	58
Figure 22 Attach Middle Mount	59
Figure 23 Attach Side Mount	59
Figure 24 Secure Mounting Bars	60
Figure 25 Tighten Mounting Bars	60
Figure 26 Mount Start Sensor	61
Figure 27 Mount Profiler Module	61
Figure 28 Position Profiler Module to Desired Location	62
Figure 29 Connect Cables	62
Figure 30 Route USB Cable to PC	63
Figure 31 Connect Power Cable	63

Figure 32 Completing Profiler Module Installation 64
Figure 33 Mounting Lug Extenders 65
Figure 34 Encoder Holder Rod 65
Figure 35 Position Encoder into Mounting Assembly 66
Figure 36 Secure Distance Encoder 66
Figure 37 Complete Encoder Installation 67

INTRODUCTION

This Appendix is divided into two sections. The first is using the UTA-Profiler Program with the portable profiler for generating surface profilers. The second is installing the portable profiler module on a typical van or truck. The calibration and initialization files used by the UTA-Profiler Program are compatible with the standard TxDOT files used with VAMOS and WinTK. Information on, deriving these files are explained in the TxDOT Profiler Operations Manual. The generated profile obtained when using the the UTA-Profiler Program with the portable profiler is consistent with the TxDOT PF9 VNET data file specifications and as such the generated profile can be directly used with current TxDOT and PROVAL application programs.

The second section, installing the portable profiler module on a typical van or truck, provides a step by step process for mounting the portable profiler sensor module.

USING THE UTA-Portable Profiler Program

The UTA-Portable Profiler Program is written in C++ and designed to run in the Windows console mode for use on multiple Windows platforms. Using the program requires three files - UTA-Portable.exe, UTA-Profiler.ini, and Header.ini. Typical TxDOT files for these two files are illustrated in Figures 1 and 2.

Header.ini File

```
Record1,HEAD3;
District,17;
County,21;
HighwaySystem,SH;
HighwayNumber,47;
HighwayDirection,S;
ReferenceStart,0;
ReferenceSuffix,A;
ReferenceOffset,2.2;
LaneMark,K;
LaneNum,6;
Record2,CMET3;
Model,Portable Profiler;
Reserved1,;
Reserved2,;
Reserved3,;
Reserved4,;
CertCode,1FTSW21P76EB82581;
CertDate,09092006;
Manufacturer,KPRF01
ElevationUnits,mil;
Wheelpath,LR;
Comment1,Comment Card;
Comment2,Comment Card;
```

Figure 1 Typical TxDOT Profiler Header.ini File

UTA-Profiler.ini File

```
AccelLeftAD1,-6117;
AccelLeftAD2,6224;
AccelLeftChannel,3;
AccelLeftD1,0.00;
AccelLeftD2,19600.00;
AccelRightAD1,-6067;
AccelRightAD2,6232;
AccelRightChannel,5;
AccelRightD1,0.00;
AccelRightD2,19600.00;
FilterLength,60.96;
LaserLeftAD1,17668;
LaserLeftAD2,20829;
LaserLeftChannel,2
LaserLeftD1,0.00;
LaserLeftD2,-25.40;
LaserRightAD1,20166;
LaserRightAD2,23782;
LaserRightChannel,4;
LaserRightD1,0.00;
LaserRightD2,-25.40;
NumberOfBuffers,Auto;
SamplingRate,4000.00;
SizeOfBuffers,Auto;
SpeedCount,40876.00;
```

Figure 2 Typical UTA-Profiler.ini File

The following steps are used for running the UTA-Profiler Program:

1. Edit the Header.ini and UTA-Profiler.ini files (Figures 1 and 2) and change the wheel path entry to LR, L, or R so that the output data file will provide the appropriate wheel path. Use either UTA's CalConsole or TxDOT Calibration program for obtaining calibration values. The Portable Profiler Module is wired as follows:
    a. Channel 0 - DMI sensor signal (See Figure 3-4)
    b. Channel 1 - Infrared start sensor (See Figure 3-4)
    c. Channel 2 and 4 – Selcom SLS 5000 Laser
    d. Channel 3 and 5 - Columbia Research ±4 g accelerometer

	Screw	Signal Terminal	Screw	Signal Terminal
	20	USB +5 V Out	40	Ext Trigger
	19	Ground	39	Ext Clock
	18	Counter 0 In	38	Ground
	17	Counter 0 Out	37	Digital Output 7
	16	Counter 0 Gate	36	Digital Output 6
	15	Ground	35	Digital Output 5
	14	Reserved	34	Digital Output 4
	13	Reserved	33	Digital Output 3
	12	Reserved	32	Digital Output 2
	11	Reserved	31	Digital Output 1
	10	2.5 V Reference	30	Digital Output 0
	9	Ground	29	Ground
	8	Reserved	28	Digital Input 7
	7	Reserved	27	Digital Input 6
	6	Analog In 5	26	Digital Input 5
	5	Analog In 4	25	Digital Input 4
Accelerometer Sensor	4	Analog In 3	24	Digital Input 3
Laser Sensor	3	Analog In 2	23	Digital Input 2
DMI Start Sensor	2	Analog In 1	22	Digital Input 1
DMI sensor sign al	1	Analog In 0	21	Digital Input 0

Figure 3 DT 9816-A Pin Assignments (See Data Translation http://www.datx.com/)

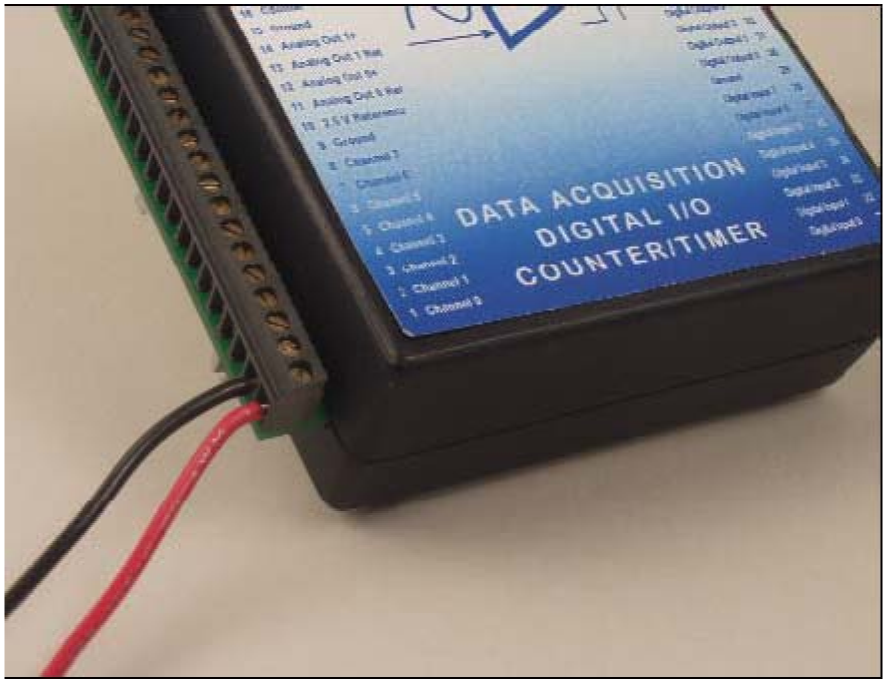

Figure 4 Connect Distance Input to Channel 0, Start Sensor to Channel 1

2. Start the UTA-Profiler by clicking on the UTAProfiler.exe icon.

3. Once the program starts, type “y” and press “ENTER” to accept the header.ini as the default header file or type in the header file name that you will be using (Figure 5).

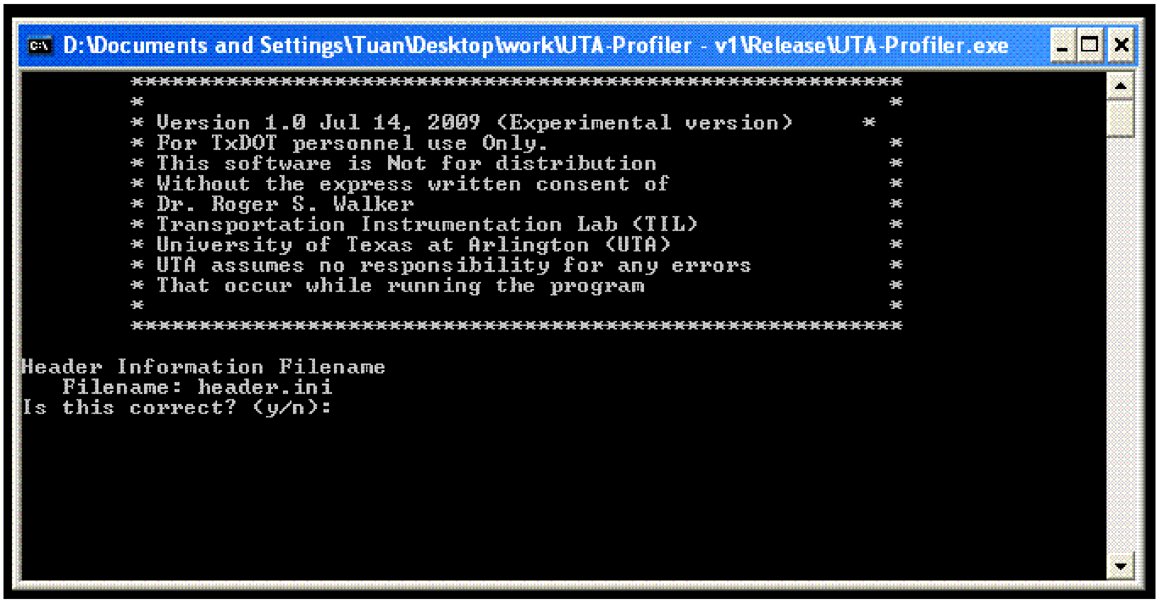

Figure 5 Entering Header.ini File Name/Location

4. Type “y” and press “ENTER” to accept UTA-Profiler.ini as the default configuration file or type in the configuration file name that you will be using (Figure 6).

