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Instrumentation of Navistar Truck for Data Collection

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January 2013

Research Project
Final Report 2013-01

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The overarching goal of this project was to instrument the new MnDOT Navistar truck used at MN Road. A rugged data acquisition, data recording and wireless transmission system was established for collection of various sensor signals from the truck. The truck was instrumented with a suite of 20 accelerometers, with these accelerometers being located both on the five axles of the truck and on the tractor and trailer bodies. In addition, the truck was instrumented with a differential GPS system and an inertial measurement unit in the tractor cab. A cRIO-based data acquisition system, a rugged laptop and Labview software together serve as a flexible platform for data acquisition. A wireless communication system has been established to communicate trigger signals to roadside cabinets when the truck is at desired GPS locations on the road. Data recording by in-pavement sensors is triggered by this system. Software has also been set up for automatic downloading of data from the truck to a server on the network at MN Road. The experimental performance of the developed system has been verified by multiple tests conducted by the research team. The above instrumentation of the truck will enable data collection on truck vibrations, enable analysis of correlations between truck vibrations and variations in signals of weigh-in-motion sensors, and enable recording of truck movements and pavement loads at MnROAD.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The overarching goal of this project was to instrument the new MnDOT Navistar truck used at MN Road. A rugged data acquisition, data recording and wireless transmission system was established for collection of various sensor signals from the truck. The truck was instrumented with a suite of 20 accelerometers, with these accelerometers being located both on the five axles of the truck and on the tractor and trailer bodies. In addition, the truck was instrumented with a differential GPS system and an inertial measurement unit in the tractor cab. A cRIO-based data acquisition system, a rugged laptop and Labview software together serve as a flexible platform to which other sensor suites could be interfaced in the future. A wireless communication system has been established to communicate trigger signals to roadside cabinets when the truck is at desired GPS locations on the road. Data recording by in-pavement sensors is triggered by this system. Further, a time stamp signal is communicated so that the time values of recordings of the in-pavement sensors and of the sensors on the truck can be synchronized. Software has also been set up for automatic downloading of data from the truck to a server on the network at MN Road.

The experimental performance of the developed system has been verified by multiple tests conducted by the research team. This report provides samples of some recorded data and also includes a user manual for use of the data recording software on the truck.

The above instrumentation of the truck will enable data collection on truck vibrations, enable analysis of correlations between truck vibrations and variations in in-pavement weigh-in-motion sensors, and enable recording of truck movements and pavement loads at MnRoad.

1. PROJECT OBJECTIVES

The overarching goal of this project was to instrument the new MnDOT Navistar truck at MnRoad. The following were specific aims of the project:

1. To instrument truck with a rugged data collection, data recording and wireless communication system in order to establish a flexible platform for data collection from various sensor suites on the truck.
2. To establish a wireless communication set up between truck and roadside cabinets at MnRoad to trigger data recording from in-pavement sensors at desired GPS locations of the truck.
3. To instrument truck with an inertial measurement unit, with accelerometers on body and axles and to integrate them with the existing MnROAD Vehicle Tracking System.
4. To set up software for automatic downloading of data from truck to a server at the MnRoad location.

The expected benefits of this project are as follows:

1. Development of the proposed instrumentation on the truck will enable automated data collection and data downloading both from the MnROAD Vehicle Tracking System and from the sensors on the truck.
2. By allowing data collection to be triggered for specific stretches of GPS coordinates, data will be collected only when the truck is actually passing over the in-pavement sensors, thus saving very significantly on storage requirements.
3. Collection of axle and truck body vibrations using accelerometers on the truck will enable the quantification of truck vibration influence on weigh-in-motion sensors signals.
4. The dynamic loading data on pavements can be recorded by measurement of truck suspension vibrations.
5. In the future, the measurement of truck suspension and axle vibrations will allow for correction of weigh-in-motion sensor readings, so that all weigh-in-motion sensors around the state can be better calibrated.

2. TRUCK HARDWARE

2.1 Introduction

The key requirements for development of the instrumentation were ability to read analog voltage inputs from sensors on truck, ability to read GPS signals (through an RS 232 serial port), ability to read CAN bus signals in the future, Wi-Fi support for communication with server, and interface with a wireless transceiver. The corresponding software for reading and processing all of these signals also needed to be written.

The National Instruments cRIO system is chosen as the basic platform for data recording, processing and communication. The cRIO system is rugged and when installed in a rugged chassis together with a rugged laptop can successfully withstand the vibrational environment in the truck.

2.2 Accelerometers

Two types of accelerometers were purchased from Analog Devices: ADXL335Z accelerometers with +/- 3g measurement range (for use on the tractor and trailer bodies) and ADXL325Z accelerometers with +/- 5g range (for use on the axles). This is because acceleration values on the axles were measured to occasionally exceed 2g on MnRoad at speeds of 50 mph or higher. Since a rougher road can cause higher accelerations, a range of +/- 3g was felt to be inadequate for axle acceleration measurements.

Accelerometers were placed symmetrically on the left and right sides of the truck. Figure 2.2 shows a schematic of the accelerometer locations on the left side of the truck. Figure 2.4 shows a schematic of the accelerometer locations on the right side of the truck. Figure 2.1 below shows a photograph of an accelerometer placed near the front of the trailer on the trailer body. As seen from the photograph, the accelerometer has been sealed inside a box that protects it from water and other environmental variables.

Figure 2.1: Accelerometer at top left near the front of trailer (TLF2 location).

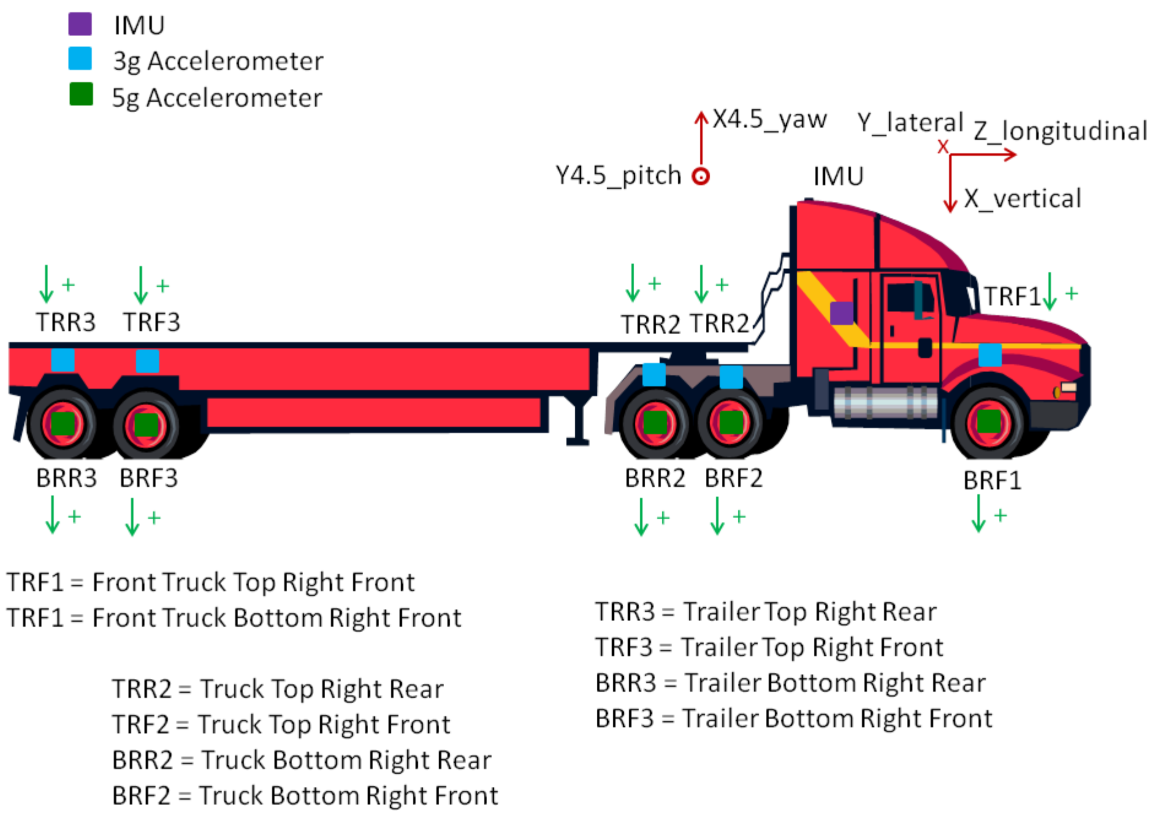


Figure 2.2: Accelerometer locations on right side of truck.

