TRAFFIC SAFETY VULNERABILITY INFORMATION PLATFORM (TS-VIP) FOR HIGHWAYS IN MOUNTAINOUS AREAS USING GEOSPATIAL MULTIMEDIA TECHNOLOGY

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December 2008

Acknowledgements

The funds for this study were provided by the United States Department of Transportation to the Mountain-Plains Consortium (MPC). Matching funds were provided by Colorado State University.

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ABSTRACT

An integrated mobile testing study that utilized a large truck equipped with various testing equipment was conducted on Interstate I-70 in Colorado. The field study integrated wind measurement, vehicle dynamic monitoring and geospatial multimedia technology on a real-time and synchronized basis. Essential multi-type data was collected in both time and spatial domains for further investigations of wind characterizations and the safety performance of large trucks under crosswinds, in complicated topographic conditions and other environmental conditions. Environmental geospatial multimedia information for transportation safety has become a very important information source with data integration from both DOT and drivers' perspective in terms of planning, precise decision-making and management. Drivers can benefit from the geospatial multimedia information of road environments in terms of driving safety and confidence. Based on the field testing results, a framework for a traffic vulnerable information system was developed, and the geospatial multimedia technology was integrated with environmental condition and just emerged in transportation engineering field and Web-based platform to assist transportation management and drivers. This study implemented Video Mapping System (VMS) technology along the I-70 mountain corridor, measured wind speeds in three dimensions and accelerations in two dimensions, and developed a Web-based geospatial multimedia database with embedded wind speeds and accelerations as environmental-related georeferenced vulnerable traffic information at selected feature points in the testing route.

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EXECUTIVE SUMMARY

Transportation infrastructure systems are designed to move people and goods, and to provide services – both safely and efficiently. Each year, adverse weather alone is associated with more than 1.5 million vehicular crashes, which result in 800,000 injuries and 7,000 fatalities in the United States (The National Academies 2006). Inclement weather, such as strong wind gusts, snow, rain, fog and ice can greatly threaten the stability of vehicles, visibility and drivers' reactions. Crashes due to adverse natural environments usually cause serious congestion and further deteriorate highway traffic conditions. A number of researchers have studied vehicle safety under crosswind conditions, including large common trucks (Baker 1991, Baker 1999, Chen and Cai 2004, Chen et al. 2006) and parking fire trucks (Pinelli et al. 2004). Chen et al. (2008) recently conducted single-vehicle crash risk assessments in crosswind and complicated topographical conditions. Most of these studies were focused on theoretical modeling to link the wind conditions to the accident risk through simulation. Some experimental studies were conducted in a wind tunnel laboratory to identify wind coefficients. Several static wind pressure tests were conducted for fire trucks in still (Pinelli et al. 2004) and other parked vehicles exposed to a tornado-generated wind field (Schmidlin 1998). Wind loading on moving vehicles is affected by terrain and other roadside environments. The safety performance assessment of a moving vehicle can be tested by both theoretically simulating wind loading and field testing. But for the theoretical simulation, the impacts from topographical conditions on the wind loading were usually omitted.

In past decades, researchers have adopted geospatial technologies such as global positioning systems (GPS), graphic information systems (GIS) and multimedia systems to document safety studies. Liu et al. (2000, 2005) investigated off-highway tracking and stability in the field. Integrating the vehicle dynamic measurement system, the study explored the application of GPS/GIS and VMS off-highway to investigate the characteristics and the structure of multiple-type data to develop a model to process multiple-type data with vehicle stability and to discuss the approach of presenting it in a Web-based information platform. The numeric data of vehicle dynamic status was acquired with a data micrologger. VMS with Differential Global Positioning System (DGPS) records site-specific information of vehicle operation. Field data of vehicle operation were used as examples in the development of the model for processing the multiple-type data on a map. Ayers et al. (2000) conducted a project involving the data collection procedure of georeferenced video for natural resource management. Khatib et al. (2007) developed the process of constructing an Idaho statewide traffic demand model with GIS techniques. GIS has also been used to graphically illustrate and evaluate traffic countermeasures in Hillsborough County Florida.

The present study develops a mobile integrated testing technology that collects and synchronizes wind data, vehicle dynamic data and roadside geospatial multimedia data. Wind, vehicle dynamic response and multimedia information of roadside environments can be collected in both time and geo-spatial domains with the positioning capability of the geospatial data. The collected data offers actual measurements of wind data and visual mapping of topographic information along the I-70 corridor in Colorado. These data can aid investigations in the impacts of roadside environments on wind loading on vehicles and link vehicle accident risks with environments. In addition, it can also be incorporated into a database on an Internet GIS platform.

1. INTRODUCTION

1.1 Background

Transportation infrastructure systems are designed to move people, goods and services – both safely and efficiently. As an important lifeline infrastructure, the transportation system is a critical "backbone" for modern society, and it is maintained and improved through technological advances. According to the Fatality Analysis Reporting System (FARS) by the National Highway Traffic Safety Administration (NHTSA) (2008), there were 22,653 single-vehicle fatal crashes in the United States in 2005, which were 1.37 times the multiple vehicles fatal crashes. Almost 48% of the single-vehicle fatal accidents occurred on roadways with speed limits above 55 mph (mostly highways). Recent studies have found that adverse natural environmental and driver's operational conditions were responsible for many of these dangerous single-vehicle accidents on highways.

Each year, adverse weather alone is associated with more than 1.5 million vehicular crashes, which result in 800,000 injuries and 7,000 fatalities nationwide (The National Academies 2006). Inclement weather, such as strong wind gusts, snow, rain, fog and ice can greatly threaten the stability of vehicles, visibility and drivers' reactions during driving. Crashes due to adverse natural environments usually cause serious congestion and further deteriorate driving conditions on highways.

From the south coast to the east coast and mountainous regions in the United States, strong winds together with other adverse weather and topographic conditions has been blamed for many single-vehicle crashes every year, especially those involving trucks. Recent single-vehicle crashes due to inclement weather are listed as follows (Figure 1.1):

- On March 21, 2001, "The Sunshine Skyway Bridge [Florida] was the scene of two crises Tuesday as a gust of wind flipped over a sport utility vehicle. Weather was a contributing cause. With the combination of wind and rain, she lost control," said Florida Highway Patrol Lt. Bobby Collins…" (Brassfield and Allison 2001).

- "The bridge [Vantage Bridge, State of Washington] is subjected to very high cross winds jeopardizing both large trucks and motor homes. Dangerous conditions on the bridge are compounded by a dangerous eastern approach characterized by a long downhill grade and a sweeping turn. High profile vehicles frequently overturn in this area with accompanying closings of the interstate in both directions for extended periods of time…" (U.S. Department of Transportation, Intelligent Transportation Systems 2003).

- On November 13, 2003, "On the Severn River Bridge on Route 50 [in Maryland], wind overturned an empty U.S. Postal Service truck about 1:30 p.m…it snarled traffic for several hours..." (Lively 2003).

- On January 7, 2003, a tractor-trailer ran off the Interstate 81 in Frederick County, Virginia, due to the strong winds (The Winchester Star news 2003).

- On May 30, 2003, a truck loaded with cattle overturned on I-29 in Iowa when the wind blew it off the road (The Iowa Channel news 2003).

Figure 1.1 Large Truck Accident under Crosswind
a) Rollover large truck in Wyoming; (b) Traffic delay and highway closed (McCarthy et al. 2006)

These crashes lead to serious injuries, fatalities and financial losses. In addition, recurrent crashes accompanied by adverse weather on highways may cause significant delays or completely obstruct important transportation routes during evacuations. Traffic delays may put the lives of many people who are stuck on the evacuation routes in danger when evacuations are interrupted by frequent crashes due to the inclement weather (e.g. hurricanes, flash flooding). Although vehicles are often bumper-to-bumper and moving slowly during evacuations, some high-sided vehicles, such as large trucks, remain vulnerable to crashes such as rollover or side slipping even during low driving speeds under strong wind actions, especially in the presence of adverse topographic conditions (e.g. grade and camber). In addition, frequent stops and drive maneuvers often cause the driver to become fatigued, which may lead to operational errors such as over accelerations/decelerations and/or oversteering/understeering. These operational errors, accompanied by slippery road surfaces (wet or icy road) and roads on a grade or with a sharp turn, could eventually lead to crashes such as running off the road or rolling over, involving large number of vehicles, in a short period of time. For example, on November 10, 1998, the south-central and southeast Wisconsin's counties experienced strong winds with sustained wind speeds of 30-40 mph, gusting to 60-70 mph. In only 17 hours, more than 40 semi-trucks were reported to have been overturned or experienced side slipping off the highways in that area (National Weather Service 1998). Some vehicles that were pushed sideways by gusts also caused multiple vehicle crashes. Transportation in that area was unavoidably delayed, and one interstate highway was reported to have been completely closed because of the crashes.

Complicated topographic conditions include sharp curving, large slopes and mountainous terrain. On highways, ramps are the primary locations where rollover crashes occur due to the curving nature of the roadway. Topographic conditions sometimes combined with adverse weather conditions cause serious crashes. Single-vehicle crashes sometimes further cause multi-vehicle crashes on highways with busy traffic.

1.2 Problem Statement

The problem of traffic safety under adverse environmental conditions has been particularly serious for large-truck drivers and emergency responders, such as emergency medical vehicles, fire trucks and police vehicles. Primary factors are the high-sided vehicle bodies and high driving speeds of these vehicles. Another important factor is that these vehicles usually are operated under adverse environments, while other vehicles (e.g. most passenger vehicles) may typically choose to avoid the trip. Most traffic safety studies are focused on multi-vehicle crashes, and limited studies have been conducted on single-vehicle crashes under adverse environments. A number of researchers have been working on vehicle safety under crosswinds, studying, in particular, large trucks (Baker 1991, Baker 1999, Chen and Cai 2004, Chen et al. 2006) and fire trucks (Pinelli et al. 2004). Chen et al. (2008) focused on single-vehicle crash risk assessments under crosswinds, and complicated topographical and driving conditions. Most of these studies were focused on theoretical modeling to link wind conditions with accident risks, through simulation. Some experimental studies were conducted in the wind tunnel laboratory to identify wind coefficients. Several static wind pressure tests were conducted for fire trucks "in still" (Pinelli et al. 2004) and other vehicles "in still" under tornado in field (Schmidlin 1998).

Wind loading on moving vehicles is affected by terrain and other roadside environments. Assessment of the safety performance of a moving vehicle can be analyzed theoretically, via simulating wind loading or field data collection. But in the former situation, the impacts on the loading due to topographical conditions are usually omitted. Snaebjornsson et al. (2007) once conducted mobile wind speed measurement with an anemometer attached to a minivan, but no further data collection and analysis was reported and the impacts from roadside environments were not included.

The present study develops a mobile-integrated testing technology that collects and synchronizes wind data, vehicle dynamic data and roadside geo-spatial multimedia data. With the positioning capability of the geospatial data, wind, vehicle dynamic response and multimedia data of roadside environment, time and geo-spatial domains can be integrated. As a result, the wind data are in both time and geospatial domains with specific roadside information included. The collected data offer interesting actual measurement of wind data for some further studies, such as investigating the impacts of roadside environment on wind loading on vehicles; linking vehicle accident risks with environments; and developing a convenient information database residing on an Internet GIS platform.

It is known that the frequency and possibility of serious single-vehicle accidents are often significantly higher at certain locations on highways, and the importance of these factors increases under severe weather conditions compared to other locations. Such a phenomenon is usually the result of the specific surrounding conditions, such as a poor highway design, complicated topographic conditions and weather conditions. For example, sudden crosswinds will apply suddenly on the vehicles just after they have moved from a segment on highways with bushes and tress on roadsides to an open area. In such conditions, rollover accidents often occur under a sweep turn of highway with road surface covered by ice in winter, or on some poorly designed ramps, etc. Drivers other than local commuters, who are usually very familiar with the highways, are especially at risk. Highway administrations and researchers often want to investigate the possible reasons behind the higher accident risks and/or the way to avoid the same problems in future highway designs. Actual site-specific data are obviously critical to these types of investigations.

1.3 Vehicle Dynamic Testing

Vehicle dynamic testing has been primarily conducted by automobile engineers. Advanced dynamic measurements of vehicle motion in different directions have been conducted both statically and dynamically, including an advanced system called "inertial navigation system."

An inertial navigation system (INS) typically includes a measurement module containing accelerometers, gyroscopes or other motion-sensing devices. The major advantage of an INS is that there is no external reference typically required to determine its position, orientation or velocity.