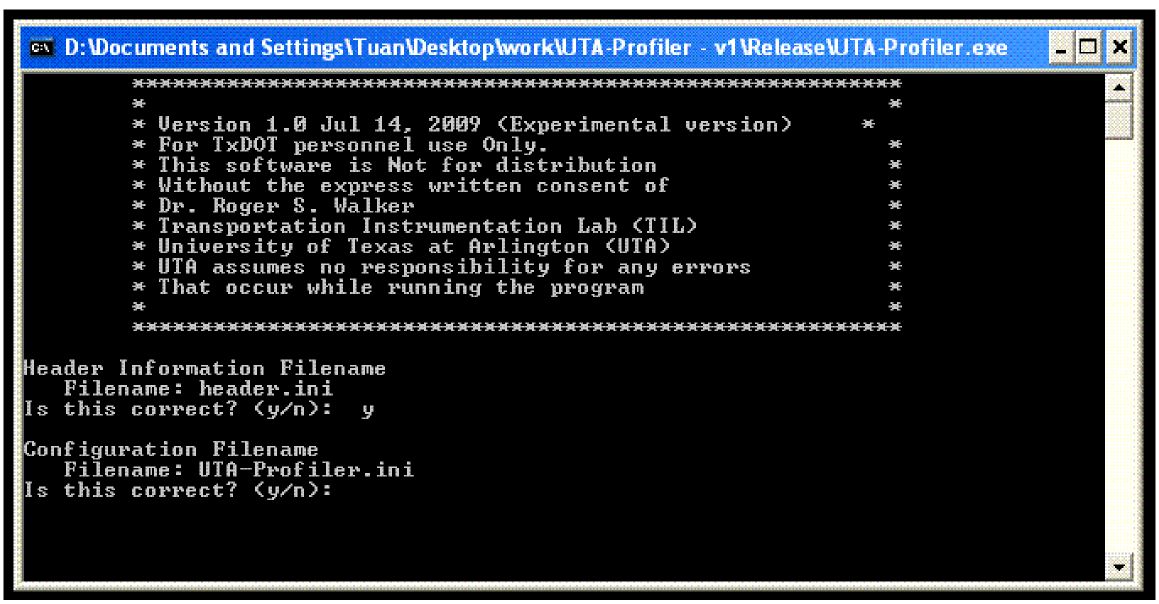

Figure 6 Entering UTA-Profiler.ini File Name/Location

5. Type “y” and press “ENTER” to accept Output.pro as the default output file or type in the output file name that you want to have. (Figure 7)

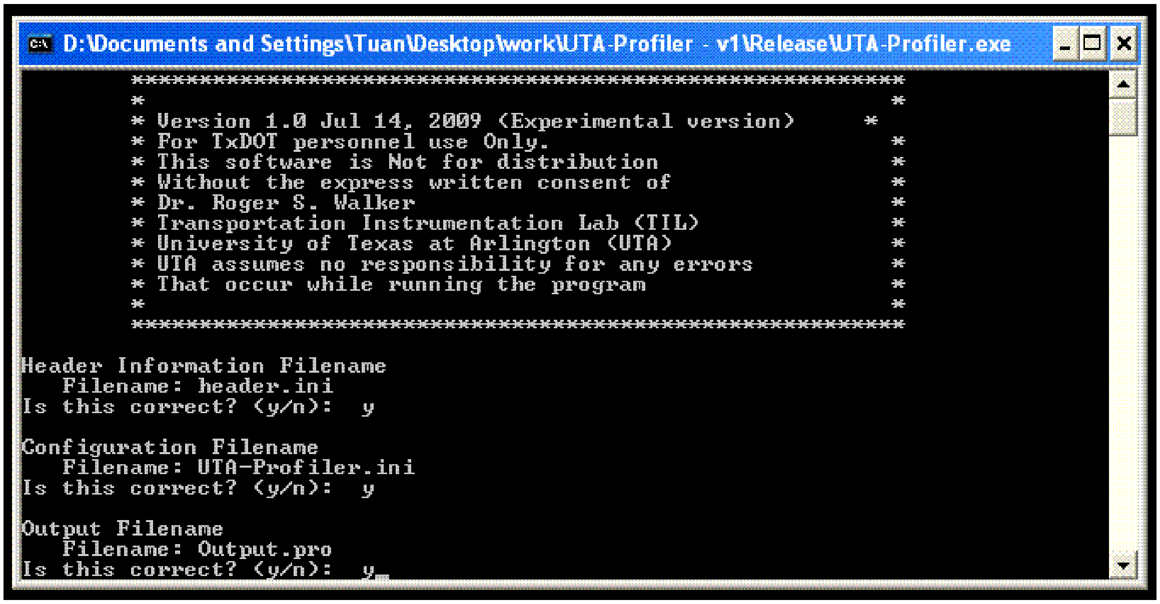

Figure 7 Entering Profile Output File Name/Location

6. Press any key to continue. The UTA-Profiler should display the current header information specified in the header file. Verify that this information is correct. (Figure 8)

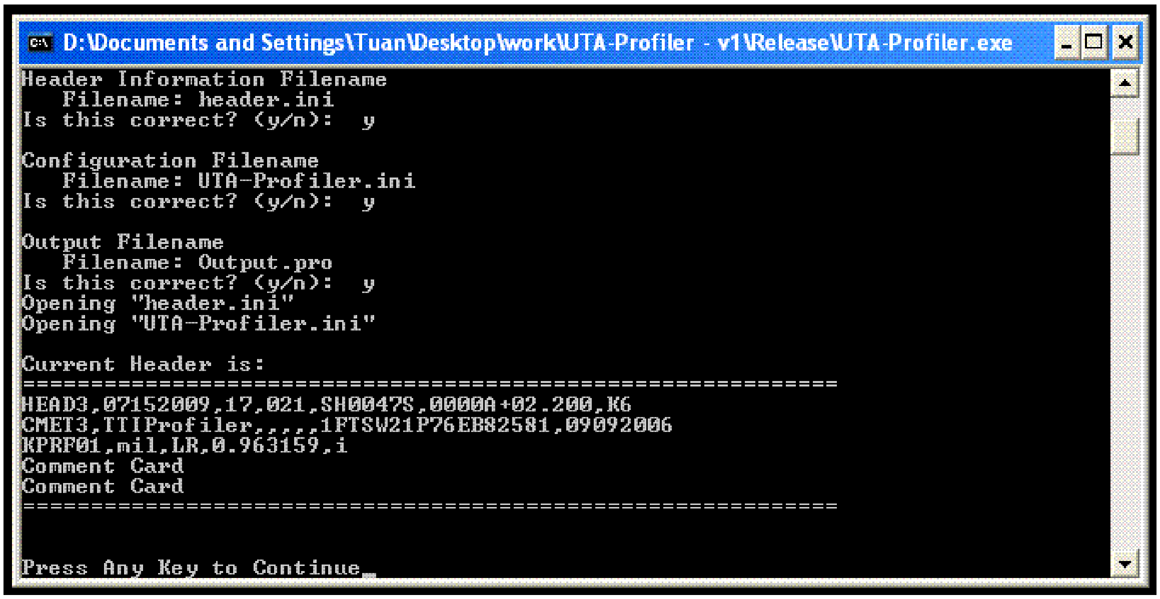

Figure 8 Verifying Initialization and Header File Information

7. Press any key twice to continue after the header information is verified. The UTA-Profiler should display the Data Translation board status. Press any key to continue after you have verified this information (Figure 9).