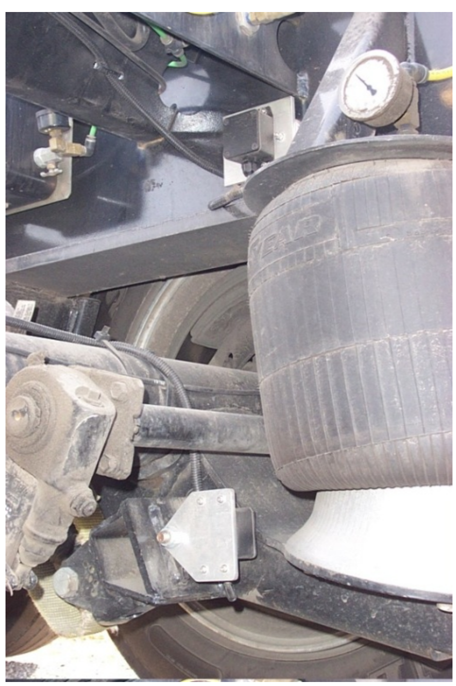


Figure 2.3: Top and bottom accelerometers near rear axle of trailer.

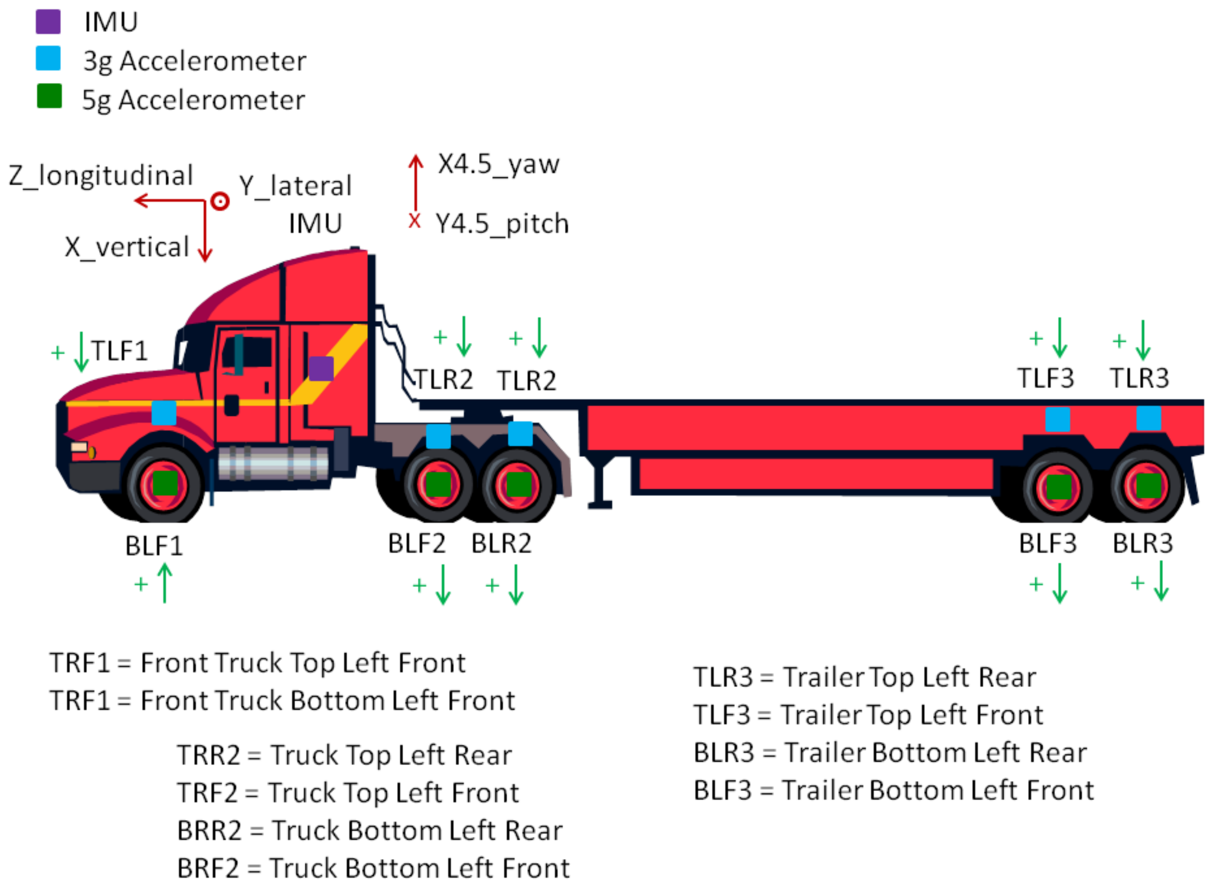


Figure 2.4: Accelerometer locations on left side of truck.

Figures 2.3, 2.5, 2.6, 2.7 and 2.8 show photographs of accelerometers at various locations on the truck.

Figure 2.5: Accelerometer at front left top of tractor.

Figure 2.6: Accelerometer at second axle of tractor on bottom right.

Figure 2.7: Accelerometer on front (steering) axle of tractor at bottom left.

Figure 2.8: Accelerometer on tractor body near the front (steering) axle.

2.3 Wiring Diagram

Figure 2.9 shows the complete wiring diagram of the truck instrumentation. It details the wiring which connects sensors (accelerometers and IMU) to the cRIO port on the right hand side of the diagram.

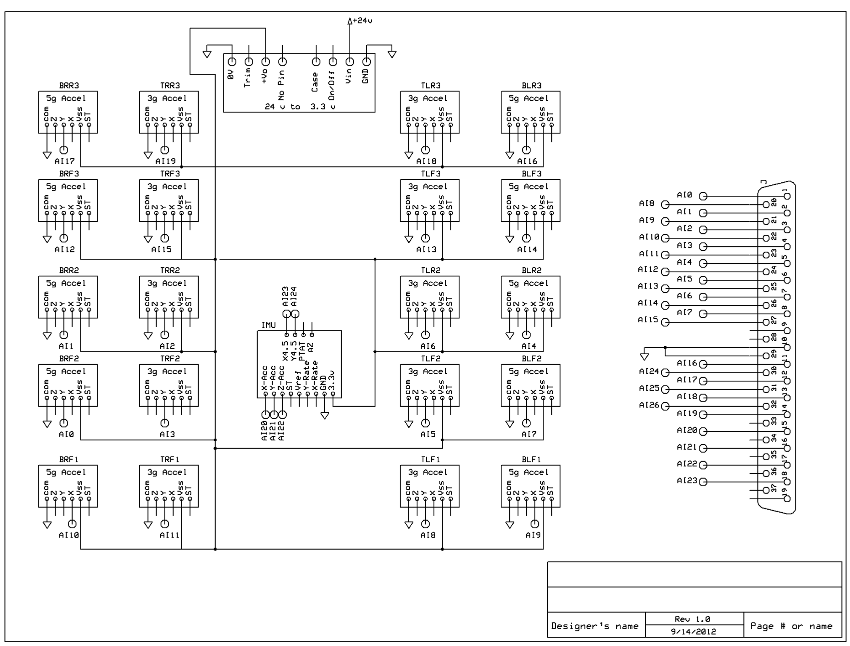


Figure 2.9: Wiring diagram showing connections of various sensors to the cRIO system.

2.4 Data Acquisition Equipment

The major items that were purchased and utilized in the instrumentation of the Navistar truck are shown in Table 2.1.

Table 2.1: List of major hardware purchases for truck.