Accelerometers measure the linear acceleration of the system in the inertial reference frame, but in directions that can only be measured relative to the moving system (e.g. vehicle). By performing integration on the inertial accelerations (using the original velocity as the initial conditions) with the theory of basic dynamics, the inertial velocities of the system and the inertial position can be obtained. But in order to know exactly the location and the driving direction of the vehicle at any time, additional information, provided for example by global positioning systems, is needed.

1.4 Wind Field Measurements

Wind is caused by the motion of the air roughly parallel to the earth's surface by the unequal heating and cooling of the earth and atmosphere by the sun. Wind observations taken at a fixed location typically include two primary parameters: wind speed and wind direction. Typically referenced with respect to north, the measured direction of the wind is measured in degrees. Wind speed is a measurement of the speed of the air past a point in space. It is typically reported in miles per hour (mph) or kilometers per hour (kph).

Wind measurement is of general interest to many disciplines, including meteorology, aircraft and maritime operations, construction, and hazard reduction. The high winds associated with severe thunderstorms and hurricanes are of critical importance since they can cause loss of life and tremendous damage to infrastructures and environments. Wind speed and direction can be measured using different devices. The most commonly used instrument is an anemometer, which provides wind speed and direction measurements.

There are five types of major anemometers: cup anemometer, wind mill anemometer, hot-wire anemometer, laser Doppler anemometer and sonic anemometer.

1.4.1 Cup Anemometer

The simplest type of anemometer is the cup anemometer, invented (1846) by Dr. John Thomas Romney Robinson. It consists of four hemispherical cups, each of which is mounted on one end of four horizontal arms. These cups are mounted at equal intervals of angles between each other on a vertical shaft. The air flow passes the cups in any horizontal direction and turns the cups in a way that is proportional to the wind speed.

1.4.2 Windmill Anemometers

For windmill anemometers, the subdivision of the axis of rotation must be parallel to the direction of the wind and therefore horizontal, and a wind vane is typically employed. An aerovane combines a propeller and a tail on the same axis to obtain accurate and precise wind speed and direction measurements from the same instrument.

1.4.3 Hot-wire Anemometer

Hot wire anemometers use a very fine wire (in several micrometers) heated up to some temperature above the ambient temperature. Air flowing past the wire has a cooling effect on the wire. The heat loss from the wire is related to the wind speed. By calibrating under controlled conditions, the relationship can be obtained between the heat loss and the flow/wind velocity.

1.4.4 Laser Doppler Anemometer

Laser Doppler anemometers use a beam of light from a laser that is split into two or more beams, depending on the number of flow velocity components to be measured. The coherent light in the beams is shifted in frequency, and the beams are crossed to generate fringe patterns. Seeding (inherent in or supplied to flow), e.g. due small particles or droplets, passing by these fringes leads to light scattering and a doppler effect that is related to the wind speed.

1.4.5 Sonic Anemometer

Sonic anemometers, developed in the 1970s, use ultrasonic sound waves to measure wind speed and direction. The time of flight of sonic pulses between pairs of transducers is used to calculate the wind speed. Measurements from pairs of transducers can be combined to yield a measurement of 1-, 2-, or 3-dimensional flow, respectively. Sonic anemometers are very suitable for turbulence measurements since they can offer fine temporal resolution in 20 Hz or better. Since the sonic anemometer does not have moving parts, it does not require intensive maintenance and thus is suitable for use in automated weather stations. The main disadvantage of this type of anemometer is that it requires special wind tunnel calibration.

In the current study, a 3-D ultrasonic anemometer is used, which will be introduced in the following sections.

1.4.6 Mobile Measurements

Most wind speed measurements use fixed stations to collect the data. Mobile measurements mean that an anemometer will be installed on a moving object, which is not as common as fixed-point measurements. For example, there are some commercial products, such as Orion™ Vehicle-Mount Weather Station, which can measure wind and other climate information with vehicles. The system has ultrasonic sensor and rainfall sensor with low power consumption.
(http://www.columbiaweather.com/Orion_Vehicle_Mount.html)

1.5 Geospatial Media Technology

Georeferenced multimedia information provides a unique resource for management and decision-making in various industries. Data collection, storage, manipulation and display of pertinent features useful for traffic and transportation management has been made easier, less expensive and more productive with the utilization of video mapping systems (VMS), which are spatial multimedia systems. Video mapping systems, as one of the most popular geospatial multimedia technologies, obtain continuously georeferenced videotape, serial images, video clips, audio and other attachable files at the desired location. With the seamless ability to geo-reference and map digital photographs, video and audio narration, utility and transportation companies can bring every mile of the corridor and every asset right to the desktop. Data collected in the field are vitally important throughout the entire organization — maintenance, legal, environmental and engineering.

Liu et al. (2000, 2005) adopted geospatial media technology to investigate off-highway tracking and stability in field. This study explored the application of GPS/GIS and VMS on off-highway conditions to investigate the characteristics and structure of the multiple-type data, to develop a model for processing the multiple-type data and to discuss the approach of presenting the models with Web-based information. The numeric data were acquired by the data micrologger. VMS with Differential Global Positioning System (DGPS) records site-specific information of agricultural machinery operation. Field data from agricultural machinery operations were used as examples in the development of the model for processing the multiple-type data.

Ayers et al. (2000) conducted a project involving the data collection procedure of georeferenced video for natural resource management. Satellite-based differential GPS information is collected on the audio track of a digital camcorder using Red Hen VMS Professional. Georeferenced still images and video clips are captured and incorporated into the GIS to develop a database of natural resource management and recreation features. Applications involving Colorado State Parks, Rocky Mountain National Park, off-road vehicle tracking and underwater video mapping have been explored (Liu et al. 2005). Captured features are determined for each application, but in the case of trail mapping include erosion control structures, campsite, signs, bridges, water sources and scenic views.

Wright (2002) described VMS and MediaMapper features and application in engineering. He indicated that a versatile data collection method called “media mapping” simplifies acquisition, organization and extension of site-specific multimedia — multi spectral image data, digital photographs, audio, video, etc.— from both aerial and proximal vantages. MediaMapper software automatically merges these source media with spatial information from GPS receivers, building an interactive media map. The spatial multimedia content generated by MediaMapper can be extended to common GIS programs, such as ESRI Inc.’s (Redlands, Calif.) ArcView and ArcInfo 8, MapInfo Corp.’s (East Troy, N.Y.) MapInfo Professional, and to the Internet through export menus and custom extension tools. The synergy of site-specific multimedia and GIS is a powerful union to employ in image classification and other spatial analyses. The rich visual information of ground-based photography increases decision-making and analysis confidence.

1.6 GIS Techniques in Transportation Safety

O’neill et al. (1992) presented and described a GIS procedure that addresses the difficulties of estimating the total population in the service area of a transit route. The general methodology for estimating populations within a service area is buffering (Euclidean distance) and polygon overlay techniques. However, the researchers also indicated that this methodology might be inappropriate for this type of analysis because it overestimates populations due to calculations associated with buffering. The distance calculations should be based on transit walking distance along paths (network distance) instead of straight-line distances (Euclidean buffering) from transit access points.

Khatib et al. (2007) developed the process and steps associated with the authors’ experience using GIS techniques to construct TAZ’s and a transportation network as input for the Idaho statewide traffic demand model. This paper outlined how a GIS is an efficient and effective tool that is useful for capturing, storing and analyzing spatial or geo-referenced data in the construction and application of a travel demand model. They described the GIS’s usefulness in creating a TAZ map interactively or by overlaying boundary files and performing query and analysis of socioeconomic and land use data. Because of the ability to maintain and manage map layers and their related attribute data, the authors also highlight the ability for a GIS to display transportation data and model results.

Because of growing urbanization, there is an increased desire for expanded traffic programs, such as traffic calming, safety improvement, speed reduction, signalization, traffic signage, school safety and roadway illumination (Rogoff et al. 2006). They focused on the ability of a GIS to graphically illustrate where roadway illuminations, as traffic countermeasures, would provide the most benefit in the case study of Hillsborough County Florida. For the purposes of the study, a database was constructed using ArcView. From the database, the county developed a methodology for ranking and prioritizing county roadway lighting needs in the form of a matrix. Using the matrix, rating scores and cost were calculated for each roadway segment. The results were coded and displayed on a map, allowing the planner to prioritize locations with the greatest need.

For decades, the primary appeal of GIS has been the graphical capabilities because “a picture is worth a thousand words.” In recent years, the rapid development of the Internet has enabled distribution of GIS-based information immediately to everywhere in the world. The current study will develop the HVL information layer on top of the USDOT transportation base map. A GIS database will be developed to describe locations, elevations, text warning messages, geo-referenced still pictures and video chips. The database will have full query function and will be updated by the researchers every week to give more adaptive and timely information. A Website will be developed to display the map and also the progress of the project.

Information based on a GIS platform can integrate transportation-related data and has the ability to display spatial, numerical and descriptive information in a visual manner and can create, organize and analyze databases. The technology consists of two major components: navigation systems and mapping sensors. The navigation component, typically a GPS receiver combined with an inertial navigation system or laser range finder, should be capable of continuously determining the complete position solution. Mapping sensors typically are digital cameras, video cameras and audio device.

Data collection, storage, manipulation and display of pertinent features useful for transportation safety and traffic management will be made easier, less expensive and more productive with the utilization of GSMT. GSMT consists of obtaining georeferenced multimedia, such as videotape, audio and digital images, which includes the image and location of the desired features. Utilizing GSMT or VMS Professional, the georeferenced multimedia is stored with each video and image. VMS Professional has the capability of converting the GPS position in NMEA (National Marine Electronics Association) or binary format into an audio signal and recording this positional information on the audio channel of the videotape. Thus, the video image and GPS position are stored simultaneously on the videotape. During indexing and playback, the GPS position is associated (and displayed) with each image frame of the videotape. Georeferenced still images and video clips can be captured and incorporated into the GIS to develop a database of transportation management. After the video images and GPS positions are recorded, the indexing procedure produces a data table for each GPS position (or event). The sensor data (if taken) associated with each GPS position is also placed in the table. Then, the playback operation provides the opportunity to capture geo-referenced images and video clips. Afterward, the VMS can export the databases in the multiple data layers in several formats, which are compatible with ArcMap (or ArcView) and MapInfo for further analysis.

1.7 Research Objectives

The approach presented in this report seeks to develop and demonstrate a framework of an information system that integrates geospatial multimedia technology that is just emerging in the transportation engineering field and GIS techniques to assist drivers unfamiliar with mountainous areas (e.g. tourists and travelers), commercial drivers, emergency vehicle drivers, novice drivers and aged drivers to travel confidently and have safe trips, even in inclement weather. Because of the project scope and demonstration nature, the research will choose Colorado section of I-70 for demonstration purposes.

2. FIELD TESTING DESIGN

2.1 Introduction

The integrated field mobile testing strategy in this study utilizes three types of testing equipment: wind, vehicle dynamic and geospatial multimedia equipment. The raw data collected in field include real-time video on I-70, GPS, wind speed and acceleration. As the research focuses on the I-70 interstate corridor with consideration of the effect of wind conditions and accelerations on vehicle traffic vulnerability, the research team selected the segment of I-70 between intersection A (W. Colfax Ave. and I-70) and intersection B (Evergreen Pkwy. and I-70). The collected data will be synchronized in terms of time stamp at three major data sets. Finally, the wind speed and acceleration at the testing vehicle at targeted feature points can be georeferenced on the map, and Web-based demonstration platform related to traffic safety vulnerability is developed as an implementation of geospatial technology in transportation.