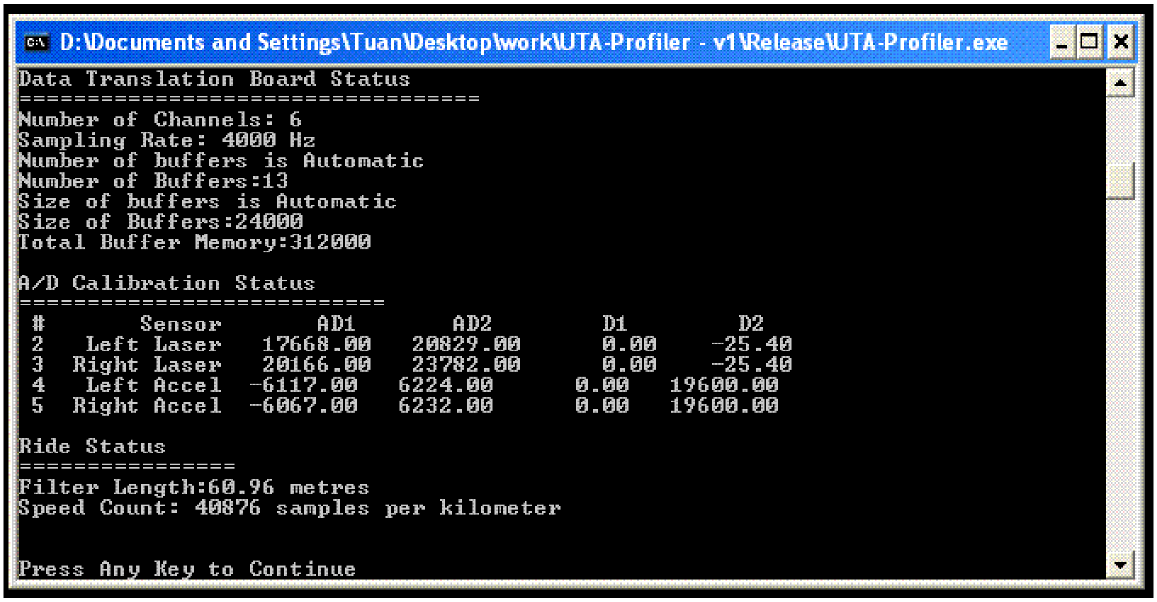

Figure 9 Verifying Initialization and Header File Information and Prepare for Data Collection

8. At the "Command Menu" (See Figure 10) select one of the following:

   a. The "S" or Start key to immediately start profile data collection, writing the profile file to the specified profile output file.
   b. The "P" or Pre-section key to begin computing profile. The computed profile is not stored but used to preload the digital filters and other initialization parameters consistent with the section to be measured. The pre-section should typically be should be at least 300 ft or about 100 feet further than the specified filter length.
   c. The "O" or Stop key to halt profile data collection
   d. The "R" or Real section key to immediately start profile data collection, writing the profile file to the specified profile output file. This is used to distinguish between the pre-section and the section that profile is to be measured and kept (Real).

e. The “A” or Arm key to tell the Profiler Program to automatically start the ‘Real’ data collection when a negative going pulse is sensed on the infrared start channel (channel 1).

f. The “Q” or Quit key to end data collection and close the specified profile output file.

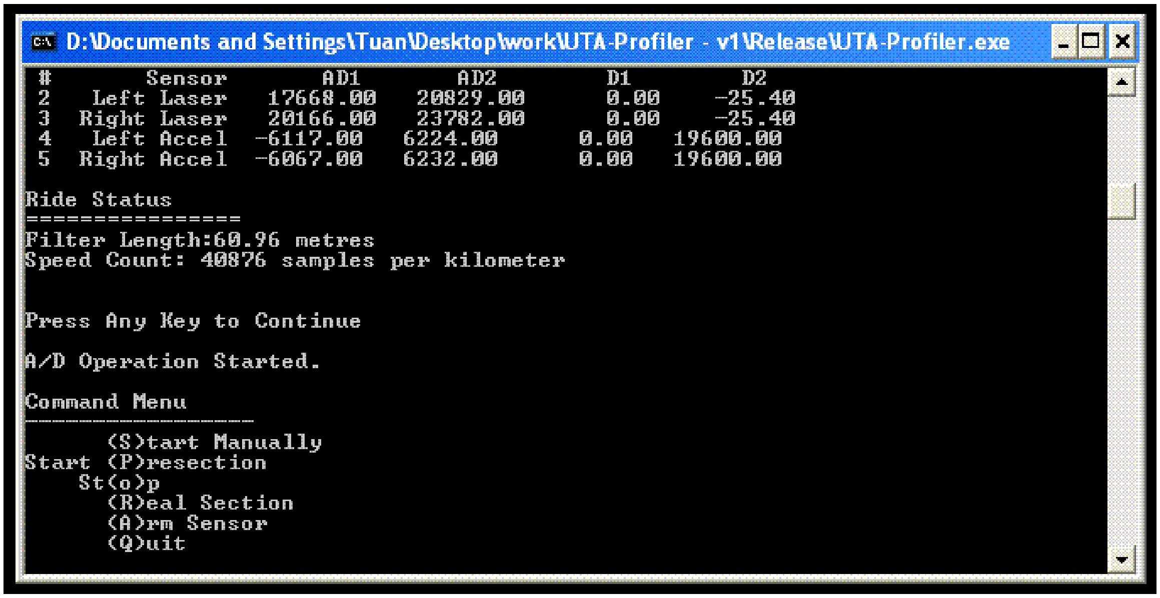

Figure 10 Verifying Initialization and Header File Information and Prepare for Data Collection

Figures 11 thru 15 depict the screens for each of the above options a. thru f.