	Item	Details
1.	Compact Rio Chassis	cRIO-9076 Part number: 781716-01 (CRIO-9076 Integrated Controller and Chassis, 4-Slot LX 45 FPGA)
2	Analog input data acquisition module	NI 9205, 32-Ch ±200 mV to ±10 V, 16-Bit, 250 kS/s Analog Input Module Part number: 779357-01 (37-pin D-Sub connector type)
3.	Power supply	781093-01 NI PS-15 Power Supply, 24 VDC, 5 A, 100-120/200-240 VAC Input
4.	Extended Warranty	a) NI Standard System Assurance Program for cRIO (Driver installation and extended warranty) CompactRIO - 960903-04 b) cRIO Standard 8-slot Chassis System Services (Installation of module, calibration and Extended warranty) 960850-08
5.	Ethernet Cable	cRIO Ethernet Cable 182219-01
6.	Serial port cable	RS232 CRIO cable 182238-01
7.	Termination panel connector	NI 9933 37 pin D-Sub connector kit part number Part # 779103-01
8.	Termination panel	CB-37F-LP Unshielded, I/O Connector Block with 37 pin D-Sub Part # 779353-01
9.	Accelerometers	10 of ADXL335Z , range +/- 3g
10.	Laptop	Dell XFR Rugged Laptop
11.	Accelerometers	10 of EVAL-ADXL325Z, range +/- 5g
12.	Inertial Measurement Unit	IMU IDG500 from Sparkfun Electronics, 5 degrees-of-freedom

2.5 Wireless Triggering

The VTS2 program is designed to send triggering signals to initiate data collection when the loaded truck drives over one of a set of trigger points that are close to pavement sensors being monitored by portable data collection cabinets. These triggering signals are sent to the portable cabinets via an Xbee/IORelay wireless connection, and to a National Instruments cRIO system in the truck that collects accelerometer data from the truck and trailer suspension. The test runs are made in two different modes. In "Back and forth" mode the truck is driven forward at a speed of about five mph over one trigger point and one set of pavement sensors then backed up and driven forward again four more times before moving on to the next trigger point. The triggering only occurs when the truck is driving forward, not when it is backing up. In "Loop" mode the truck is driven over the full set (usually six or seven) of trigger points then loops back to the beginning making a total of five laps at a speed of about 40 mph. In "Back and forth" mode the sensors (in the truck and in the portable cabinets) collect data for fifteen seconds each time they are triggered. In "Loop" mode the sensors collect data for five seconds each time they are triggered. To trigger the cabinet data collection the VTS2 program in the truck uses an Xbee radio to send the IORelay in the cabinet a packet containing the IORelay address and an "on" byte followed 150 milliseconds later by a similar packet with an "off" byte. At the same time the VTS2 program uses an Ethernet socket connection to trigger the National Instruments cRIO accelerometer data collection in the truck.

2.6 Sample Accelerometer Data

The figures below (Figures 2.10 – 2.14) show axle vibrations on the first and second axles of the semi truck at speeds ranging from 10 mph to 50 mph. It can be seen that vibrations are low at 10 mph (< 100 milli-g's rms), increase to 500 mg rms at 40 mph and increase significantly to 900 mg rms at 50 mph.

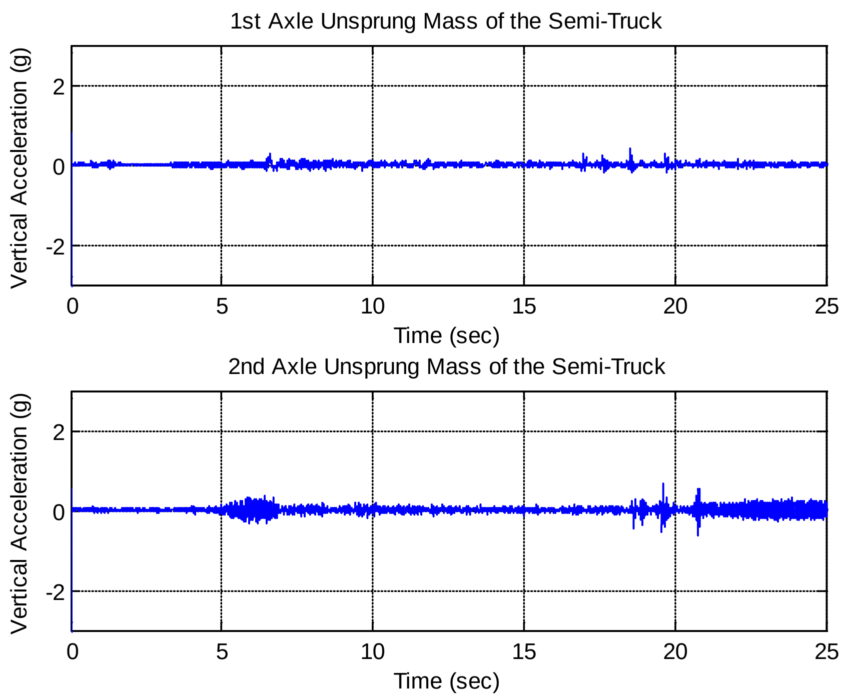


Figure 2.10: Axle vibrations on semi-truck at 10 mph.

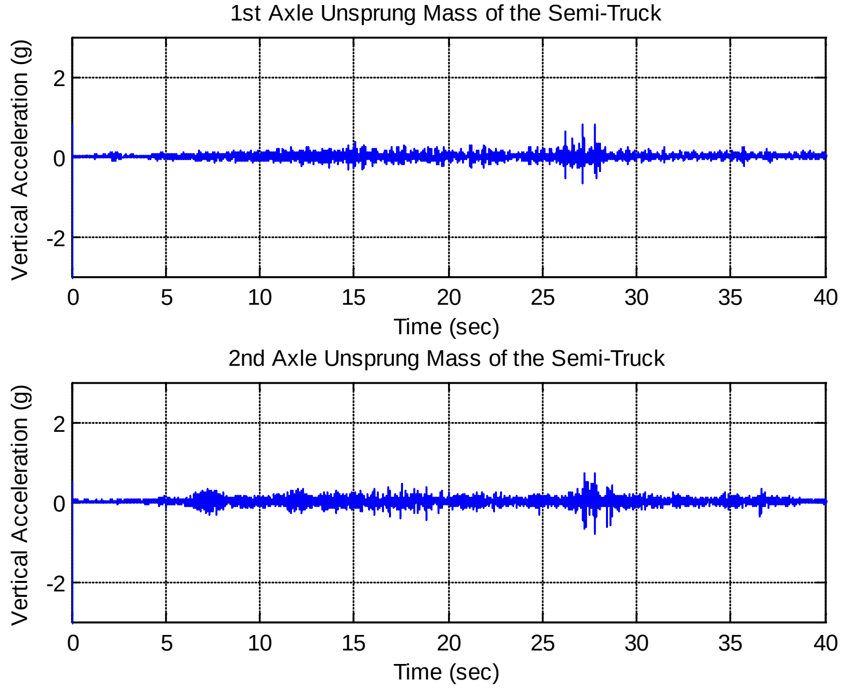


Figure 2.11: Axle vibrations on semi-truck at 20 mph.

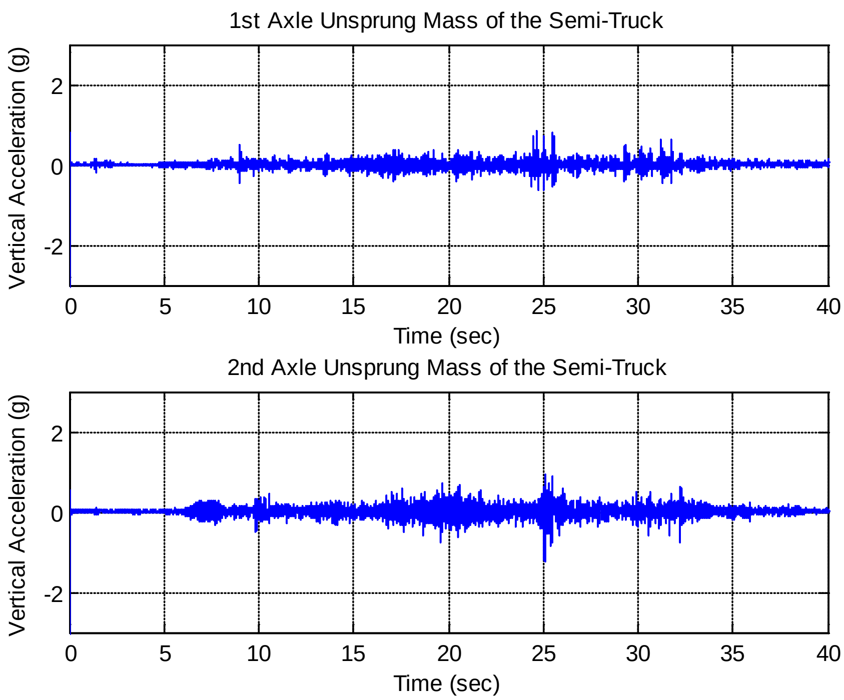


Figure 2.12: Axle vibrations on semi-truck at 30 mph.