2.2 Overall Testing Plan

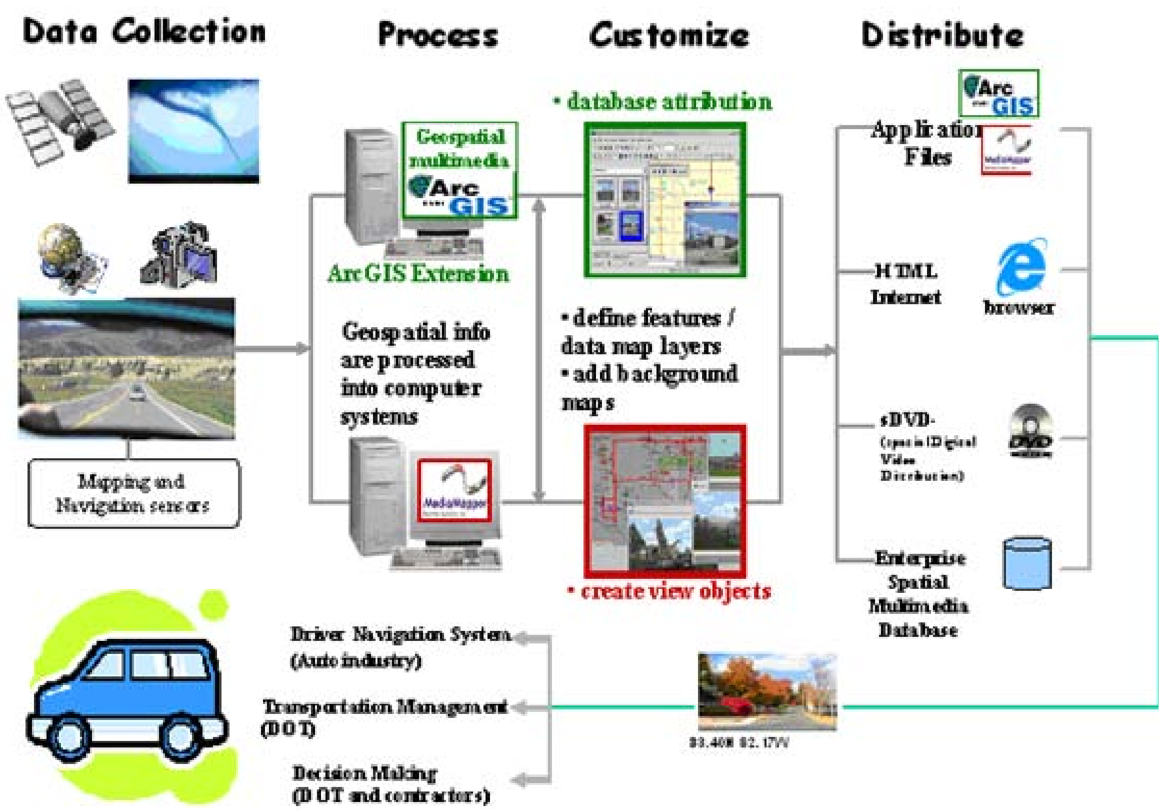


Figure 2.1 Diagram of the Data Collection, Process and Delivery

The overall field study includes four stages (shown in Figure 2.1): data collecting in field, processing, customizing, and data delivery. Table 2.1 lists the major three sets of measuring systems and parameters, and the equipment mounting configuration plan is shown in Figure 2.2.

Table 2.1 Measuring System and Parameters

Measuring System	**Data Type and Format**
VMS 300	Georeferenced Video clips (avi, mpeg)
	Still images (jpg, gif)
Red Hen Systems	GIS (Lat, Long, Elevation, time, speed, course, heading)
	GIS compatible data formats: shapefile, tab, dbf
Wind Speed	Driving direction
	Lateral
(R.M. Young's ultrasonic 8100 anemometer)	Upright
Acceleration	Left upright
	Right upright
(NI data acquisition system with PCB 333B30 accelerometer)	Lateral

As the required data is relative season sensitive, a relative strong wind day is needed for this study. Table 2.2 presents the overall test plan to achieve our research goals.

Table 2.2 Overall Test Plan

	Time Line											
Tasks	Jul 07	Aug 07	Sep 07	Oct 07	Nov 07	Dec 07	Jan 08	Feb 08	Mar 08	Apr 08	May 08	Jun 08
1. Prepare each set of equipment	→	→	→									
2. Training students		→	→	→	→	→	→	→	→			
3. Preliminary tests in field				→			→					
4. Process preliminary data					→	→	→	→	→			
5. Prepare and conduct major field tests								→	→	→		
6. Process data										→	→	→

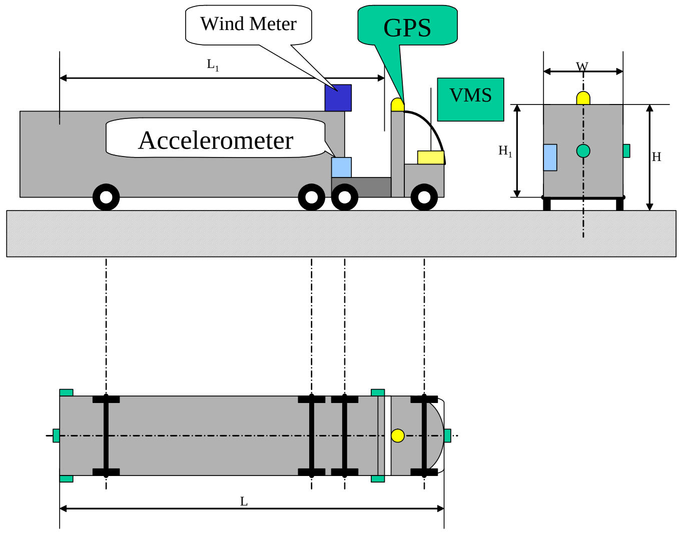


Figure 2.2 Equipment Mounting Configuration

2.3 Wind Measurement

2.3.1 R. M. Young 8100 Ultrasonic Anemometer

The Young model 8100 ultrasonic anemometer is a three-axis, no-moving-parts wind sensor. The sensor features durable corrosion-resistant construction with three opposing pairs of ultrasonic transducers supported by stainless steel members. 160 Hz internal sampling rates and output rates from 4 to 32 Hz. Model 8100 has four voltage output channels. Serial RS-232 is used for communication with computers. It can measure wind speed from 0 to 40 m/s (90 mph) with resolution of 0.01 m/s and wind direction from 0 to 360 degrees. The speed of sound is between 300 to 360 m/s, and sonic temperature is between -50 degree and +50 degree.

The anemometer analog voltage outputs have four voltage outputs between 0 and 5000 mV, from which U, V, W, speed of sound, sonic temperatures, 2D speed, 3D speed, azimuth and elevation can be selected. Wind speed and direction configuration are shown in Figure 2.3. Figures 2.4-2.5 show pictures of anemometer and how it is installed on the testing truck.

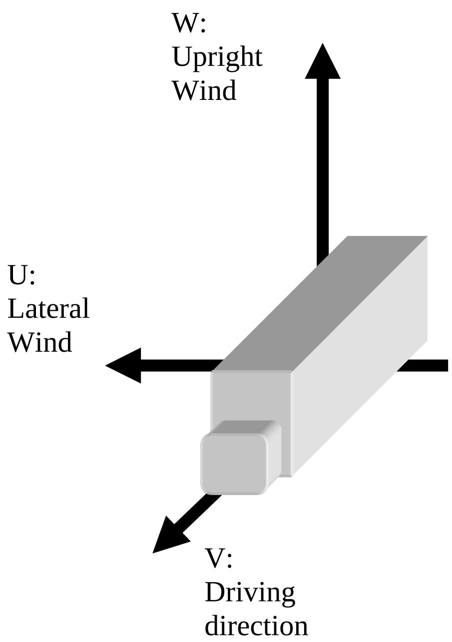


Figure 2.3 Wind Speed and Direction

Figure 2.4 R.M. Young 8100 Anemometer

Figure 2.5 Anemometer Installed on Top of the Truck

2.4 Mobile Dynamic Measurement

2.4.1 National Instruments Mobile Data Acquisition System

The National Instruments cDAQ-9172 is an eight-slot NI CompactDAQ chassis that can hold up to eight C Series I/O modules. The chassis operates on 11 to 30 VDC and includes an AC/DC power converter. The NI cDAQ-9172 is a USB 2.0-compliant device that includes a 1.8 m USB cable. The NI cDAQ-9172 has two 32-bit counter/timer chips built into the chassis. With a correlated digital I/O module installed in slot five or six of the chassis, tessters can access all the functionality of the counter/timer chip including event counting, pulse-wave generation or measurement and quadrature encoders (Figure 2.6).

Figure 2.6 NI cDAQ-9172

The NI 9233 is a four-channel dynamic signal acquisition module for making high-accuracy audio frequency measurements from IEPE sensors with NI CompactDAQ or CompactRIO systems. The NI 9233 delivers 102 dB of dynamic range and incorporates integrated electronic piezoelectric (IEPE) signal conditioning for accelerometers and microphones. The four input channels simultaneously digitize signals at rates from 2 to 50 kHz per channel with built-in antialiasing filters that automatically adjust to the sampling rate. It has two mA IEPE signal conditioning for accelerometers with 50 kS/s per-channel maximum sampling rate (Fig. 2.7).

Figure 2.7 NI 9233 Dynamic Signal Acquisition Module

2.4.2 PCB Accelerometers

This type of accelerometer has a measurement range of +/- 50 g and a frequency range from 0.5 to 3000 Hz. It has a sensitivity of 100 mV/g (Figure 2.8).

Figure 2.8 PCB Model 333B30 Accelerometer

The mobile testing facility and mobile power supply used in the test are shown in Figure 2.9 and Figure 2.10, respectively. The mobile power supply supported the data acquisition system, the anemometer and the laptop.

Figure 2.9 Mobile Testing Facility Used in the Testing

Figure 2.10 Mobile Power Supply for Data Acquisition System, Anemometer and Laptop

2.5 Geo-spatial Multimedia Measurement

2.5.1 Georeferenced Multimedia Data Collection System

Utilizing the Red Hen System's VMS 300 (Figure 2.11) Professional and Mediamapper 5.2, a GPS position and visual information were systematically integrated together and processed with high efficiency. A video mapping system (VMS) can be used to record machinery operation visual information and GPS information. It is composed of a camcorder, a GPS receiver and VMS 300 developed by Red Hen System (VMS 200-Video Mapping System Hardware User's Guide 2004). The VMS 300 converts the GPS signals into audio signals, which are sent to the camcorder through its microphone input connector. These audio signals are recorded on one channel of the audio track of the videotape. Utilizing VMS Player (VMS 300-Video Mapping System Software User's Guide 2004) and VMS 300, the video can be played back for indexing to transfer the GPS data from the videotape to a computer.

A digital video camera (SONY) is mounted on the control panel in front of the passenger position and pointed to the driving direction. It can record very wide scenes which are similar to what a driver normally sees. A GPS receiver antenna is mounted outside on the top of driver cab to get a rich signal from eight satellites constantly, and the acquiring frequency of the GPS receiver is 1 Hz.

Figure 2.11 Geospatial Multimedia System: VMS 300, Digital Video Camera, Antenna

3. DATA PROCESSING AND GIS-BASED APPLICATIONS

3.1 Introduction

In this study, three categories of data from three sets of equipment were collected independently. The raw data from I-70 provides resources to analyze the effect of the environmental and vehicle dynamic status on TS-VIP. As the data were recorded and acquired in different frequencies, the important step of processing data was to synchronize them together in terms of UTC time from VMS/GPS after the feature data is processed individually. Figure 3.1 shows the data flow of data collection and process as well synchronization.

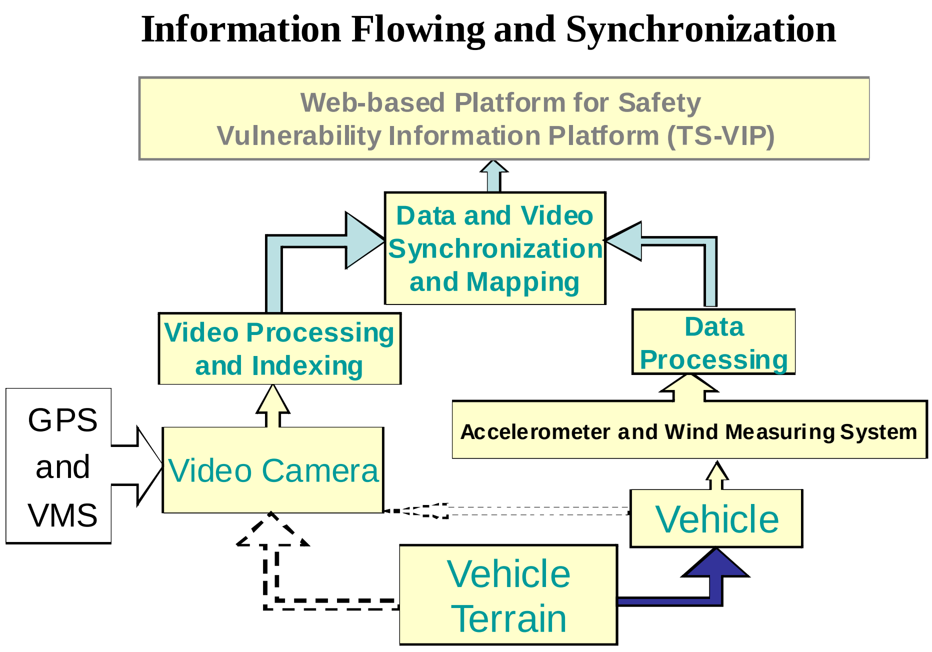


Figure 3.1 Information Flow Diagram of Data Collection and Processing

The following procedures were considered in the data collection and post processing:

1. Videotape computer screen to get a time stamp of computers, which are used to collect and record the wind speed and vehicle accelerations in field.
2. Videotape the testing routine as the truck was driven its designed route.
3. Process VMS: indexing the video to generate GIS database as shapefile, which presents GPS (Lat, Long, Elevation, UTC time, video time, speed, etc.).
4. Process wind speed in three directions in time domain.
5. Process accelerations at three positions in time domain.
6. Scale the time for three data sets: find the difference between UTC time at shapefile and the time shown at computers from video footage; then synchronize them identically.
7. Select the five typical feature points based on the video scenarios and footage with consideration of TS-VIP.
8. Capture the video clips and still images at the selected feature points: obtain georeferenced video clips and still images.
9. Based on the synchronized time, process the wind speed and vehicle accelerations at five feature points.