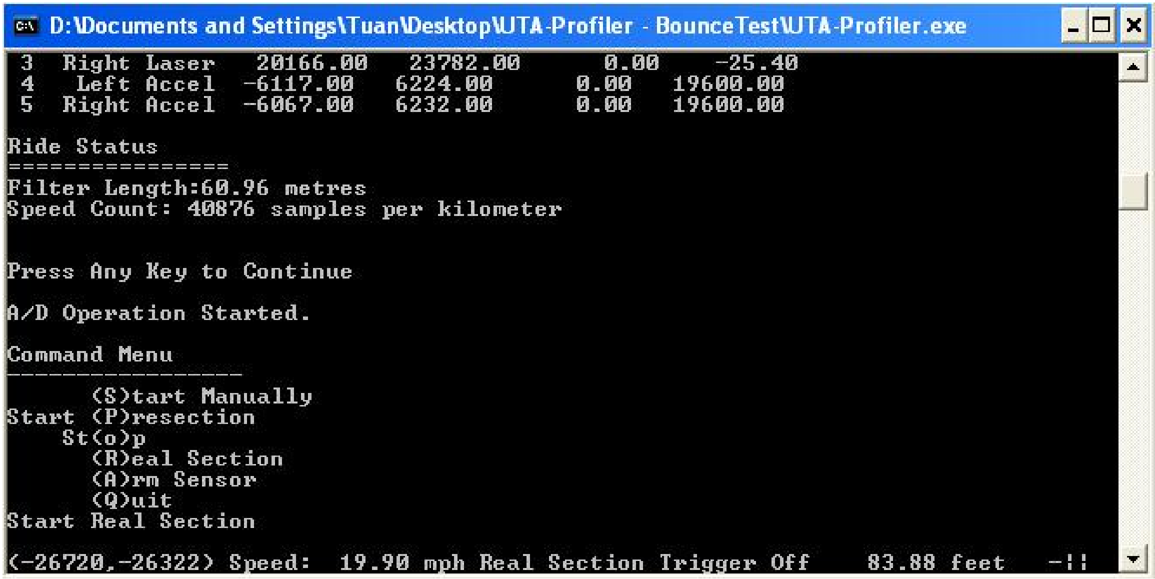

Figure 11 Selecting the Start Manually option

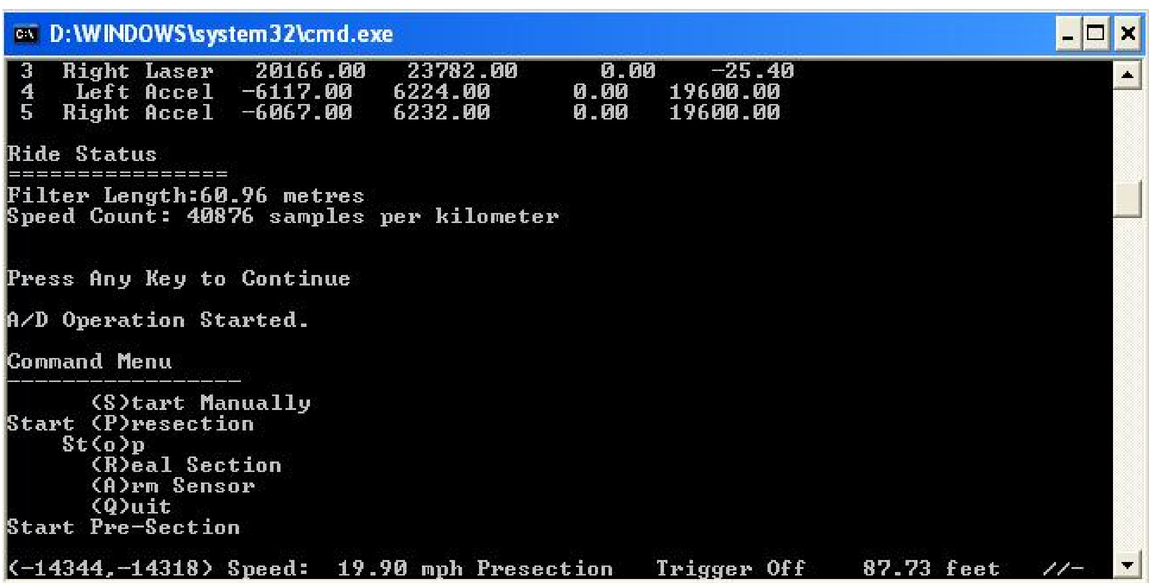

Figure 12 Selecting the Start (P)resection option

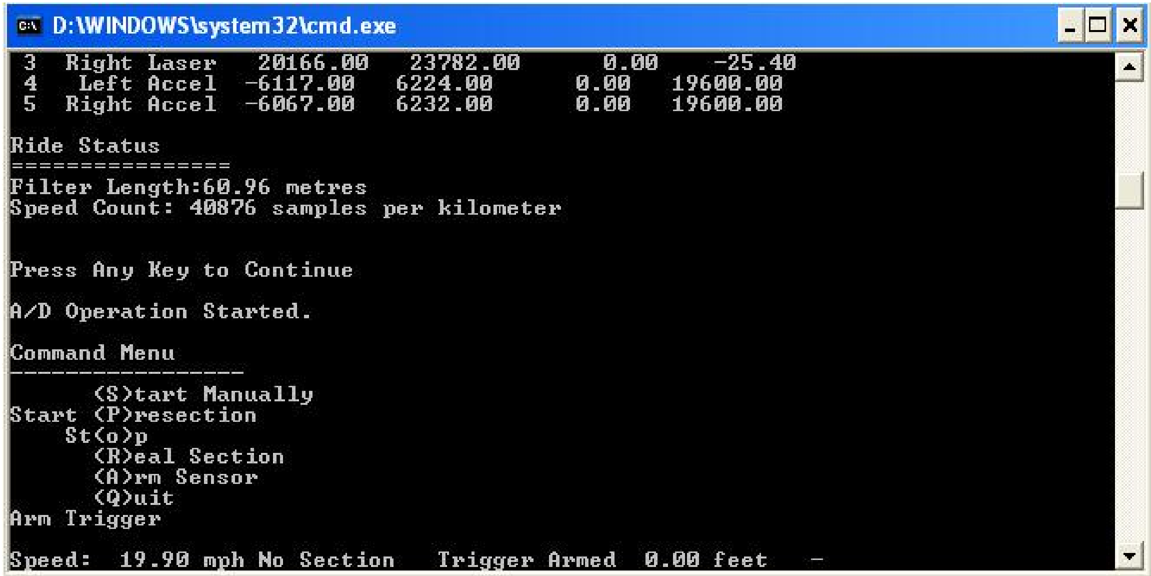

Figure 13 Selection the (A)rm sensor option

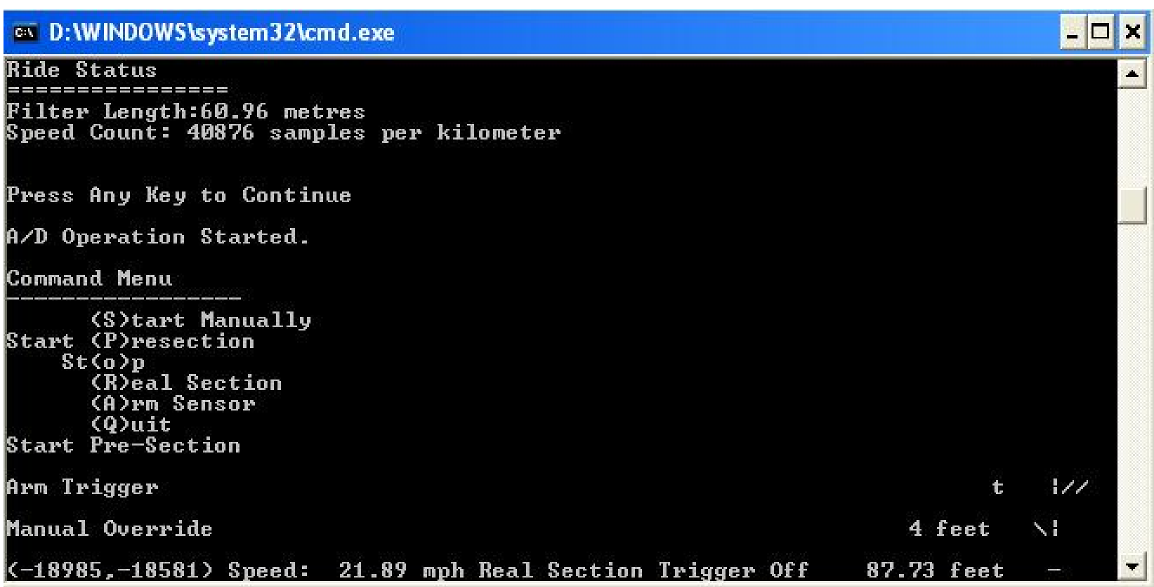

Figure 14 Selecting the (R)eal Section option

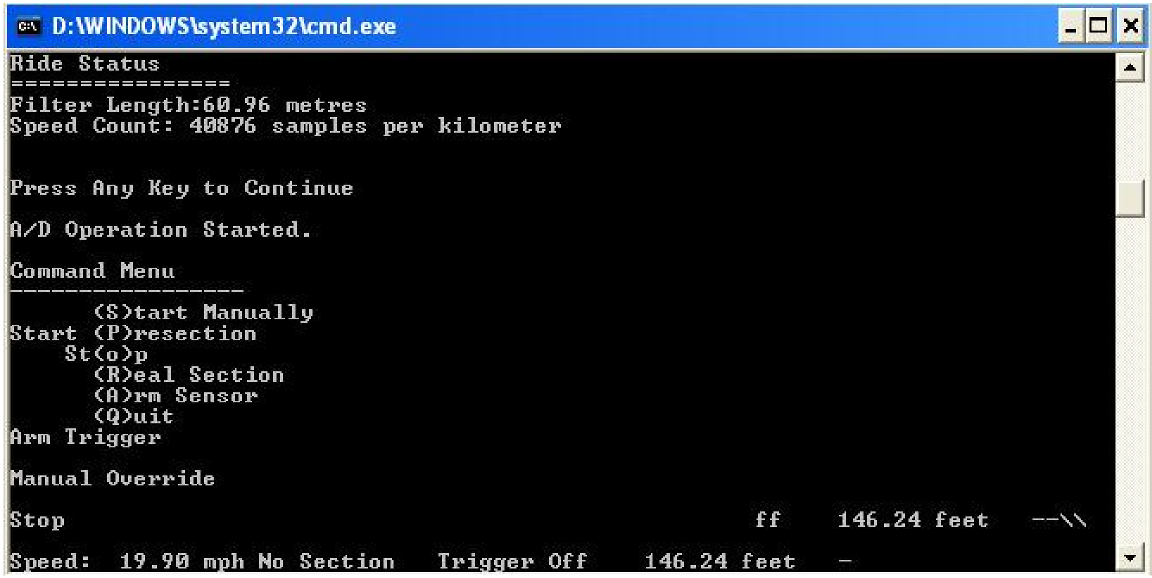

Figure 15 Selecting the St(o)p option

Portable Profiler Installation Guide

The following illustrations depict the installation of the Portable Profiler Mounting and Installation procedures.