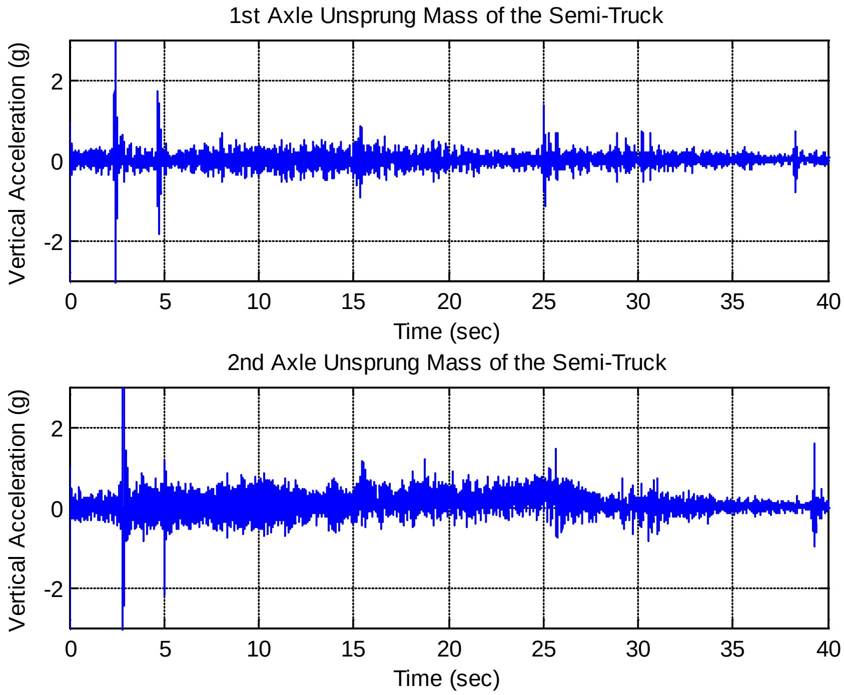


Figure 2.13: Axle vibrations on semi-truck at 40 mph.

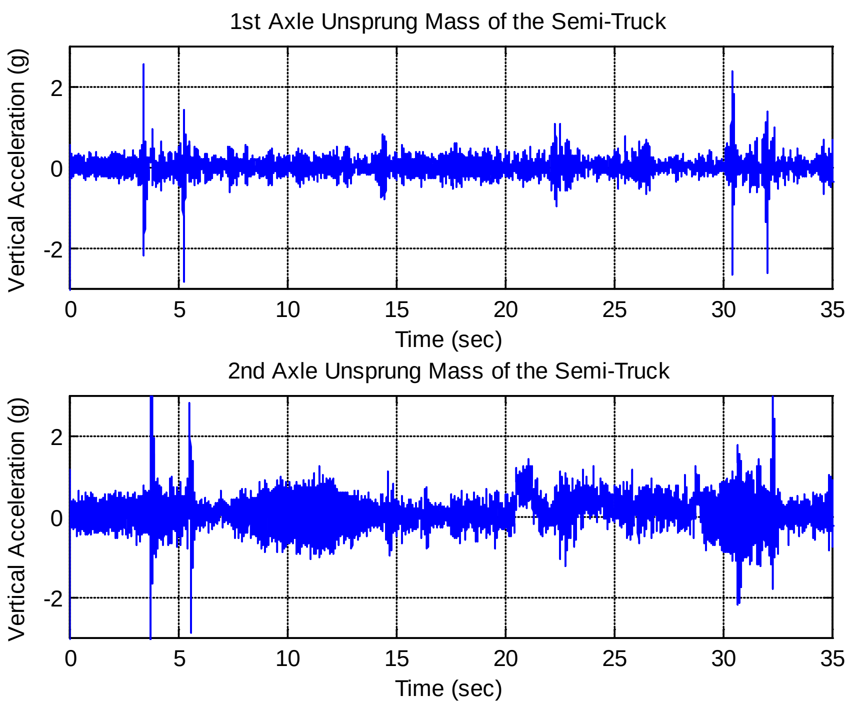


Figure 2.14: Axle vibrations on semi-truck at 50 mph.

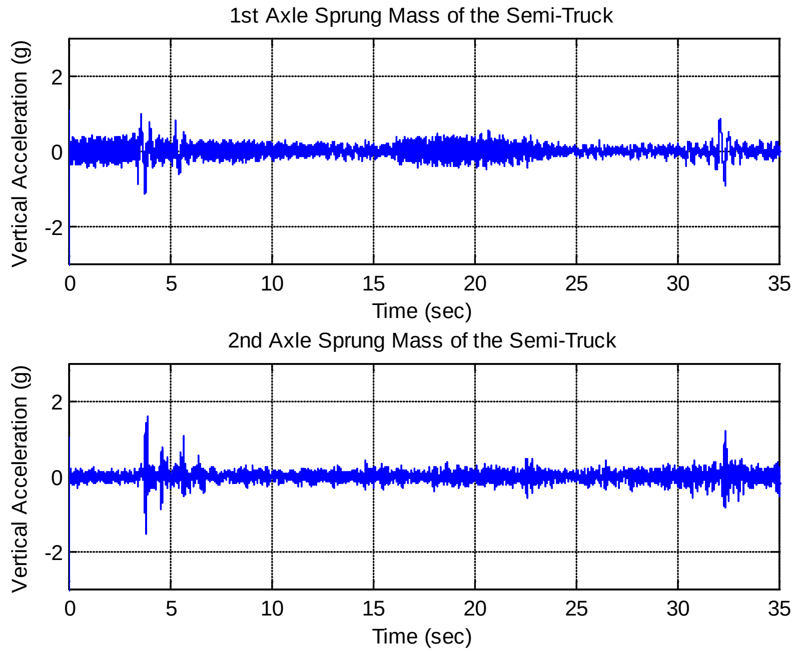


Figure 2.15: Sprung mass vibrations near first axle at 50 mph.

Figure 2.15 shows acceleration on the sprung mass (vehicle chassis) of the tractor at a longitudinal location near the front axle. It can be seen that the sprung mass vibrations are significantly smaller than the axle vibrations, with rms acceleration values being less than 200 mg.

2.7 Testing the Triggering System

Initial development of the triggering system was accomplished using a portable Garmin R8 differential GPS receiver mounted to a pickup truck at the MnRoad test facility using actual trigger points on the low volume road. The first version of the VTS2 program implemented the "Loop" mode where the program sends a trigger signal when it calculates that the current position as sensed by the GPS is within three meters (later changed to one meter) of the first trigger location on a predefined trigger list. A pointer is then incremented to the next record on the trigger list and the program starts calculating the distance to the next trigger point repeating the process until the last point on the list has been reached.

Our first attempt to use the system was during the regularly scheduled spring sensor calibration data collection at MnRoad. One of the things that became apparent at that time was the need for the "Back and forth" mode that automatically disarms the triggering system when backing up past a trigger point and then rearms the system for the forward pass. This capability was added to the program over the summer. The final system test was in late September during the fall sensor calibration data collection and after the correction of a few more program bugs (many thanks to the crew at MnRoad for their patience) the system seemed to work as designed with the VTS2 GPS log files and the cRIO accelometer log files appearing to be in order. The final test will be when MnDOT analyzes the data from the cabinets and correlates that data with the data from the sensors on the truck.

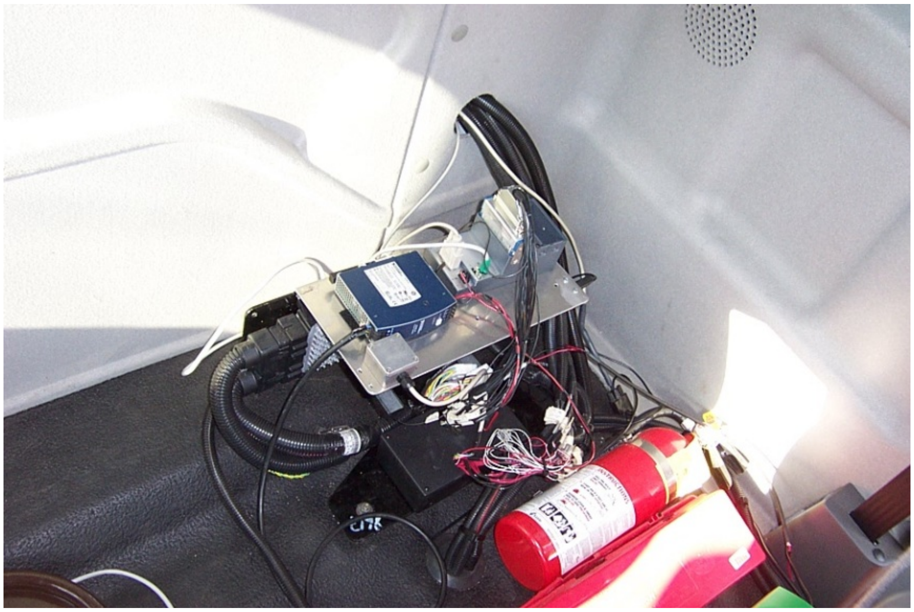


Figure 2.16: Equipment inside the tractor cab at a location behind driver's seat. The cRIO system and power supply are seen.