10. Post process via Mediamapper: add the wind speed and acceleration charts as attachment file into feature points on background map, respectively.
11. Export the HTML file through Mediamapper, and generate a demo Web-based platform for TS-VIP.

3.2 Data Processing Strategy

Three categories of data, such as VMS, wind speed and acceleration, are included in the data collection process. To target the safety feature points, the Fatality Analysis Reporting System (FARS) (http://www-fars.nhtsa.dot.gov/main.cfm), which is operated by the National Highway Traffic Safety Administration (NHTSA), has the data of all serious accidents that occur on public roadways and involve fatalities in the United States. Information about accidents (such as time and location) in each individual state can be retrieved. The hazard vulnerable locations (HVL) can be identified on the major highway I-70 in Colorado. These identified HVL will become candidates of feature points for the data collection and processing. In addition, existent static warning signs information will also be collected as georeferenced features, which will be incorporated into the GIS platform. A data collection vehicle equipped with Video Mapping Systems (VMS) and anemometer will drive through the selected segments of I-70. For each HVL, environmental and traffic conditions in each direction will be continuously recorded at one-second interval. For dense HVL areas, continuous data will be collected, including the geometry of the highway, surroundings, bridges, ramps, rails and wind speed all on a geo-referenced basis.

Data collection, storage, manipulation and display of pertinent features useful for transportation safety and traffic management will be made easier, less expensive and more productive with the utilization of VMS (Figure 3.1). The geospatial multimedia technology consists of two major components: a navigation system and the mapping sensors. The navigation component, typically a GPS receiver combined with an inertial navigation system or laser range finder, should be capable of continuously determining the complete position solution. Mapping sensors typically are digital cameras, video cameras, and audio devices.

As shown in Figure 3.1, the proposed TS-VIP includes the following four stages.

3.2.1 Data Collection

Identify hazard vulnerable segments of I-70 with historical accident data and incorporate existent warning information on the static signs along the highway; videotape computer screen to get a time stamp of computers that are used to collect and record the wind speed and vehicle accelerations in field; collect the GPS-based multimedia information continuously through those selected segments. Geospatial multimedia information, wind speed and accelerations were collected and stored with time calibration for all of three measurement systems.

3.2.2 Data Processing

The VMS Professional (e.g. VMS300) has the capability of converting the GPS position (in NMEA or binary format) into an audio signal and recording this positional information on the audio channel of the videotape. Thus, the video image and GPS position are stored simultaneously on the videotape.

After the video images and GPS positions are recorded, during indexing and playback with MediaMapper, the GPS position is associated (and displayed) with each image frame of the videotape. Georeferenced still images and video clips can be captured.

Then, after the important feature points with traffic safety vulnerability were first identified, the still images and video clips were captured by the VMS and MediaMapper software. Then, according to the calibration of stamped times, wind speed and acceleration at the targeted featured points were processed in time domain.

3.2.3 Customize Information

As all the collected data information at feature points were processed and modeled, the wind speed and acceleration were synchronized with geospatial multimedia information through MediaMapper platform. The featured layer was generated with wind speed and acceleration as attachment files to develop a traffic safety vulnerability database. Afterward, the VMS can export the databases in the multiple data layers in several formats, which are compatible with ArcMap (or ArcView) and MapInfo for further analysis.

The information could be also fed into the GIS system to develop the GIS database, which would be available to general drivers, highway administrations and commercial fleet companies through the Internet and to export in the format of other standard GIS data files for further implementations.

3.2.4 Information Distribution

Once the GIS-based database is developed, various formats of the database can be exported for distribution purposes, such as shapefile as ArcMap-GIS application files, HTML file for Internet, sDVD and enterprise spatial multimedia database. Because of the scope of the project and also because it was a demonstration project, only Web-based information distribution has been implemented in the proposed study; a Web-based demo platform in terms of HTML for TS-VIP was developed at the official Website.

3.3 Database of VMS and Output

After data process and synchronization, the following data formats are generated in terms of data characteristics.

3.3.1 Output Format from MediaMapper

- Database format (*.dbf file)
- Graphics format (*.jpg/jpeg,*.gif,*.bmp,*.tif)
- Shape file (*.shp file for Arcview or other GIS software)
- HTML (*.html)

3.3.2 Web Homepage Making

- HTML
- Java and VB scripts

3.3.3 ArcMap/Arcview Application

- Export data to GIS in shapefile and dbf.

3.3.4 Traffic Safety Vulnerability Information

- Safety factors

4. FIELD TESTING RESULTS ON I-70

4.1 Introduction

In this chapter, detailed testing facility, process and data will be presented, and six feature points are selected for detailed analysis in terms of geospatial still images, lateral wind speed and lateral and rolling accelerations.

4.2 Testing Vehicles

The testing truck is a GMC SAVANA G3500 16' moving truck. The major information of the truck is listed below:

- 117 square feet of floor space
- 800 cubic feet of loading space
- A 2,700 lb. load capacity
- Interior dimensions of 15'3"L x 7'8"W x 6'2"H
- A 35 gallon gasoline fuel tank

Another testing vehicle is a 2008 Ford Expedition XLT style.

Figures 4.1 and 4.2 give the geometric dimensions of the testing truck with equipment. Figures 4.3 through 4.6 are pictures of the testing vehicles.

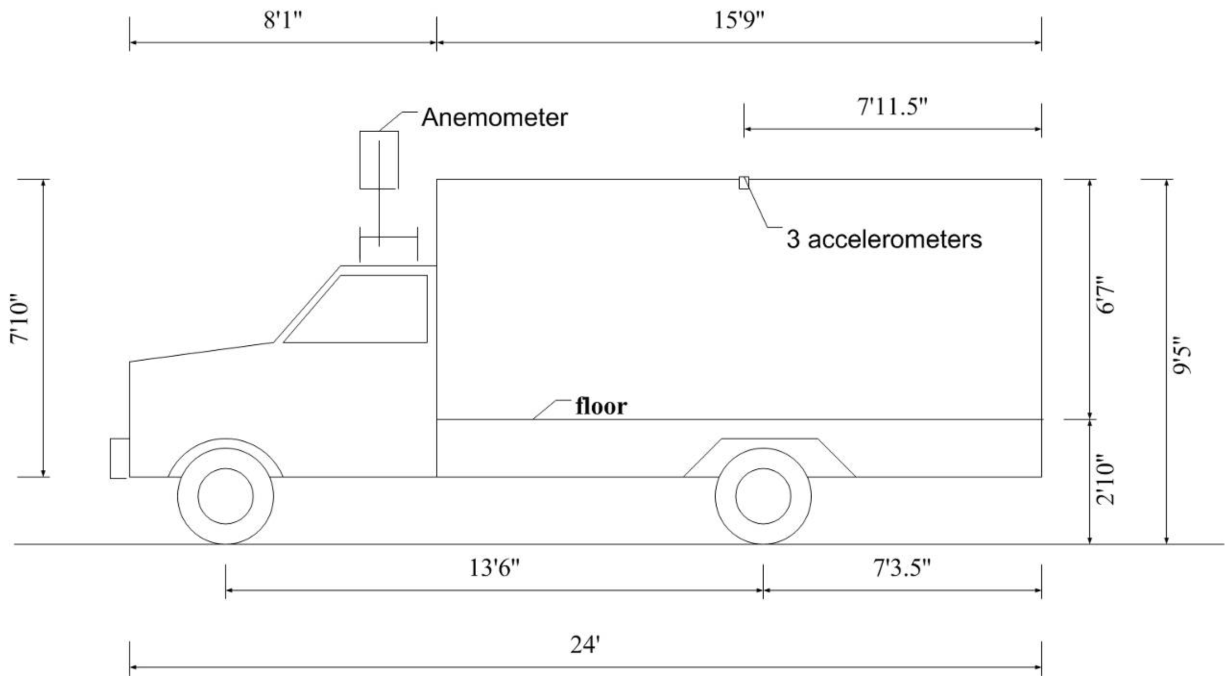


Figure 4.1 Geometric Dimension of Truck and Location of Equipment

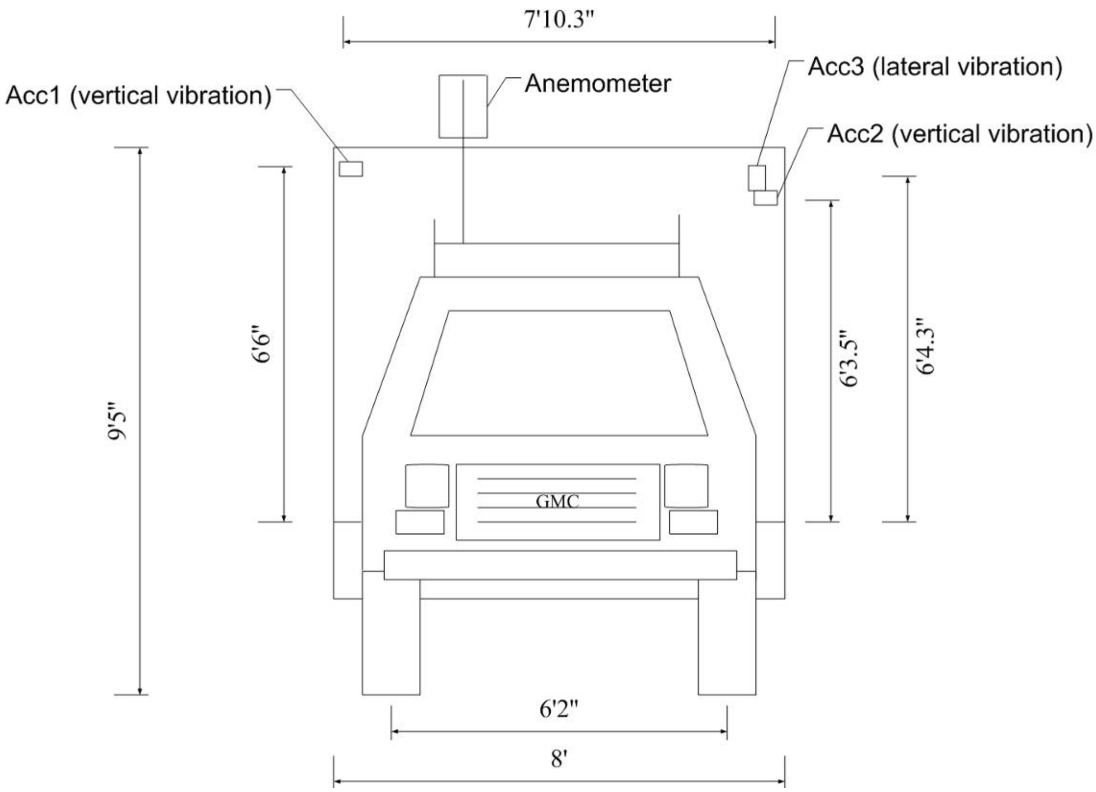


Figure 4.2 Geometric Dimension of Truck and Location of Equipment

Figure 4.3 Project Poster and the SUV

Figure 4.4 Project Poster and the Truck

Figure 4.5 Anemometer on the Truck

Figure 4.6 Panorama of the Testing Truck

4.3 Testing Routes

The Interstate 70 Mountain Corridor from Denver to Grand Junction is an important interstate highway in Colorado that is very well-known for complex terrain and strong snowstorms during winter and even spring. Testing routes are all on the I-70 highway from exit 252 to exit 266. There are two testing sections: one on I-70 W and another on I-70 E. All the measurement data, such as wind data and acceleration data, will be recorded on a laptop during the test, and the multimedia data will be recorded on the mini videotape of VMS during the test and will be transferred to the computer in a later time. The data synchronization is conducted based on the time stamps of various measurement equipments after a brief calibration between different equipments. Figure 4.7 demonstrates the test routes on I-70.