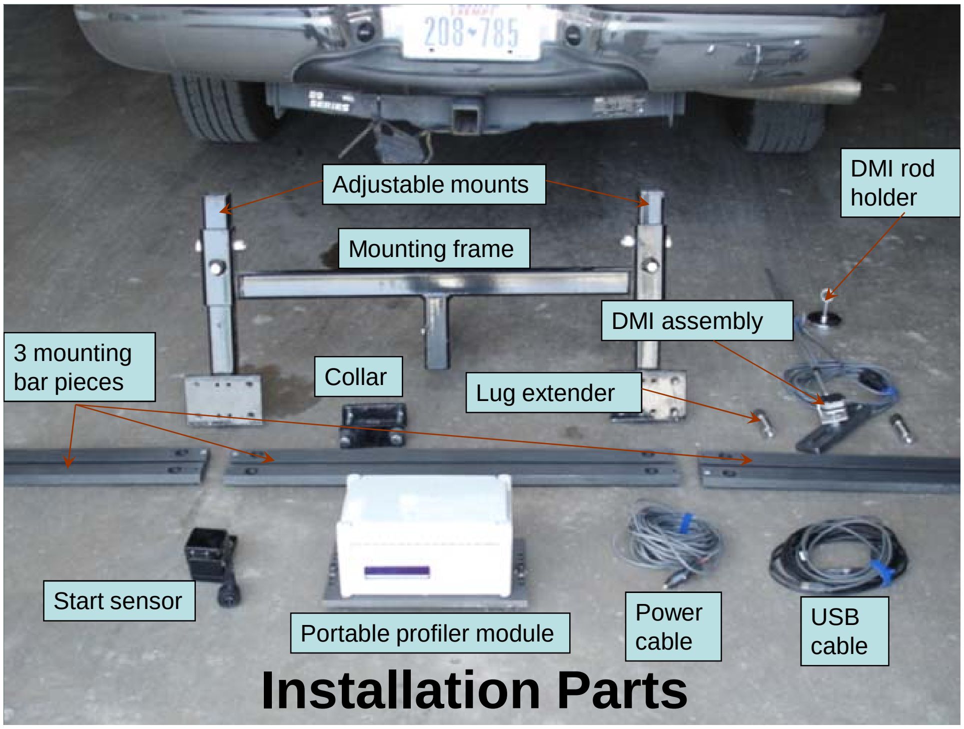

Figure 16 Installation Parts

Mounting the Portable Profiler Module

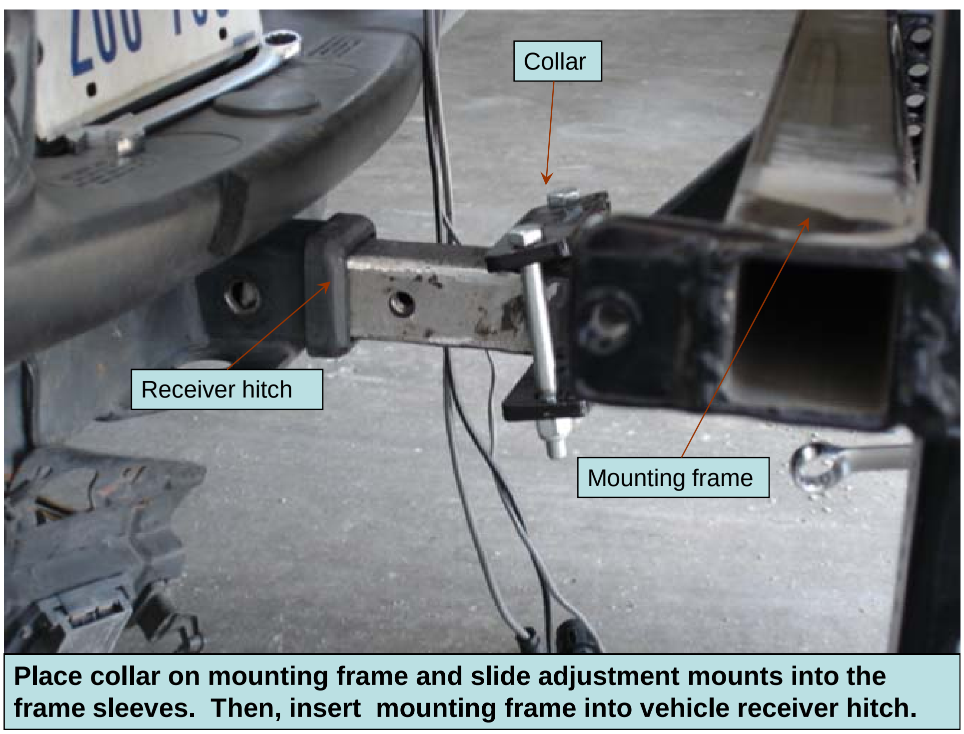

Figure 17 Place Collar on Mounting Frame

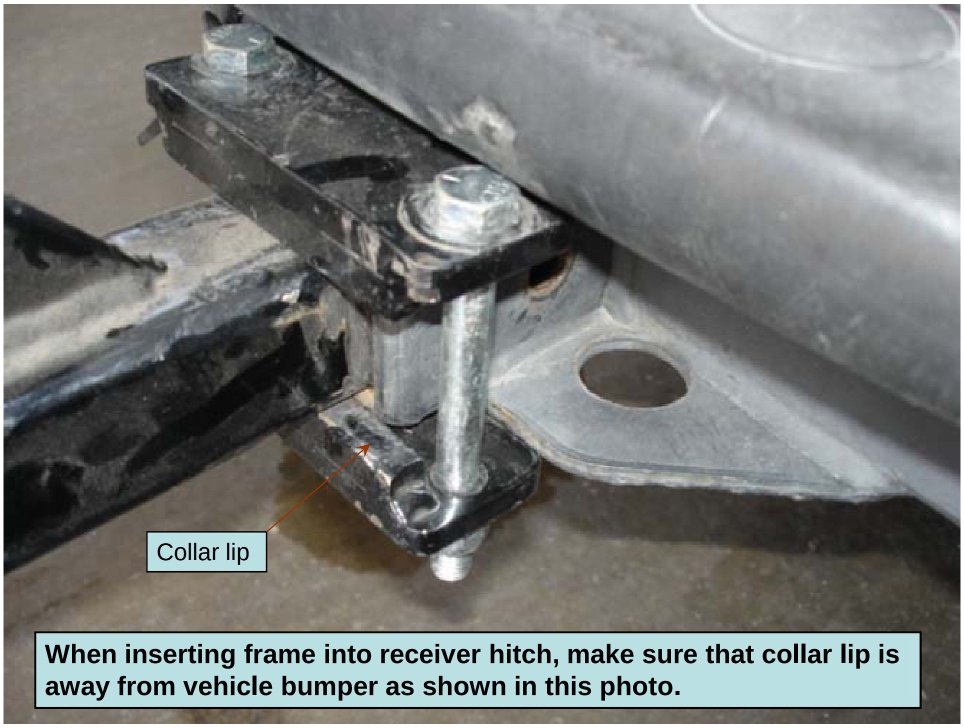

Figure 18 Insert Frame into Receiver Hitch

Figure 19 Secure Mounting Frame

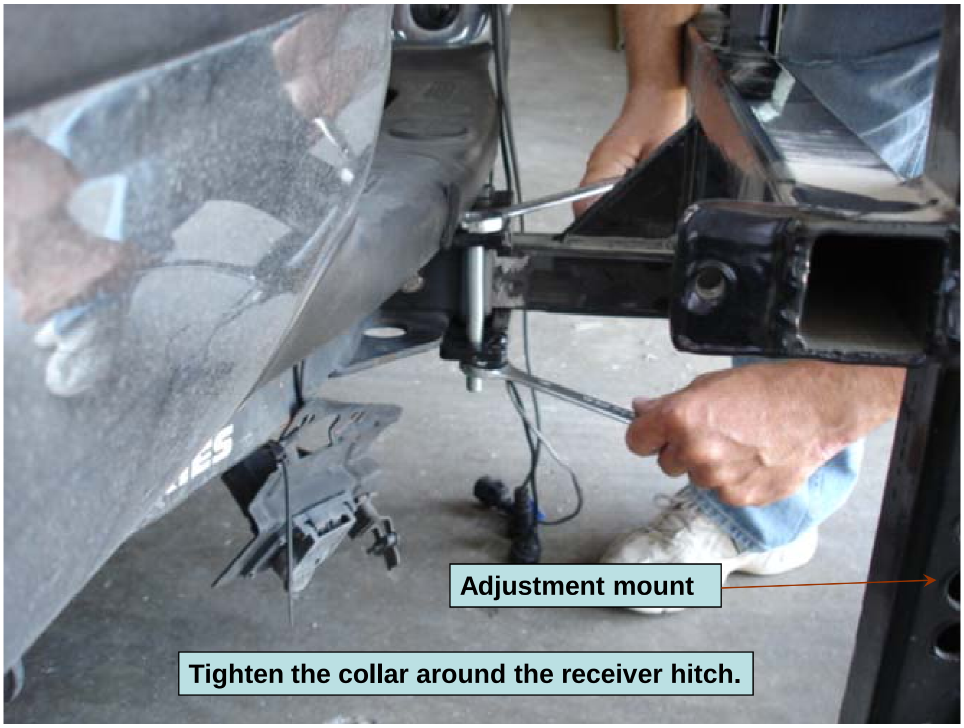

Figure 20 Adjust Mount