Figure 2.17: Differential GPS system located above tractor cab.

3. TRUCK SOFTWARE AND USER MANUAL

3.1 Vehicle Tracking System Software

The vehicle tracking system program (VTS2) can run by itself to trigger sensor cabinets and collect the same GPS files that the previous vehicle tracking program collected, or it can be run in combination with a National Instruments (NI) program that collects data from a set of accelerometers installed on the WorkStar tractor and attached semi-trailer at MnRoad. The NI program can also be run by itself without the VTS2 program. To run both programs start the National Instruments program first (see instructions on following pages) then run the VTS2 program.

VTS2.tcl Quick Start

1. Connect the Trimble R8 GPS and an Xbee (or IORelay) radio to the laptop's USB ports.
2. Start the National Instruments program (instructions on following pages) if accelerometer data is to be collected.
3. Open the VTS2 program by clicking on the VTS2.tcl icon on the desktop.
4. Use the buttons in the middle of the right side of the VTS2 screen to pick a trigger mode:

   Back and Forth for repeated low speed passes over each trigger point.

   LVR Loop to make several complete laps while automatically resetting to the first cell at the end of each lap.

   ML Loop to make several laps while manually resetting at the beginning of each lap.
5. Click on the "Accelerometers" button (top left) if the NI program has been started in step 2 to collect accelerometer data .
6. Click on "Start Recording" (top center) to start recording GPS logs.
7. Click on the "Trigger is OFF" button (lower right just above "Test Node") to arm the cabinet triggering system. The button will change to "Trigger is ON".
8. System is ready to go.

   To end,
9. Click on the "Quit" button (lower right) to end data collection, save the files, and shutdown the VTS2 program.

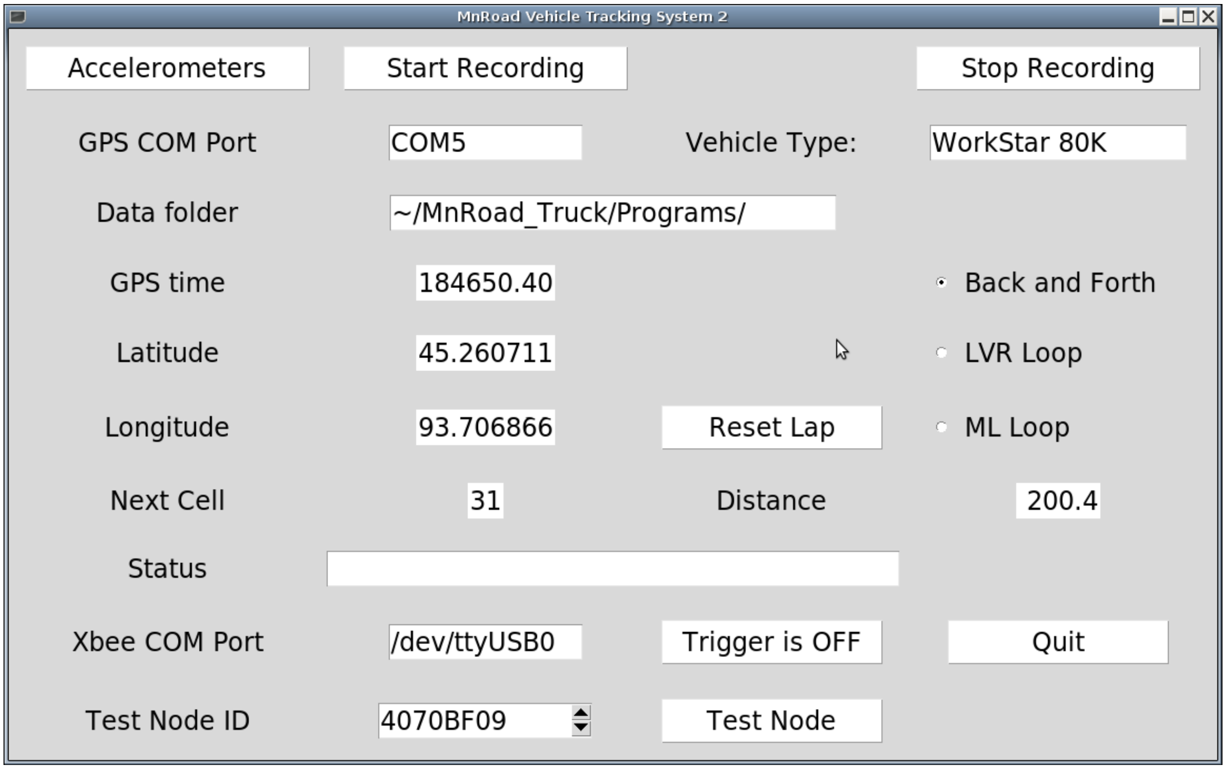


Figure 3.1: Screen shot of vehicle tracking system 2.

Node Test

The bottom row of the VTS screen provides a quick way to test the cabinet triggering system. Pick a cabinet Xbee/IORelay address from the scroll box, then press the "Test Node" button to send a trigger signal out through the Xbee connected to the laptop.

3.2 Directory Structure

C:\VTS

- NI Program
- NI data
  - Accel data
    - (data folders by date)
  - GPS data
    - (data folders by date)
- VTS data
  - *_*-*-*-*-GPS-Data.txt
  - *_*-*-*-*-Raw-GPS-Data-txt
    - where *_*-*-*-* is: (hour)_(minute)-(day)-(month)-(year)
- VTS Program
  - VTS2.tcl
  - build_trigger_list.tcl
  - trigger_list.txt

LVR_cells.txt
Mainline_cells.txt
Xbee_addresses.txt

3.3 VTS Program Files

Table 3.1: Descriptions of VTS program files.

VTS2.tcl	The main Vehicle Tracking System program. Collects GPS data, triggers the National Instruments data collection system and triggers the cabinets over a wireless link.
build_trigger_list.tcl	Composes a list of test cell trigger point locations (latitude & longitude) and the wireless xbee addresses of the cabinets at those cells.
trigger_list.txt	The list of trigger points created by the "build_trigger_list.tcl" program.
LVR_cells.txt	A list of all possible trigger point locations on the low volume road. This list is used by the "build_trigger_list.tcl" program.
Mainline_cells.txt	A list of all possible trigger point locations on the mainline. This list is used by the "build_trigger_list.tcl" program.
Xbee_addresses.txt	A list of all possible xbee (IORelay) addresses in the portable data collection cabinets. This list is also used by the "build_trigger_list.tcl" program.

Note: To add new trigger points edit either the "LVR_cells.txt" file or the "Mainline_cells.txt" file.

To add new xbee addresses edit the "Xbee_addresses.txt" file.

3.4 National Instruments Accelerometer Data Collection Software

There are 2 NI collecting data programs. One is the Accelerometer program. This program is used to collect data from only accelerometers. Another one is the GPS/Accelerometer program. This program is used to collect data from GPS and accelerometers.

The Accelerometer program and the GPS/Accelerometer program are in the folder, C:\VTS\NI program. To run the Accelerometer program, open the project, **Accel_project.lvproj**.

Accel_project.lvproj can be found at C:\VTS\NI Program\Accelerometer, C:\VTS, or on the desktop.

To run the GPS/Accelerometer program, open the project, **GPS_Accel_project.lvproj**. **GPS_Accel_project.lvproj** can be found at C:\VTS\NI Program\ GPS and Accelerometer, C:\VTS, or on the desktop.

The process to run and use the Accelerometer program and the GPS/Accelerometer program are the same. In this case, we will show how to run and use only the GPS/Accelerometer program.

Process to Run the GPS/Accelerometer Program

1. Open the project, **GPS_Accel_project.lvproj**. **GPS_Accel_project.lvproj** can be found at C:\VTS\NI Program\ GPS and Accelerometer, C:\VTS, or on the desktop.
2. You will see the project explorer window as shown in Figure 3.2.