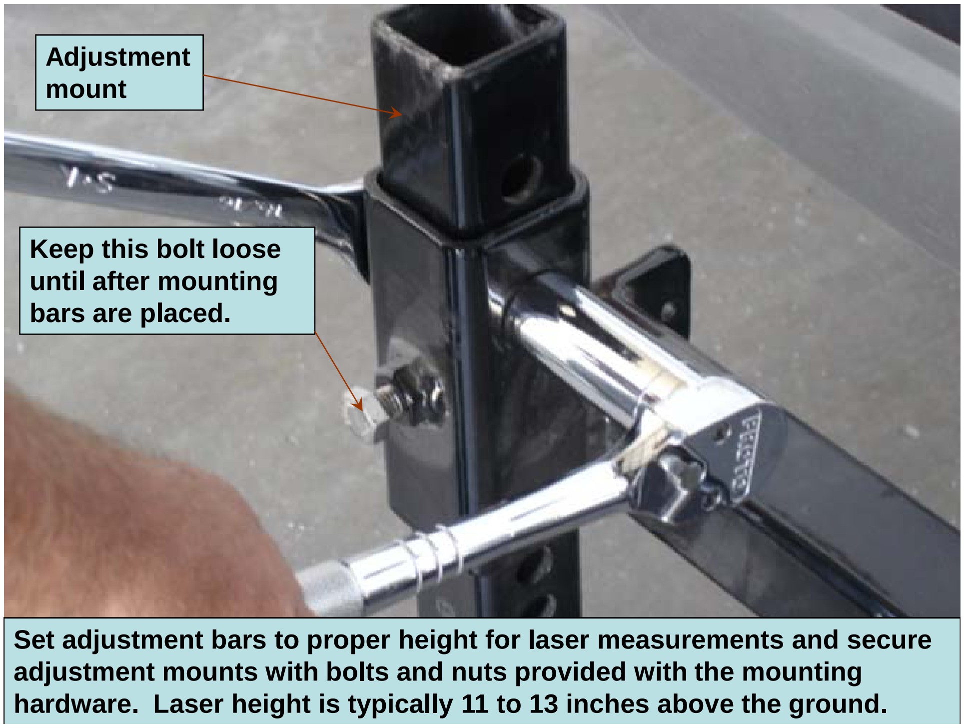

Figure 21 Adjust Height

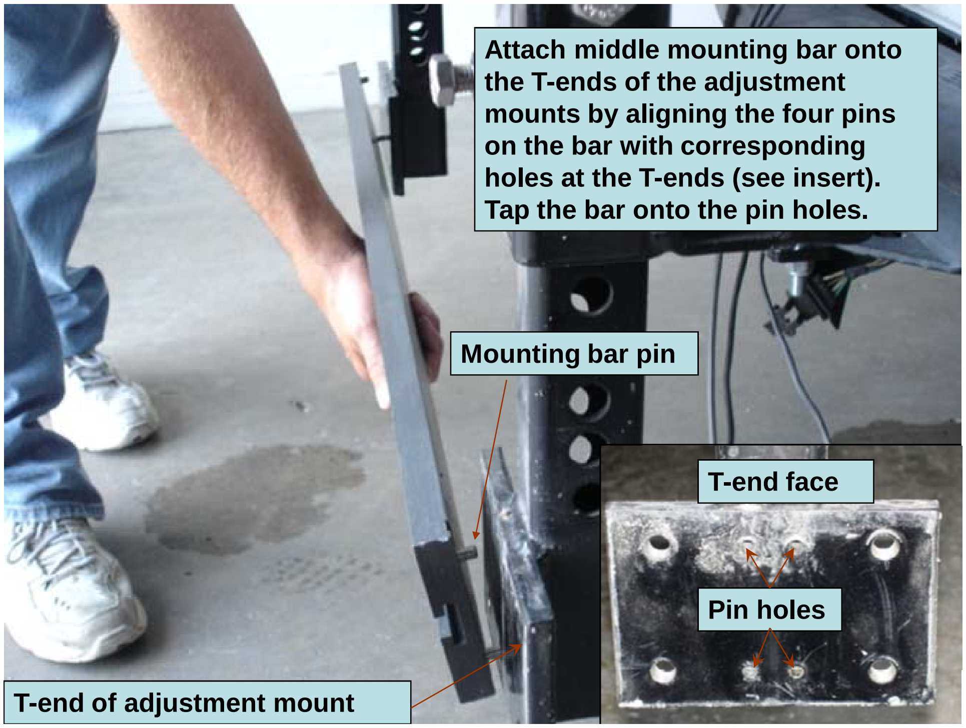

Figure 22 Attach Middle Mount

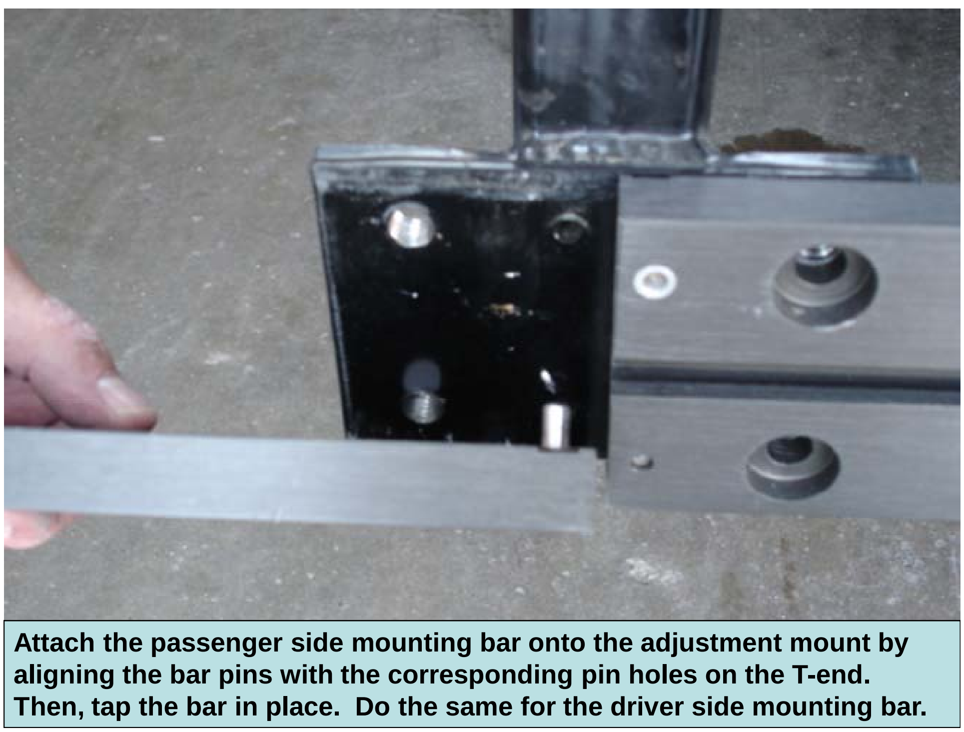

Figure 23 Attach Side Mount

Figure 24 Secure Mounting Bars

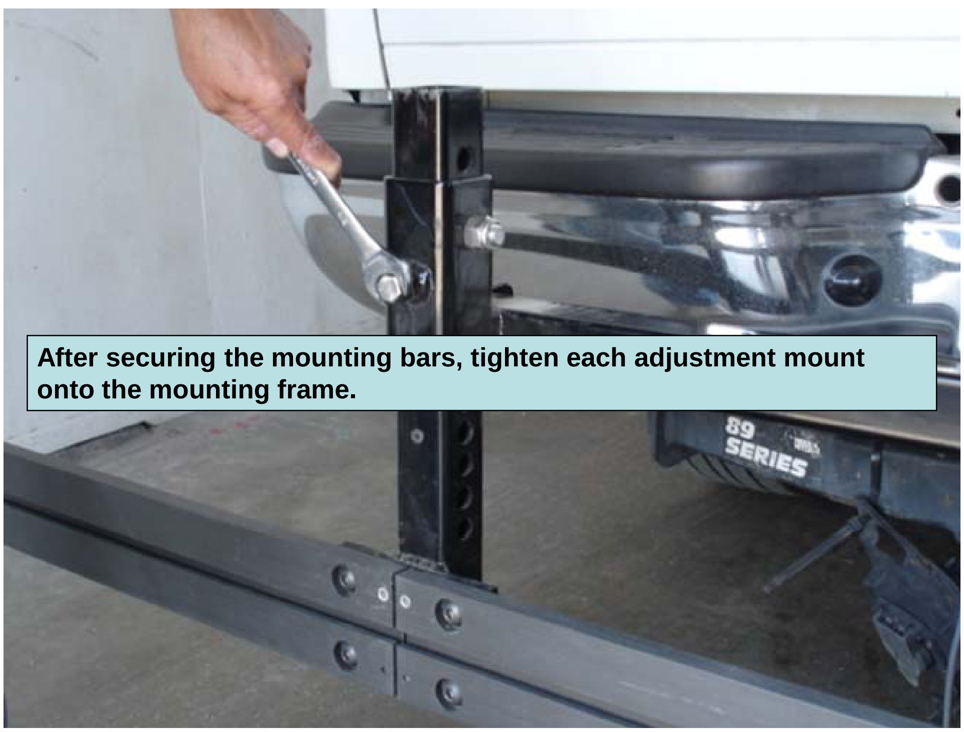

Figure 25 Tighten Mounting Bars

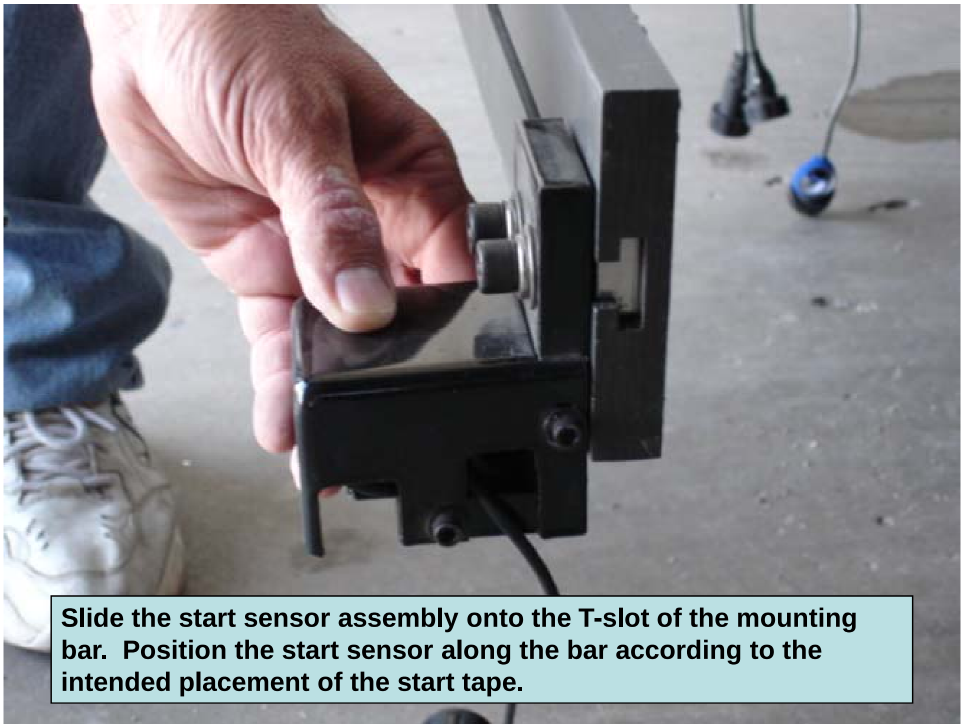

Figure 26 Mount Start Sensor

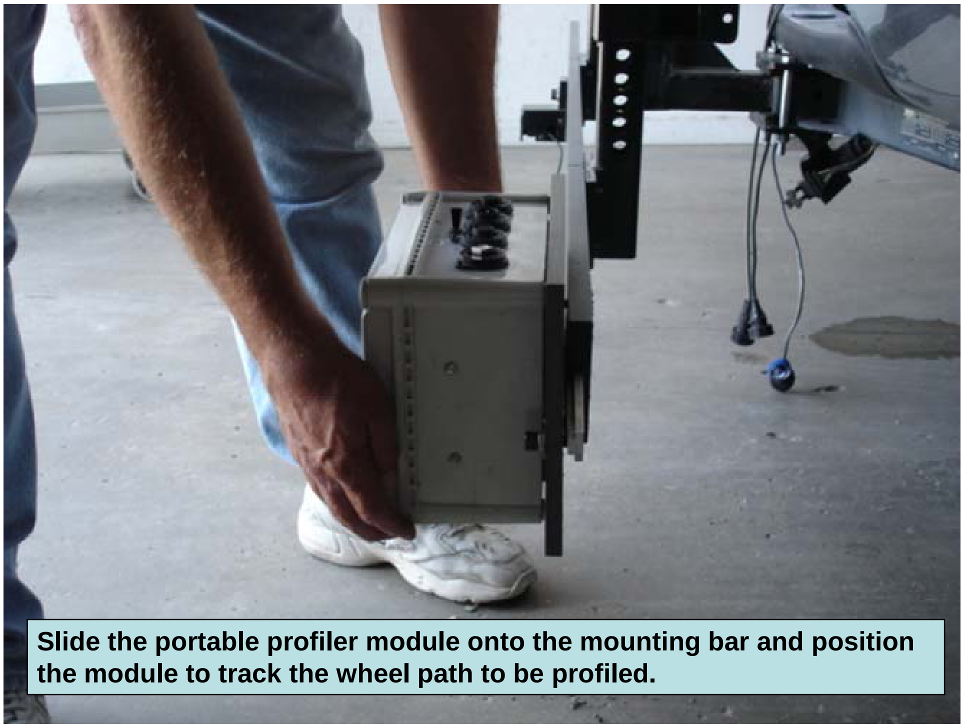

Figure 27 Mount Profiler Module

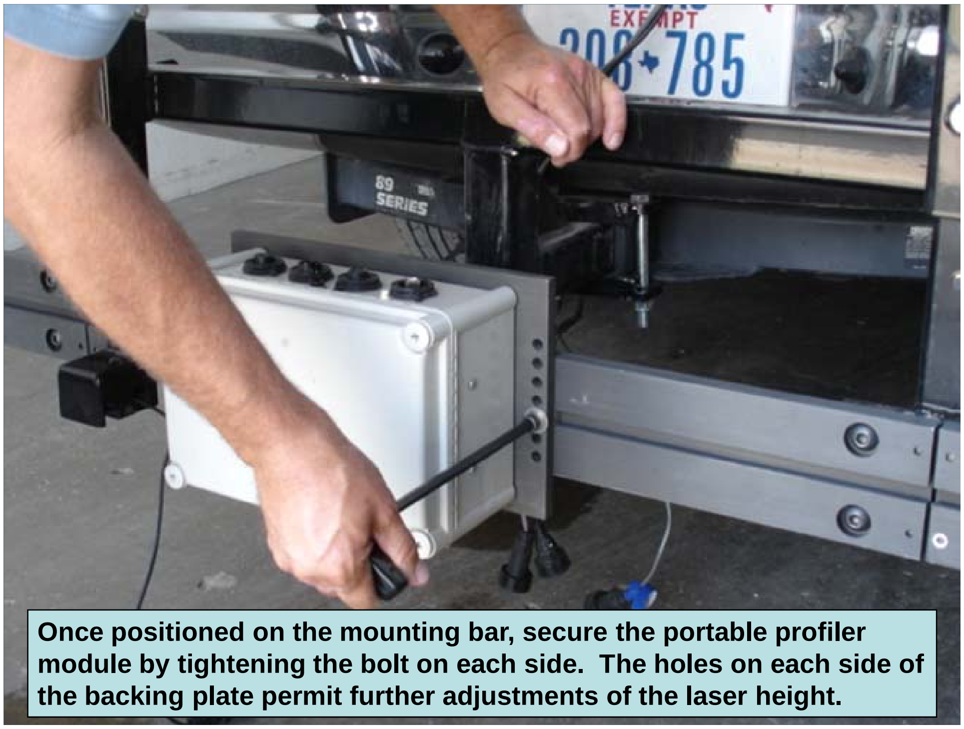

Figure 28 Position Profiler Module to Desired Location

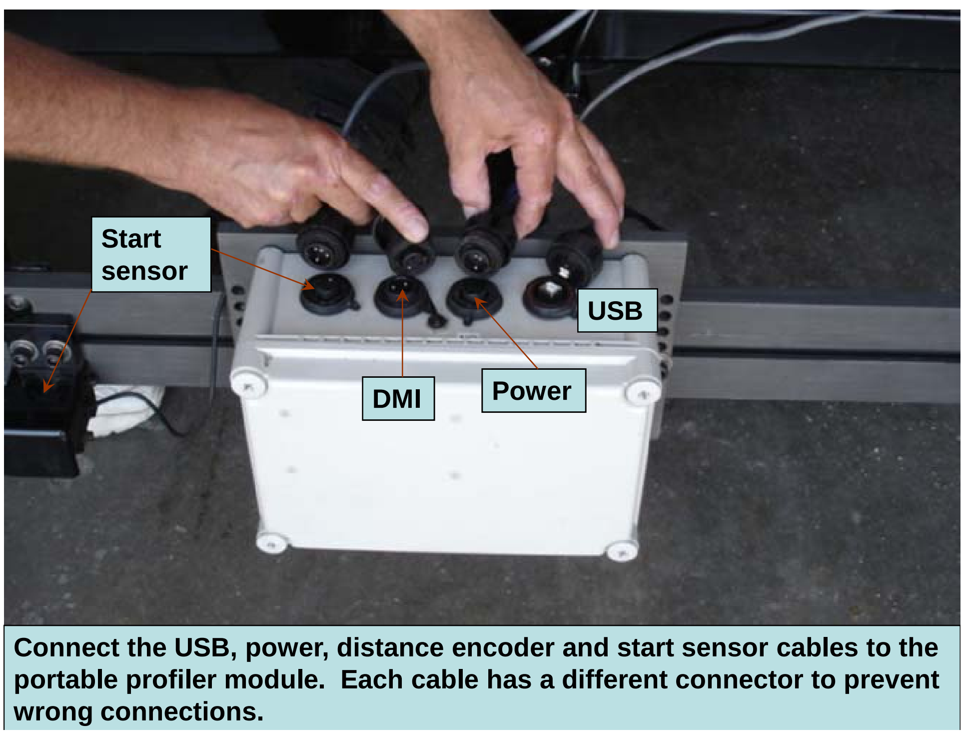

Figure 29 Connect Cables

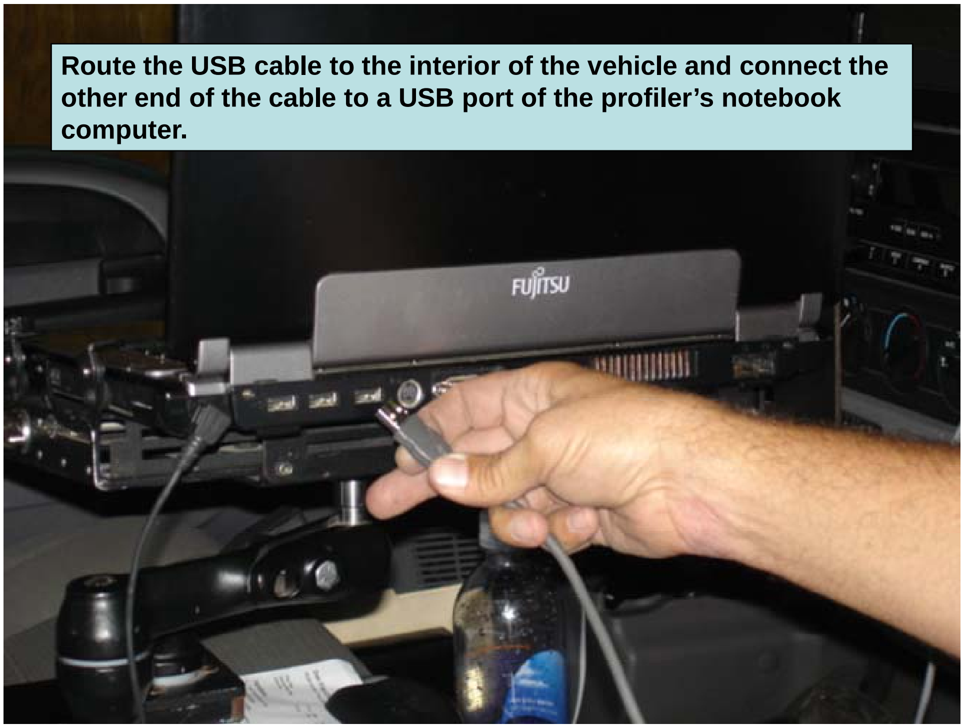

Figure 30 Route USB Cable to PC

Figure 31 Connect Power Cable