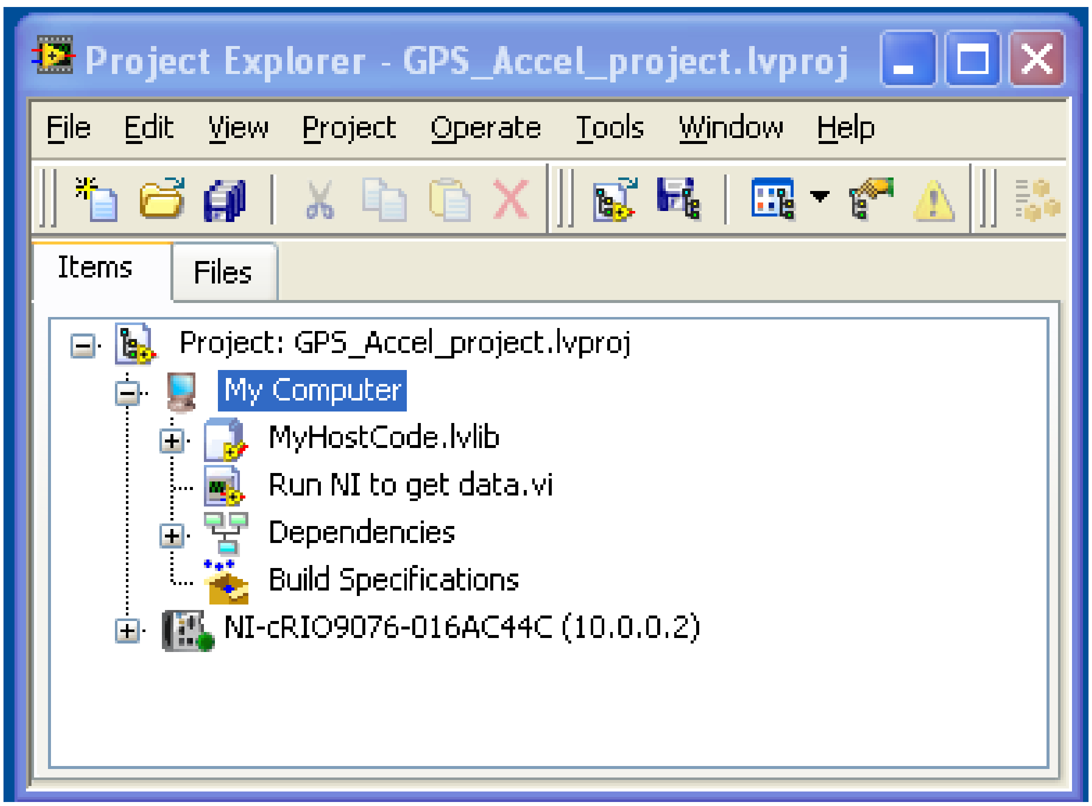


Figure 3.2: Project explorer.

3. Click NI-cRIO9076-016AC44C (10.0.0.2) 

4. Connect Laptop to cRIO: Right click NI-cRIO9076-016AC44C (10.0.0.2) and select **Connect** (Figure 3.3).

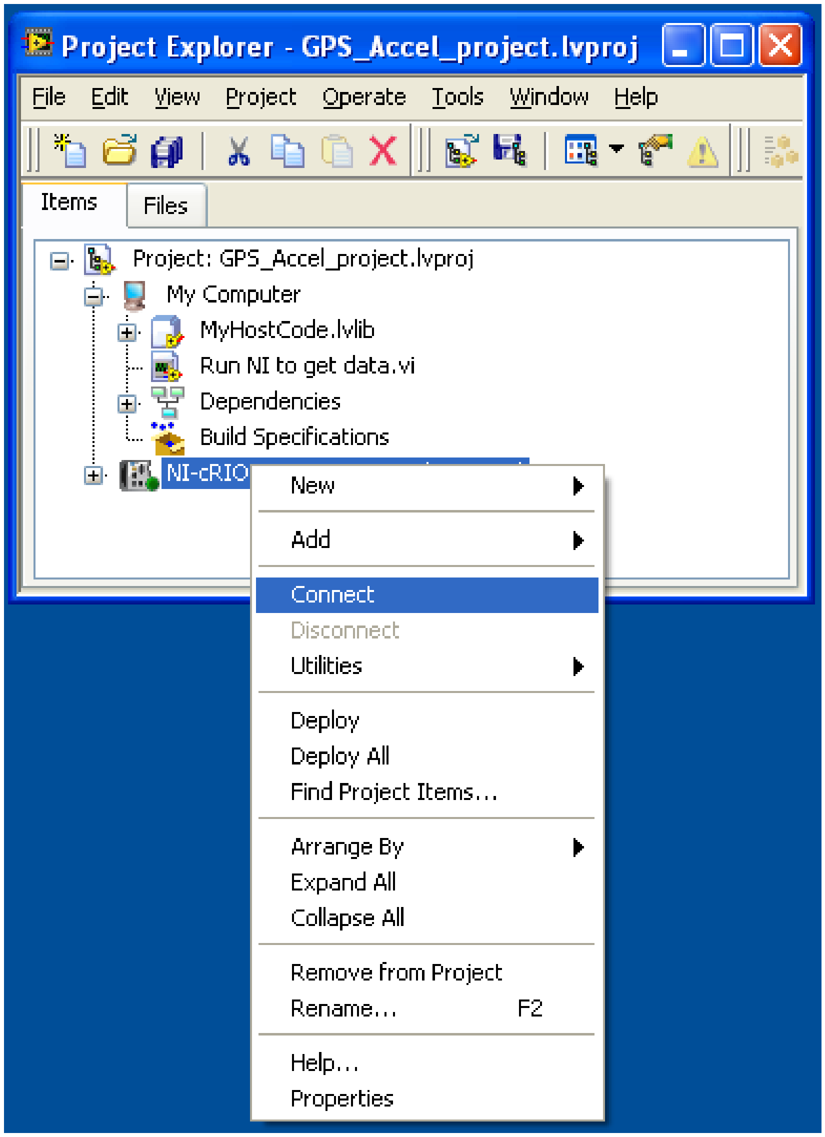


Figure 3.3: Click Connect Laptop to cRIO.

5. After finishing connecting the Laptop to the cRIO, close the **Deployment Progress window** by clicking **close** (the Deployment Progress window may be automatically closed.)
6. This icon 

shows that the connection between Laptop and cRIO is successful.
7. Open the software: double click the file, **Run NI to get data.vi** 

8. You will see the MyHostCode window as shown in Figure 3.5. The window will be used to collect the data. Now you may minimize the project explorer window by click  (Figure 3.4).

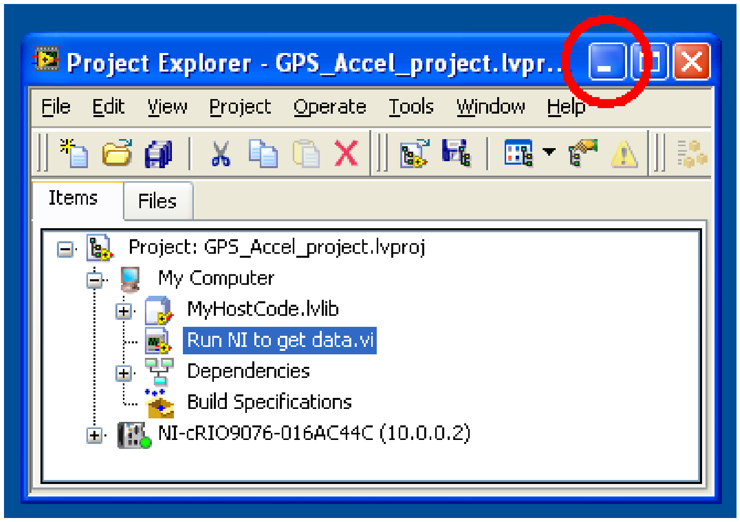


Figure 3.4: Minimize the project explorer window.

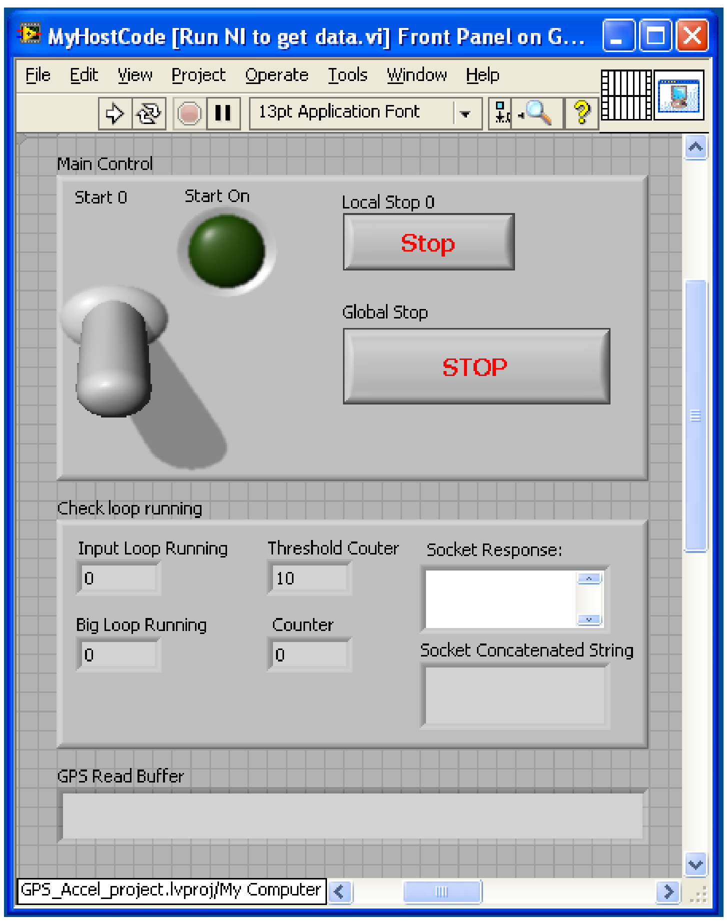
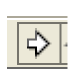


Figure 3.5: MyHostCode window.

9. Run the program: click the icon  (Figure 3.6).

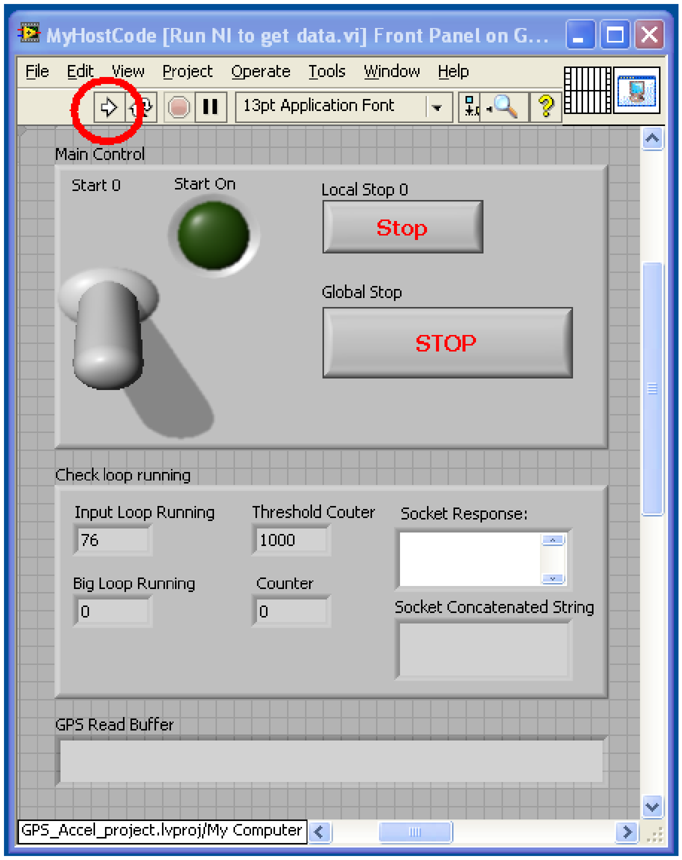
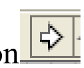
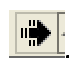
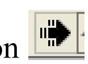


Figure 3.6: The icon **.**

10. The program is running if the icon  is changed to . If you do not see the icon , this means there is something wrong. (This icon  also means there is something wrong.)
11. Then, we can use the program **VTS2.tcl** to automatically control the program to collect the data.
12. When the program collects the data, the **Start On** light will turn green and the Start 0 switch will be up position (Figure 3.7). When the program does not collect the data, the **Start On** light will turn off and the Start 0 switch will be down position (Figure 3.8).

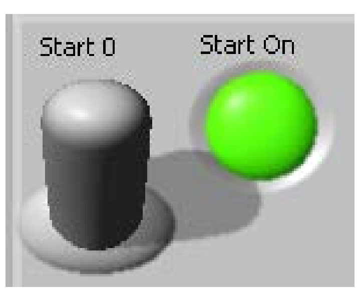


Figure 3.7: Collecting the data.

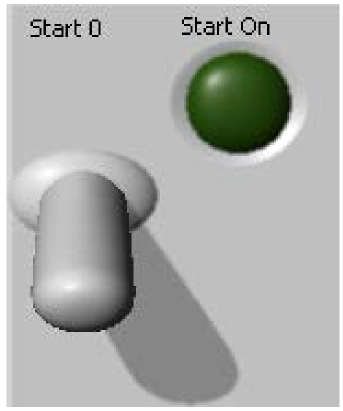


Figure 3.8: Not collecting the data.

13. We can manually use the program without using **VTS2.tcl.** To start collecting data, click the **Start 0** switch (Figure 3.9). To stop collecting data, click the Local Stop 0 button (Figure 3.10).

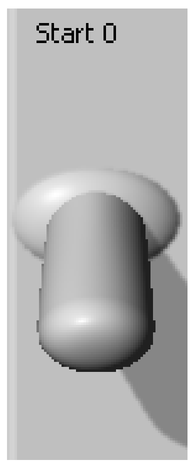
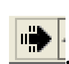
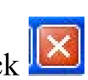


Figure 3.9: Start 0 switch.

Figure 3.10: Local stop 0.

14. The Global Stop button is used to stop collecting data and end the program. Use this button only, when you want to stop collecting data and end the program.

15. Close the program if you see the icon , click the icon  and then click  to close the program (Figure 3.11).

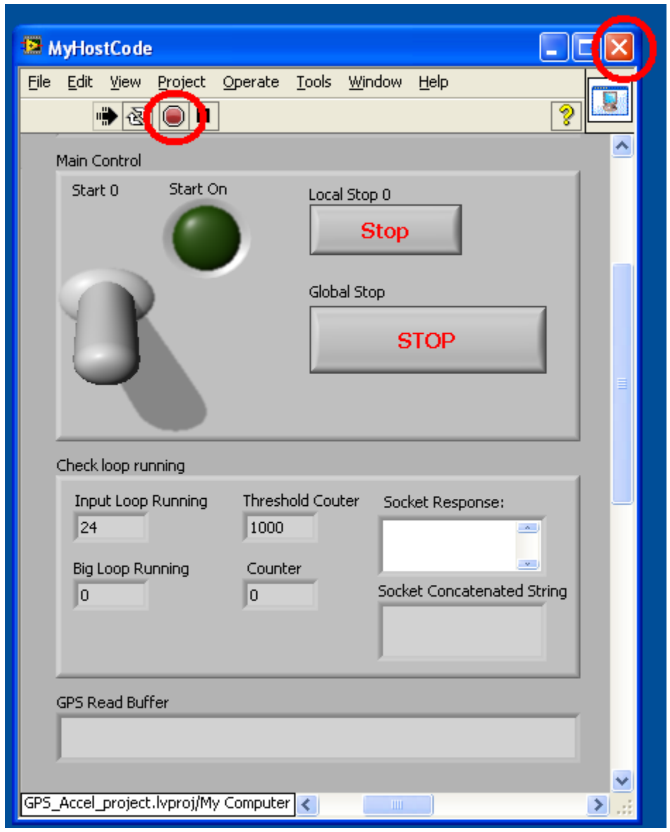


Figure 3.11: Close the program.

If you see the icon , click  to close the program (Figure 3.11).

16. Close the project explorer window by clicking . If there is a window asking you to save project, you may click **Don't Save**.
17. Now you may close all windows that you do not want.

Data

The data that are collected from the software are stored in the folder, C:\VTS\NI data. The folder, Accel data, contains the data from accelerometers. The folder GPS data, contains the data from the GPS. The format of these data is TDMS that can be opened with Excel or Labview. The TDMS file can be converted to a text file by using a software in the folder For converting TDMS file to text file.

Laptop Setup for Connecting to cRIO

1. In the Windows Control Panel, open Network Connections and double-click Local Area Connection.
2. On the General tab, click Properties. The Local Area Connection Properties dialog box is displayed.

3. Choose Internet Protocol (TCP/IP) and click Properties. The Internet Protocol (TCP/IP) dialog box is displayed.
4. On the General tab, select Use the following IP address. If it was already selected, move on to the next step where you configure CompactRIO with a static IP address.
5. Enter the following:

   IP address: 10.0.0.1
   Subnet mask: 255.255.0.0

Click OK and close each of the network settings windows.