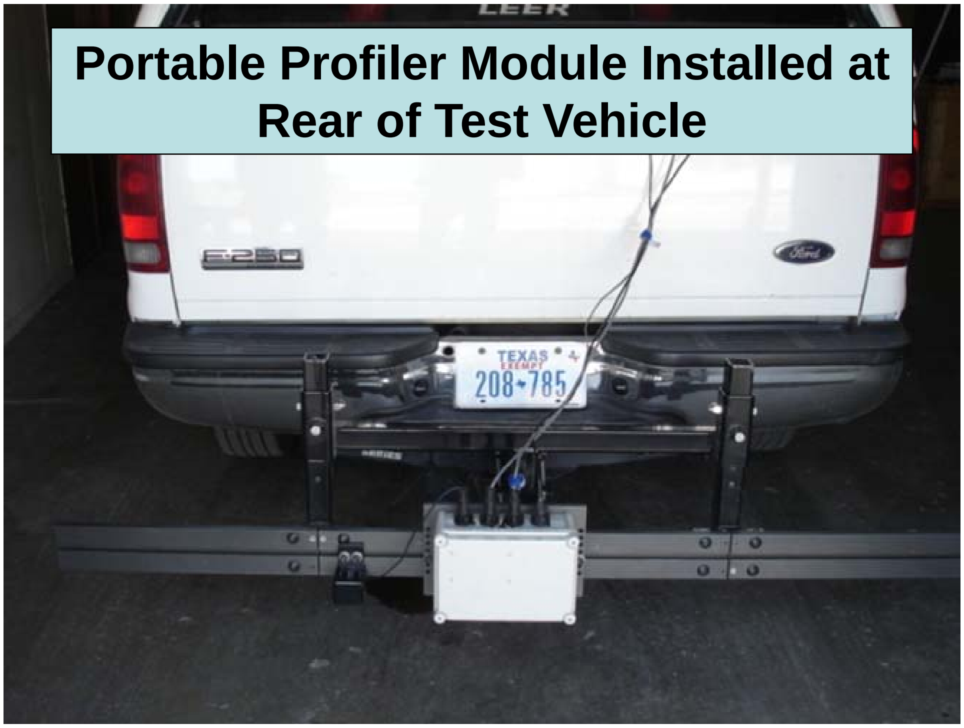

Figure 32 Completing Profiler Module Installation

Distance Encoder Installation

Figure 33 Mounting Lug Extenders

Figure 34 Encoder Holder Rod

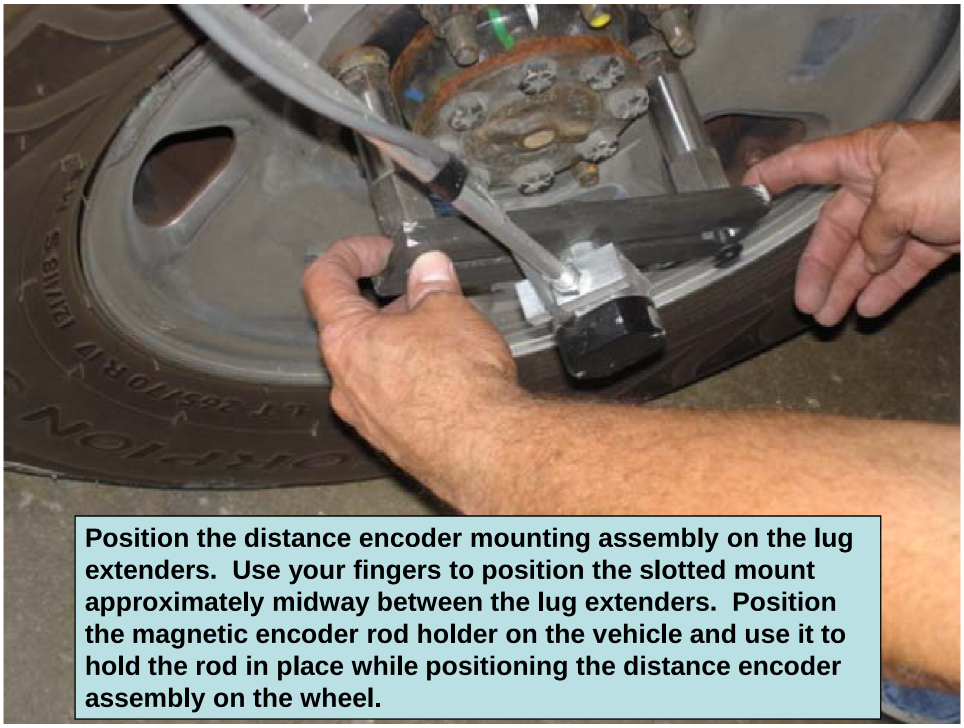

Figure 35 Position Encoder into Mounting Assembly

Figure 36 Secure Distance Encoder

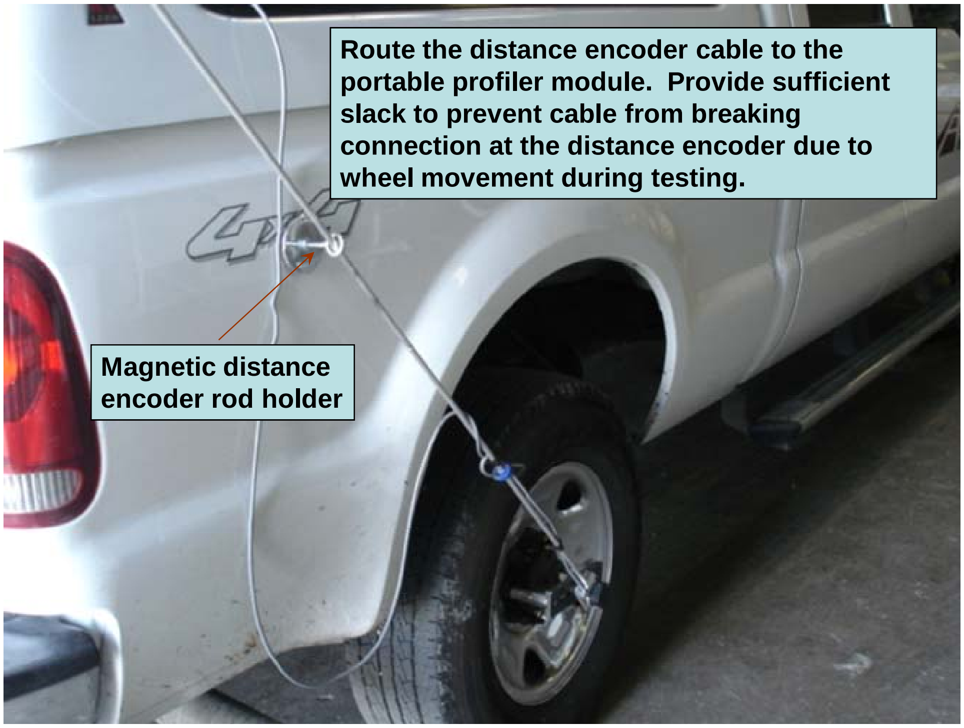

Figure 37 Complete Encoder Installation