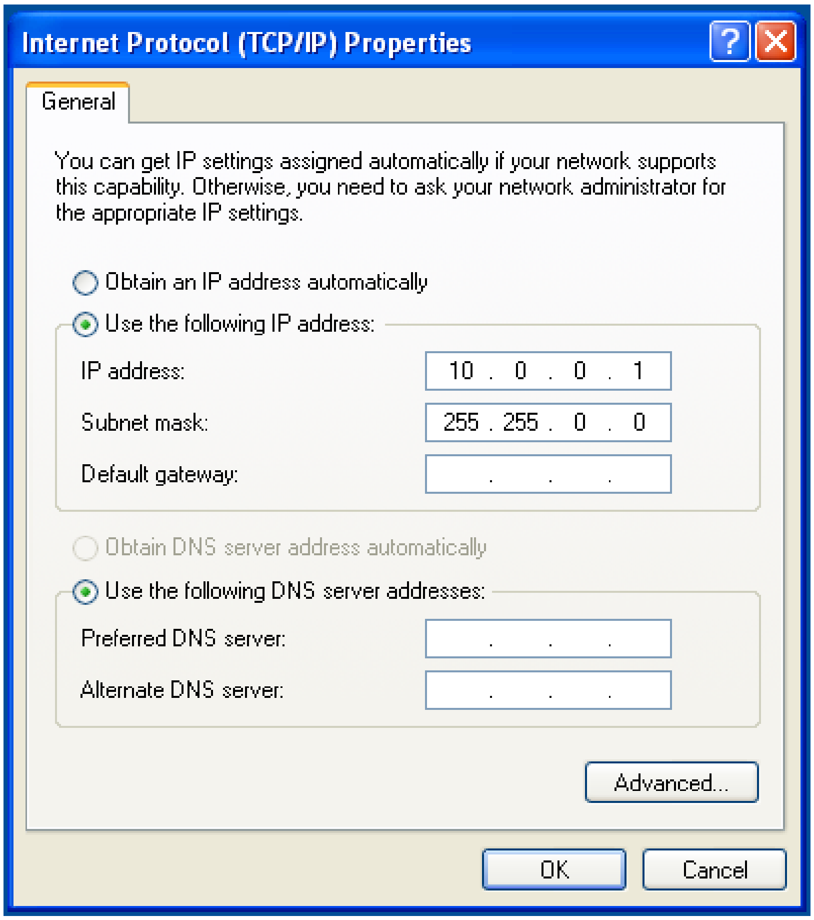
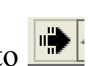


Figure 3.12: Setup TCP/IP.

3.5 Troubleshooting

1. If click the icon , the icon does not change to  or there is error about FPGA
   a) Open the project explorer and double click **MyFPGACode.vi** to open (Figure 12).

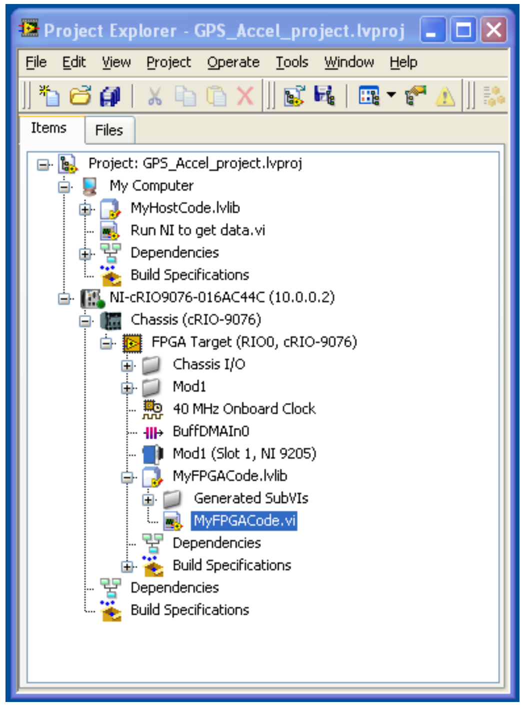


Figure 3.13: MyFPGACode.vi.

a. b. You will see the MyFPGACode window as shown in Figure 3.14.

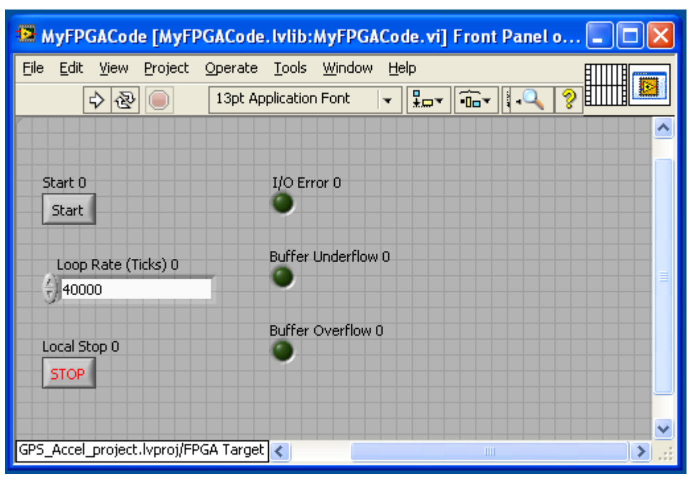
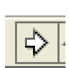


Figure 3.14: MyFPGACode window.

b. Click  on the MyFPGACode window to recompile the code. This process may take about 15-25 minutes.
c. After finishing recompile the code, you may close the MyFPGACode window.
d. Now the program should be ready to run. You may follow the instruction in **Process to Run the GPS and Accelerometer Program.**

2. If something has been changed in the Accelerometer or GPS/Accelerometer program, the program may be not work.
   a. You may need to copy the folder, **Accelerometer** or **GPS and Accelerometer** folder from the **Backup NI Program** folder to the **NI Program** folder.
   b. Open the project explorer and double click **MyFPGACode.vi** to open (Figure 3.13).
   c. You will see the MyFPGACode window as shown in Figure 3.14.
   d. Click  on the MyFPGACode window to recompile the code. This process may take about 15-25 minutes.
   e. After finishing recompile the code, you may close the MyFPGACode window.
   f. Now the program should be ready to run. You may follow the instructions in **Process to Run the GPS and Accelerometer Program.**

3.6 Build_trigger_list.tcl

This program is used to write the "trigger_list.txt" file of cell trigger locations with corresponding wireless Xbee addresses that is used by the VTS2.tcl program.

To make a new trigger list:

1. Select either the Low Volume Road or the Mainline using the buttons at the top of the window.
2. Select a cell location from the left box.
   a. 3.Select an Xbee address from the right box.
3. Repeat for all the cells in the next data collection run.
4. The list appears in the bottom box. When it is finished click on "Save and Quit" to create the new trigger list file.

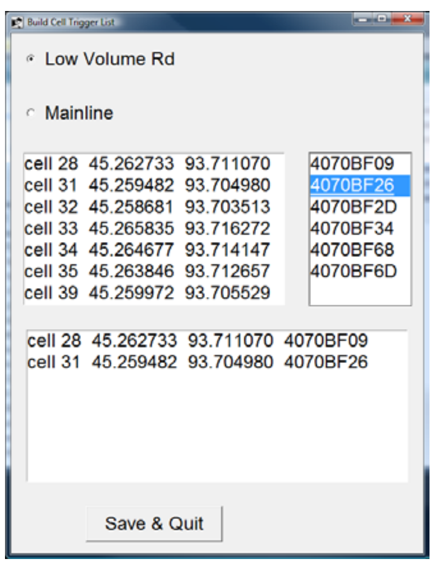


Figure 3.15: Build cell trigger list.

4. CONCLUSIONS

This project instrumented the new MnDOT Navistar truck with a suite of sensors and developed a data acquisition system for recording sensor signals. The truck was instrumented with 20 accelerometers, including accelerometers on the axles of the tractor and the trailer and on the bodies of the tractor and the trailer. A differential GPS system on the truck was used to obtain truck position. A National Instruments cRIO system and a rugged laptop were used as the platform for data acquisition. A vehicle triggering software system was developed wherein the truck sends a wireless signal to roadside cabinets for triggering data recording when the truck passes over in-pavement weigh-in-motion sensors. The points at which data recording needs to be triggered are set by the truck operator. A time stamp signal is also sent with the data trigger so that the time values on the truck and of the in-pavement sensor system can be synchronized. Data can be downloaded from the truck to a network server using a wireless WiFi system.

The developed instrumentation and the wireless data triggering system were both experimentally evaluated and the system was demonstrated to work well. A user manual is included in this report to help the truck operator use the developed software system.