Test Routes in I-70

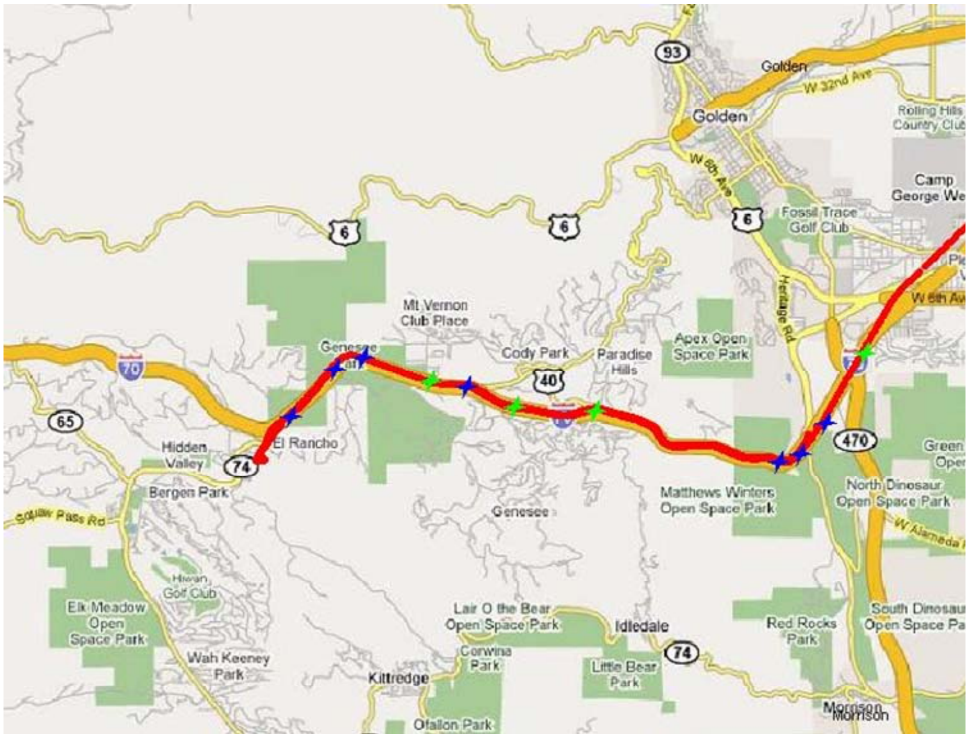


Figure 4.7 Testing Route

Testing Section 1:

Start Location: Take the ramp onto **I-70 W** at **W Colfax Ave/I-70-BL** (exit **259**)
End Location: Take exit **252** to merge onto **CO-74 E/Evergreen Pkwy** toward **CO-74**
Mile: **7.3** mile Time from **13:05:55-13:13:56** (hh:mm:ss) on April 26th, 2008

Testing Section 2:

Start Location: Take the ramp onto **I-70 E** at **Evergreen Pkwy** (exit **252**)
End Location: Take exit **266** toward **CO-72**
Mile: **15.0** mile Time from **14:21:40-14:35:20** (hh:mm:ss) on April 26th, 2008

4.4 Testing Results

4.4.1 Wind data

The sampling frequency of the wind data is 12.8 Hz. Six kinds of wind-related data are recorded: U, V, W, 3D-V, Azi, and Ele. U, V and W are the orthogonal u, v, w wind velocities (Figure 2.3). All three values are collected. 3D-V is wind magnitude in three dimensional spaces. Azi (Azimuth) is the 0.0-359.9 degree wind direction angle in the u-v plane. 0.0 is north, 90.0 is east, 180 is south and 270 is west. Ele (Elevation) is the +-90.0 wind direction angle relative to the u-v plane. Values are positive when wind is from below. Typically the anemometer is oriented with the u-axis aligned east-west and the v-axis aligned north-south. In this orientation, +u values = wind from the east of the anemometer, and +v values = wind from the north of the anemometer. Wind from below (updraft) = +w. In the I-70 testing, the north direction of the anemometer is aimed at the driving direction of the truck along the longitude axle of the vehicle.

4.4.2 Acceleration data

The sampling frequency of the acceleration data is 50000 Hz. There are 3 channels: 0 and 1 channels record the vertical acceleration data of the truck, and 2 channel records the lateral acceleration of the truck. The positions of the three accelerometers can be found in Figure 4.1 and Figure 4.2.

4.4.3 Geospatial Video Clips

Geo-spatial video clips have been continuously captured and some still pictures are extracted from the video clips according to the feature points.

4.4.4 Feature Points

Figure 4.8 demonstrates the six feature points on a GIS map and Table 4.1 shows the location of six feature points and vehicle moving status.

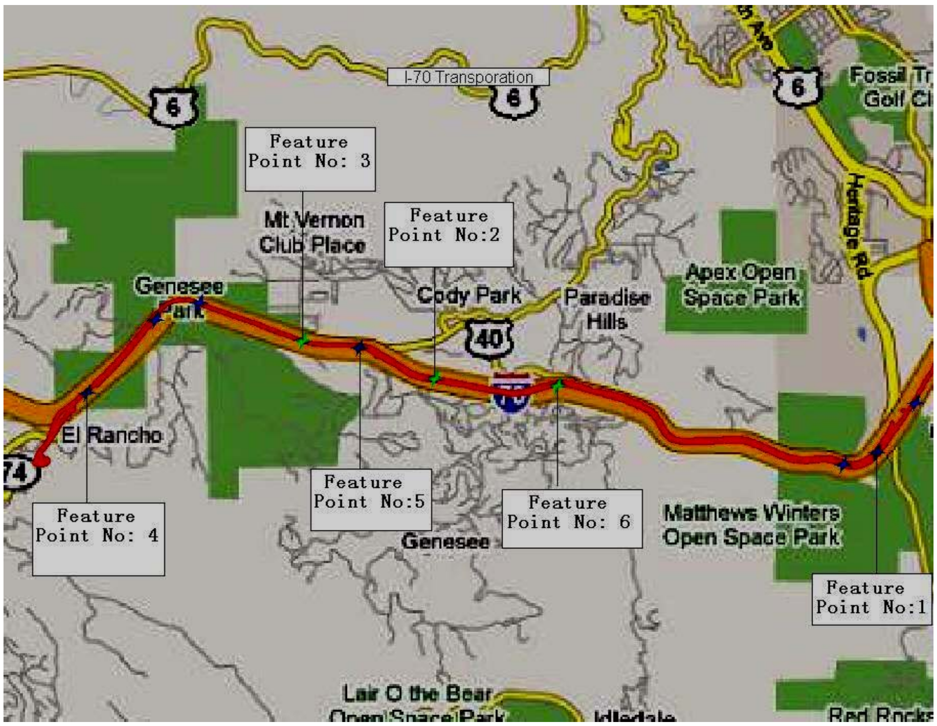


Figure 4.8 Overview of Feature Points and Background on I-70

Table 4.1 GPS Data for Specified Feature Points

Feature Point	LON	LAT	ALT	Speed (m/s)	Course (degree)	Description
No.1	-105.20767472	39.69651722	1980.590	19.190	220.600	Turning right
No.2	-105.27344278	39.70567333	2312.070	23.740	280.400	Passing a heavy truck
No.3	-105.29392167	39.71006000	2381.040	26.120	286.200	Under a bridge
No.4	-105.32594833	39.70508444	2386.330	19.490	235.900	On ramp
No.5	-105.28405139	39.70888139	2334.380	27.860	97.000	Turning right
No.6	-105.25537472	39.70442472	2209.310	25.860	82.600	Passing truck and turning

Figures 4.9 through 4.14 illustrate the results of still images, lateral wind speed, and accelerations for these six feature points. For each feature point, different durations of data are plotted to describe the whole process of each event, for example, a curve. For each feature point, there are two still images (e.g. Figure 4.9 a-b) showing the starting point and the ending point of the process, respectively. Corresponding to both pictures, there are two black lines on the time-history data labeled with “respective time” that define the data range (Figure 4.9 c-e). Statistical data analysis was assigned to the wind and acceleration data of all feature points. Figure 4.15 shows the mean and standard deviation of lateral wind speed, lateral acceleration and rolling acceleration for all six feature points, respectively.

Feature Point 1:

Figure 4.9a Geospatial Still Image at Feature Point No. 1

Figure 4.9b Geospatial Still Image at Feature Point No. 1

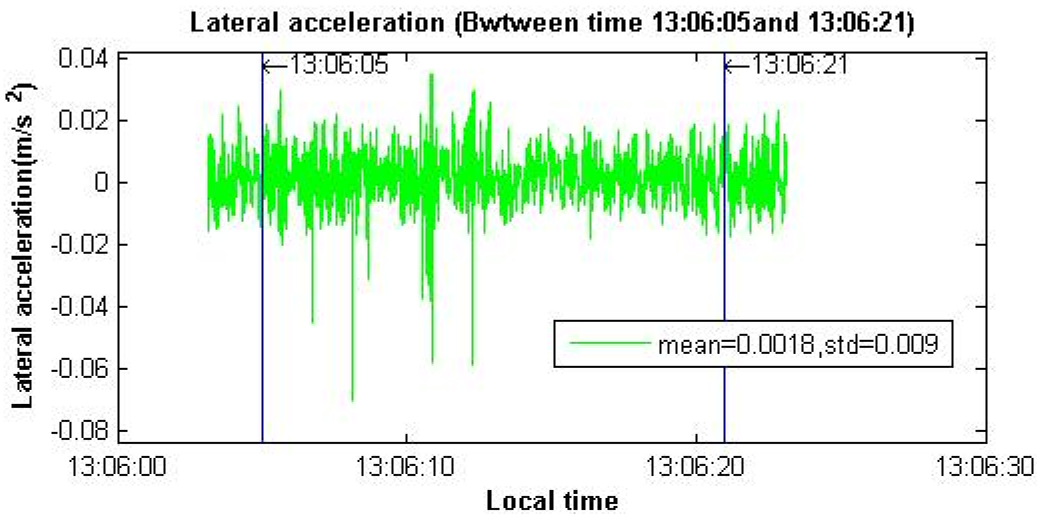


Figure 4.9c Lateral Acceleration at Geospatial Feature Point No. 1

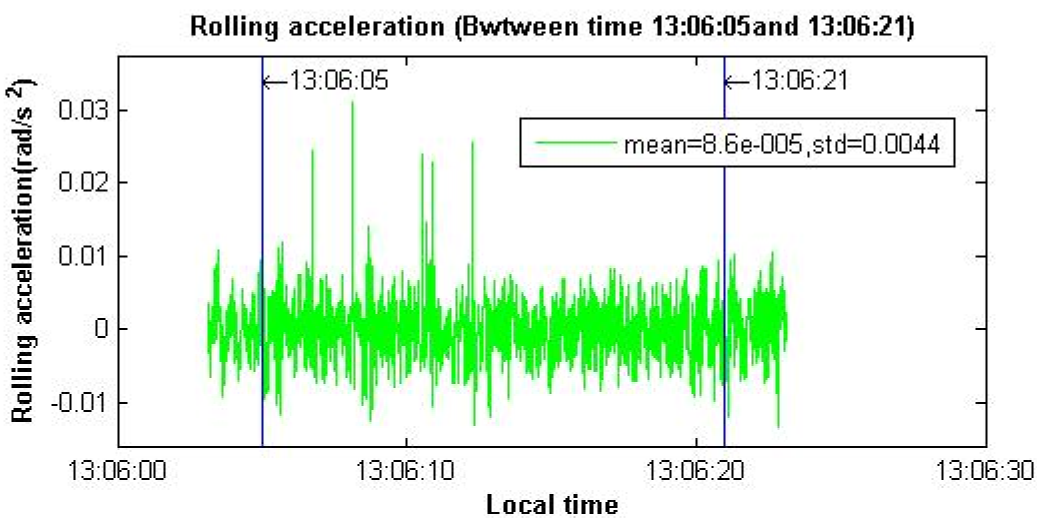


Figure 4.9d Rolling Acceleration at Geospatial Feature Point No. 1

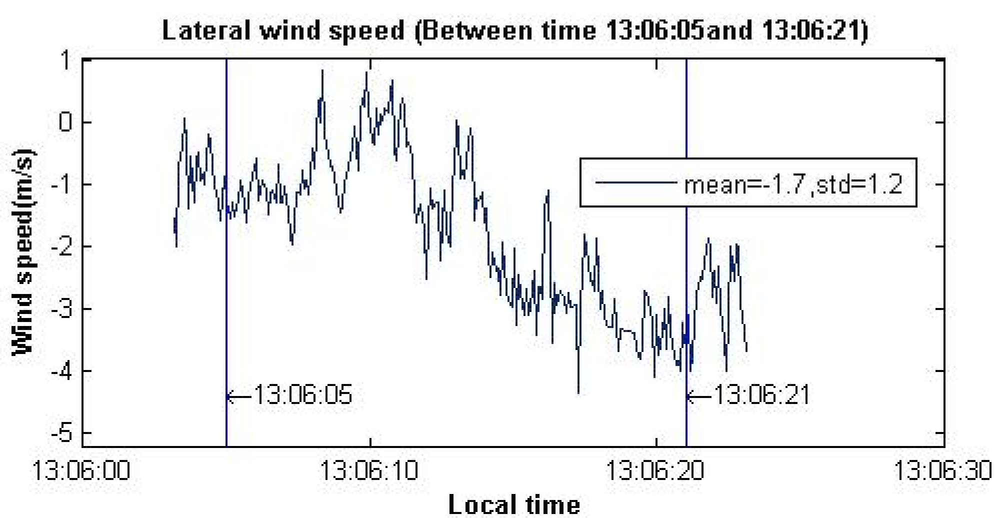


Figure 4.9e Lateral Wind Speed at Geospatial Feature Point No. 1

Feature Point 2:

Figure 4.10a Geospatial Still Image at Feature Point No. 2

Figure 4.10b Geospatial Still Image at Feature Point No. 2

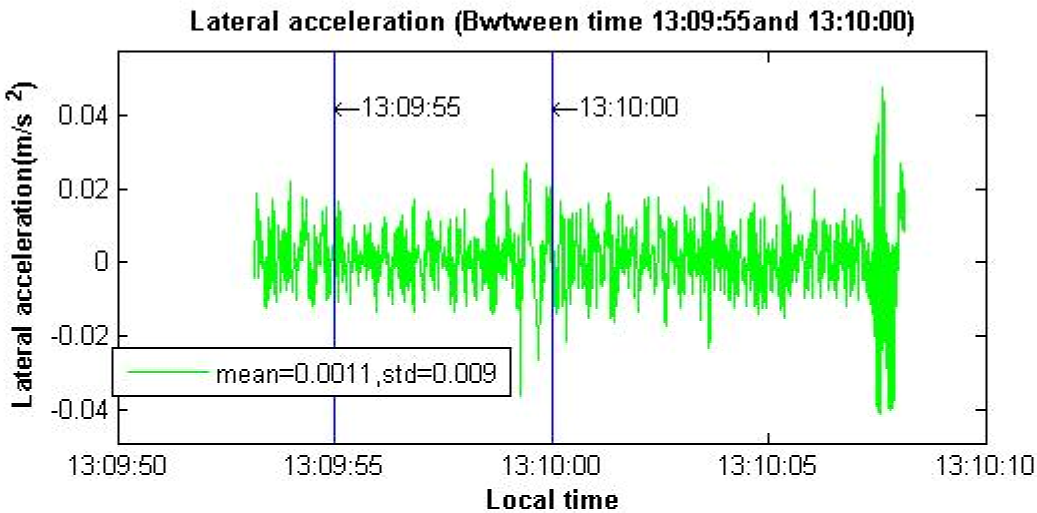


Figure 4.10c Lateral Acceleration at Geospatial Feature Point No. 2

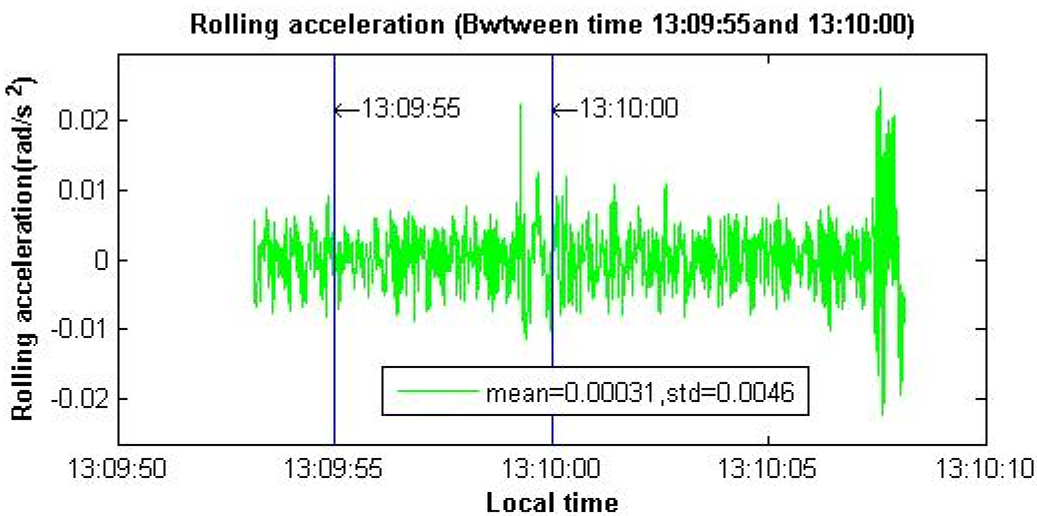


Figure 4.10d Rolling Acceleration at Geospatial Feature Point No. 2

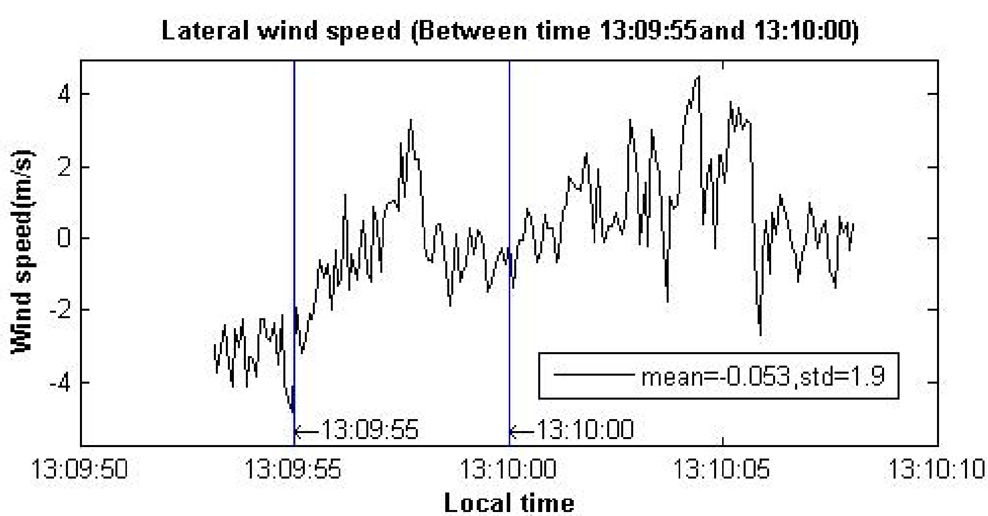


Figure 4.10e Lateral Wind Speed at Geospatial Feature Point No. 2

Feature Point 3:

Figure 4.11a Geospatial Still Image at Feature Point No. 3

Figure 4.11b Geospatial Still Image at Feature Point No. 3

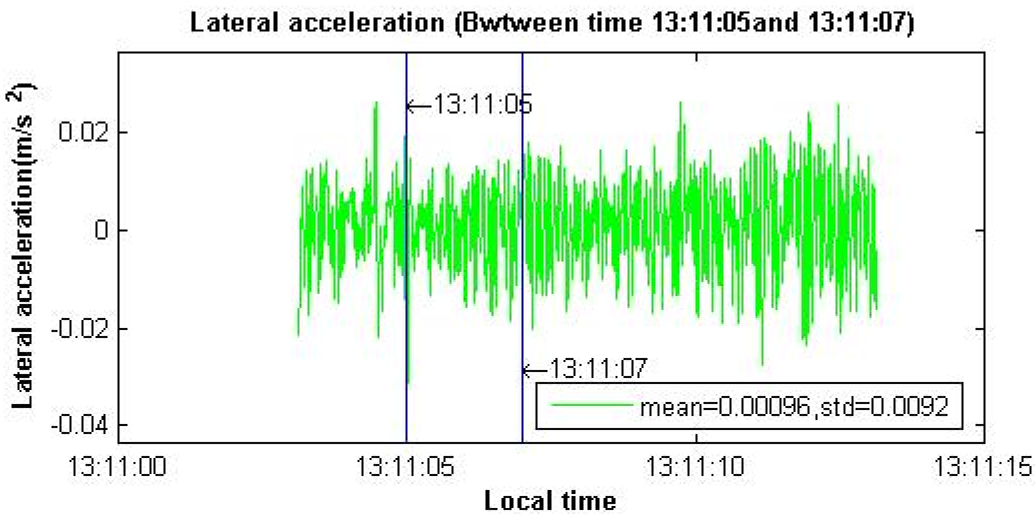


Figure 4.11c Lateral Acceleration at Geospatial Feature Point No. 3

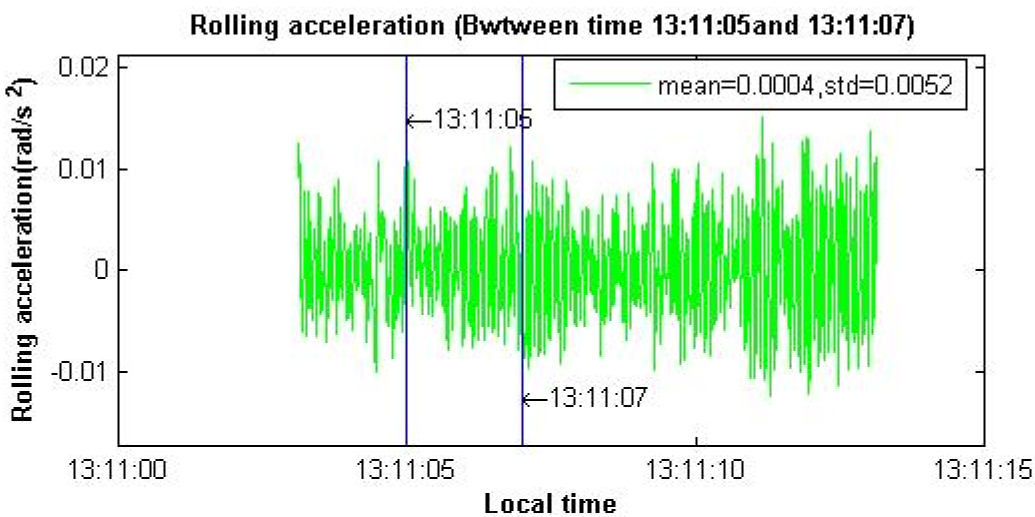


Figure 4.11d Rolling Acceleration at Geospatial Feature Point No. 3

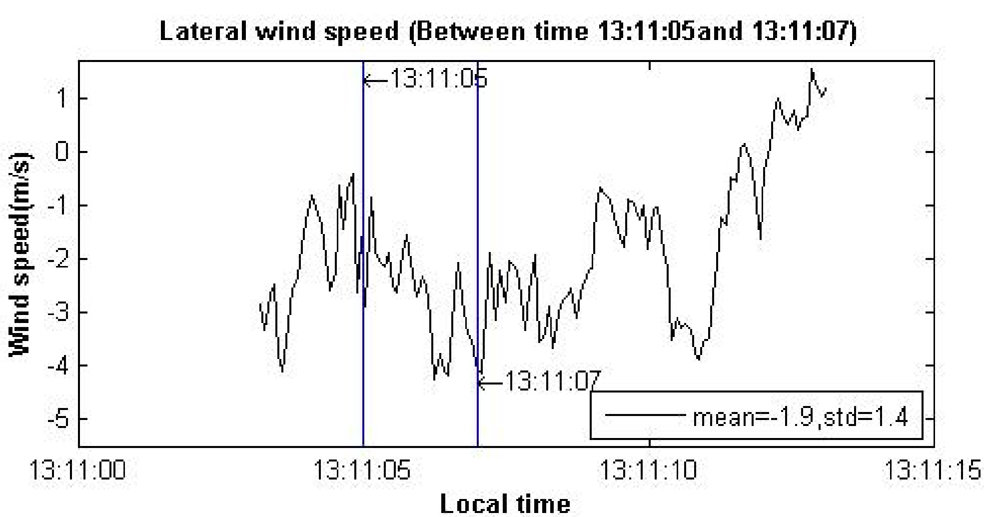


Figure 4.11e Lateral Wind Speed at Geospatial Feature Point No. 3

Feature Point 4:

Figure 4.12a Geospatial Still Image at Feature Point No. 4

Figure 4.12b Geospatial Still Image at Feature Point No. 4

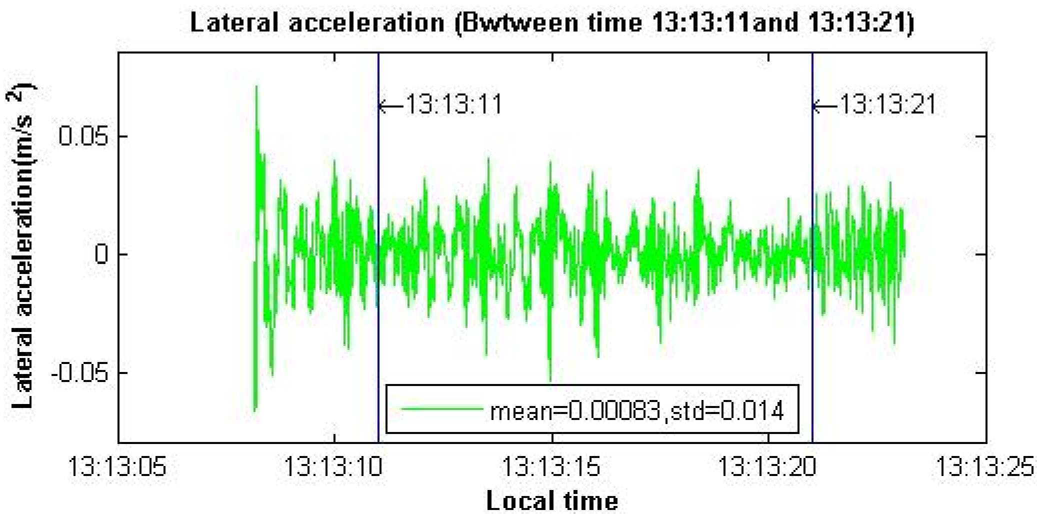


Figure 4.12c Lateral Acceleration at Geospatial Feature Point No. 4

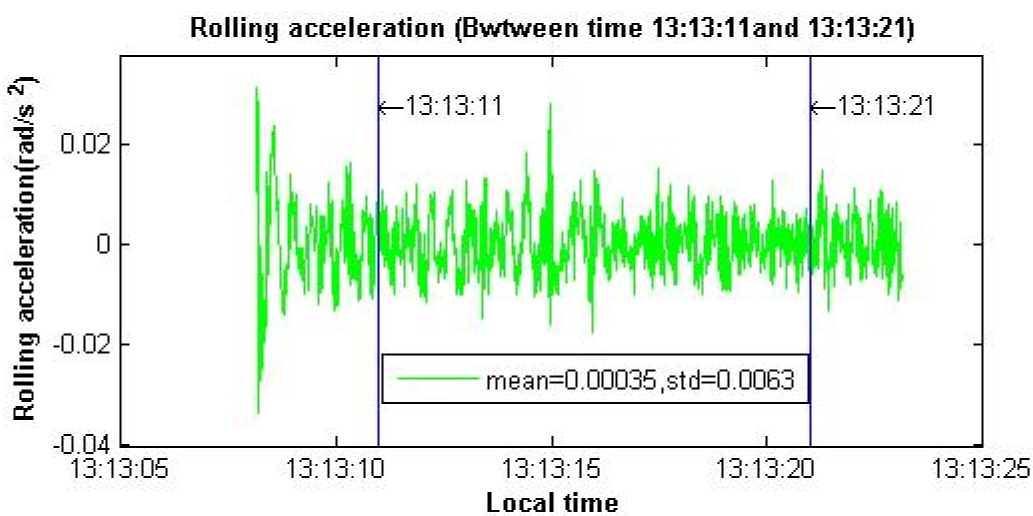


Figure 4.12d Rolling Acceleration at Geospatial Feature Point No. 4

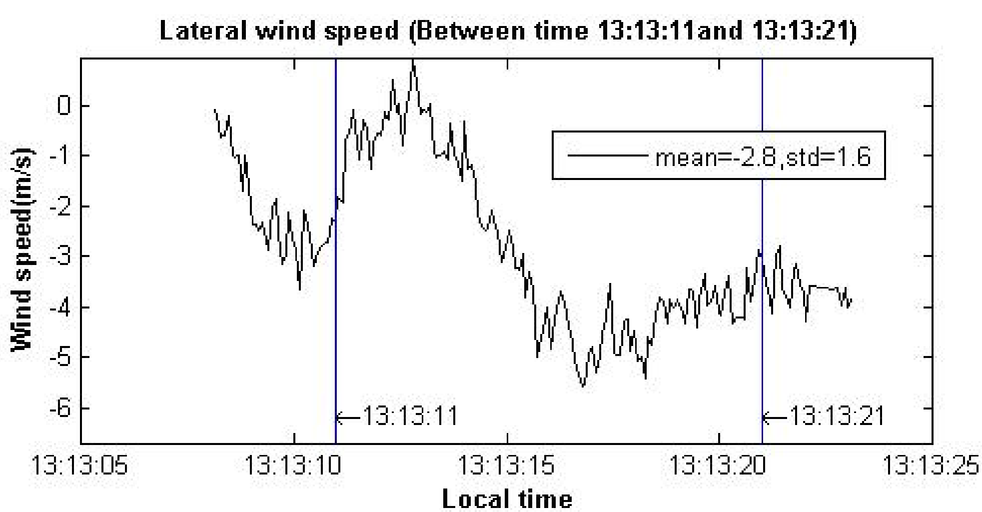


Figure 4.12e Lateral Wind Speed at Geospatial Feature Point No. 4

Feature Point 5:

Figure 4.13a Geospatial Still Image at Feature Point No. 5

Figure 4.13b Geospatial Still Image at Feature Point No. 5

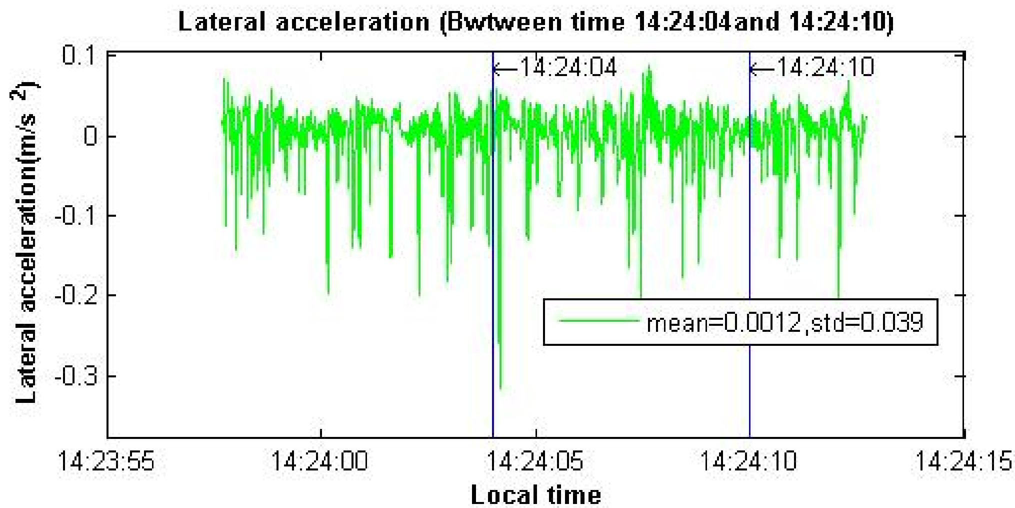


Figure 4.13c Lateral Acceleration at Geospatial Feature Point No. 5

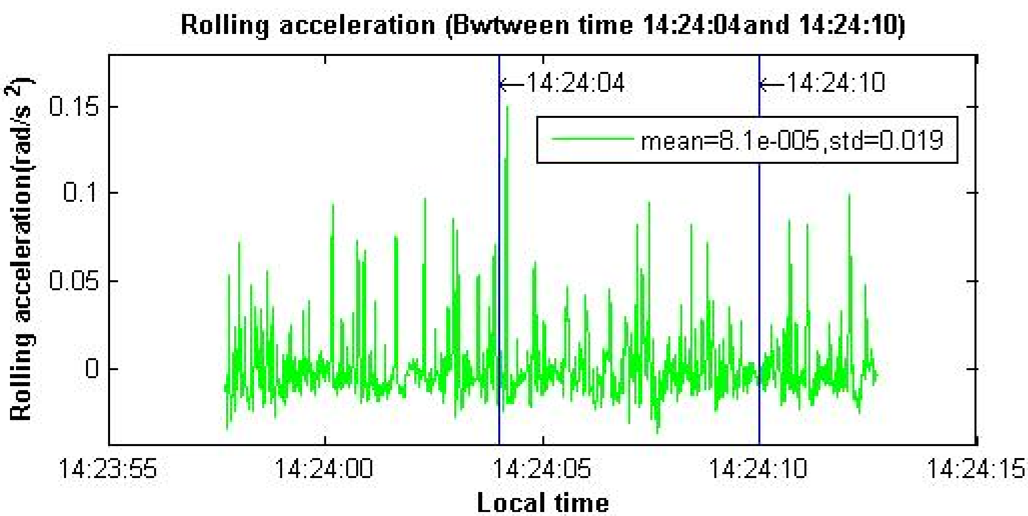


Figure 4.13d Rolling Acceleration at Geospatial Feature Point No. 5

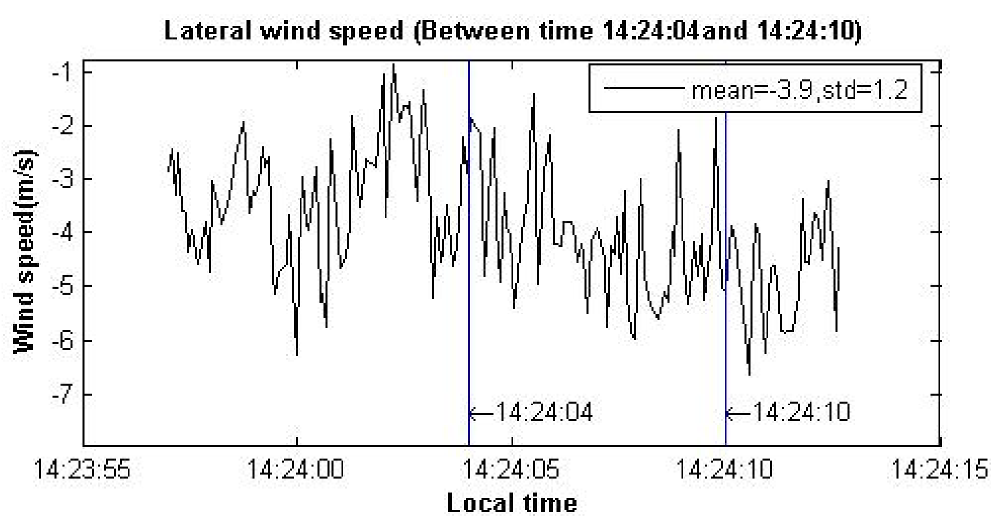


Figure 4.13e Lateral Wind Speed at Geospatial Feature Point No. 5

Feature Point 6:

Figure 4.14a Geospatial Still Image at Feature Point No. 6

Figure 4.14b Geospatial Still Image at Feature Point No. 6

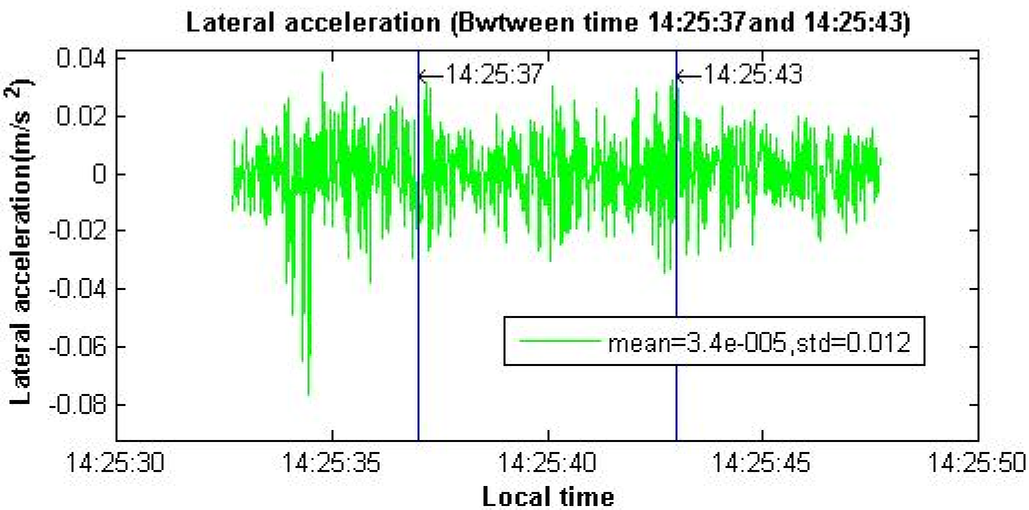


Figure 4.14c Lateral Acceleration at Geospatial Feature Point No. 6

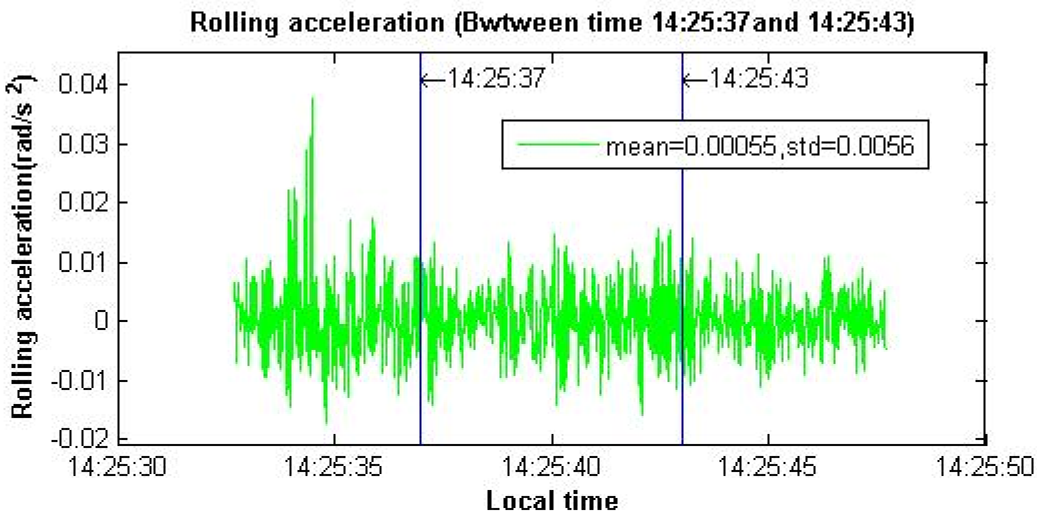


Figure 4.14d Rolling Acceleration at Geospatial Feature Point No. 6

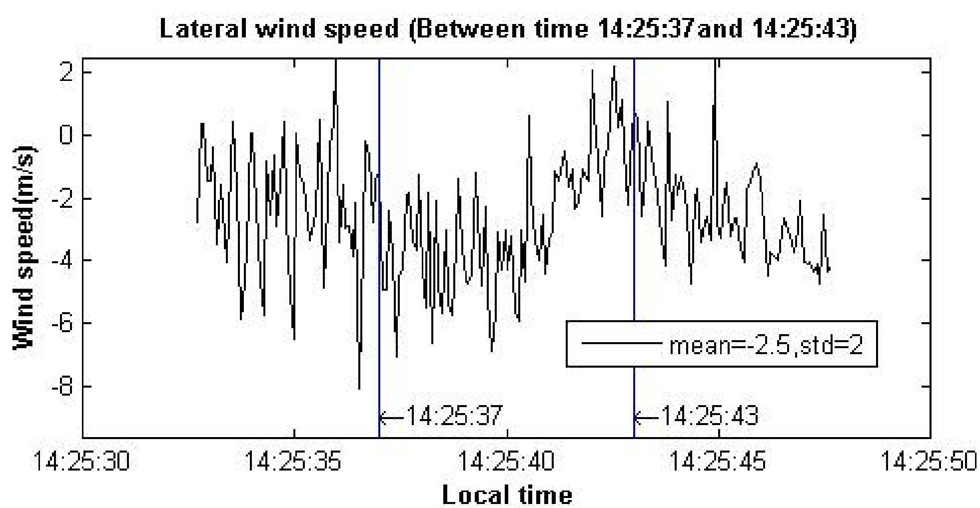
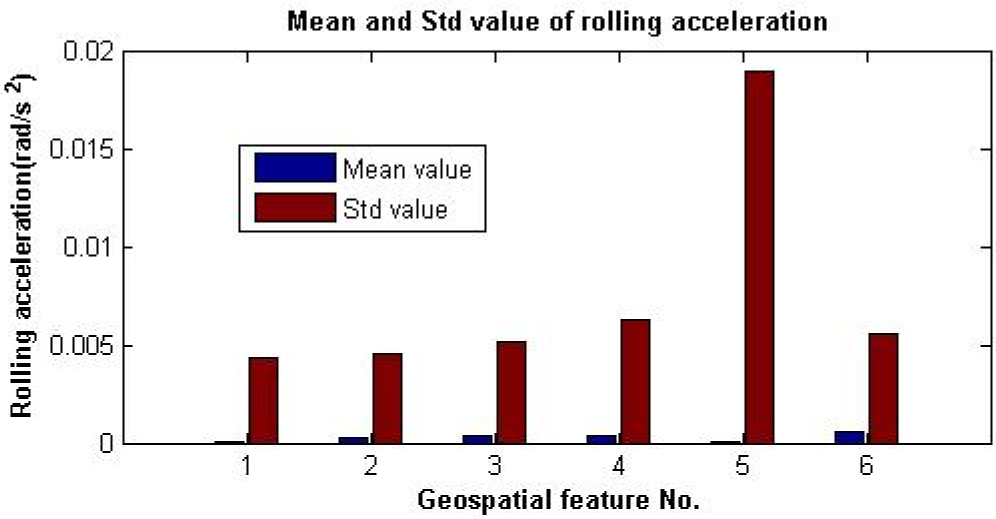
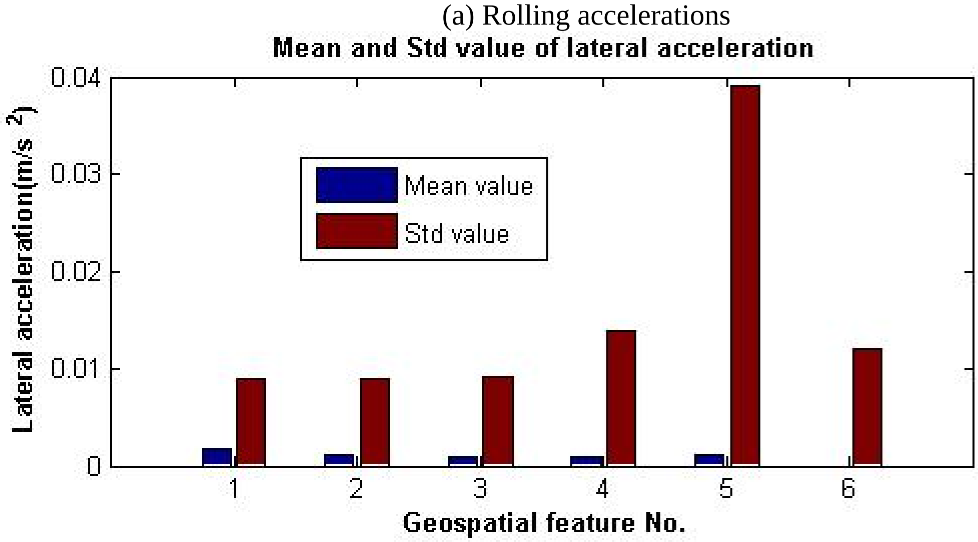


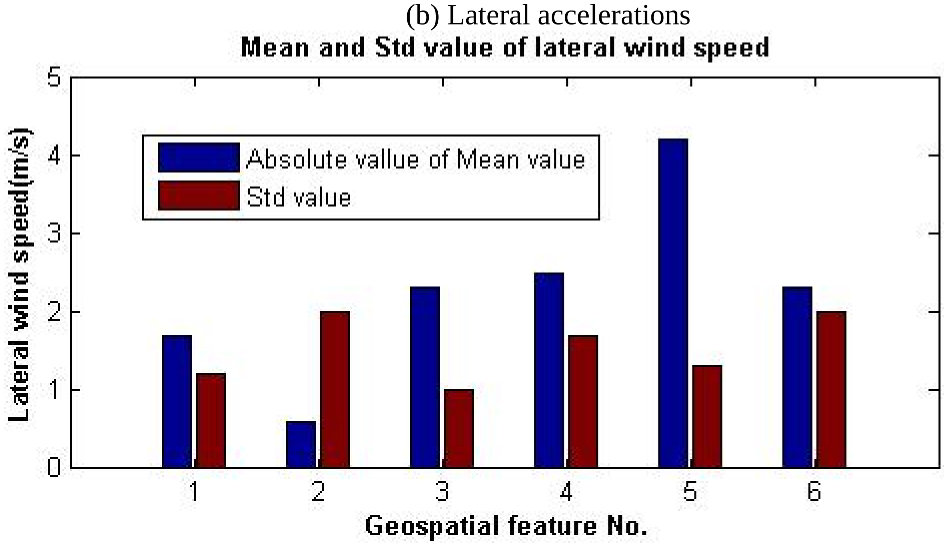
Figure 4.14e Lateral Wind Speed at Geospatial Feature Point No. 6



(a) Rolling accelerations



(b) Lateral accelerations



(c) Lateral wind speed

Figure 4.15 Statistical Results of Measurements at Different Feature Points

4.4.5 Safety factor

Rollover accidents are mostly related to the lateral acceleration of the truck. In the vehicle industry, a lateral acceleration around 0.25g is always taken as the critical point of rollover (Winkler et al. 2000). So in this project, we compare the actual lateral acceleration of the truck to 0.25g, then we decide the safety factor, which is defined as follows:

$$\text{Safety Factor} = acceleration_{lateral}(\text{t}) / 0.25\text{g}$$

where $acceleration_{lateral}$ is $acceleration_{lateral}$ of the truck on time t, taken as 0.2s-average maximum value of the lateral acceleration from t-5s to t+5s.

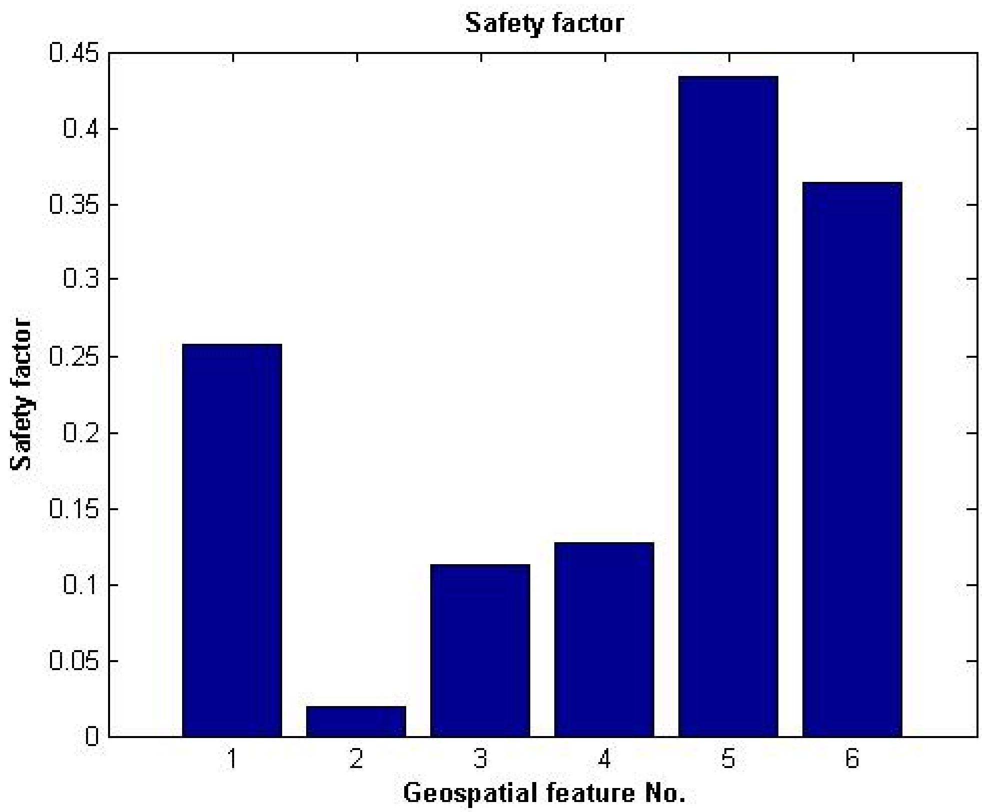


Figure 4.16 Safety Factors at Different Feature Points

4.5 GIS Web-Based Platform

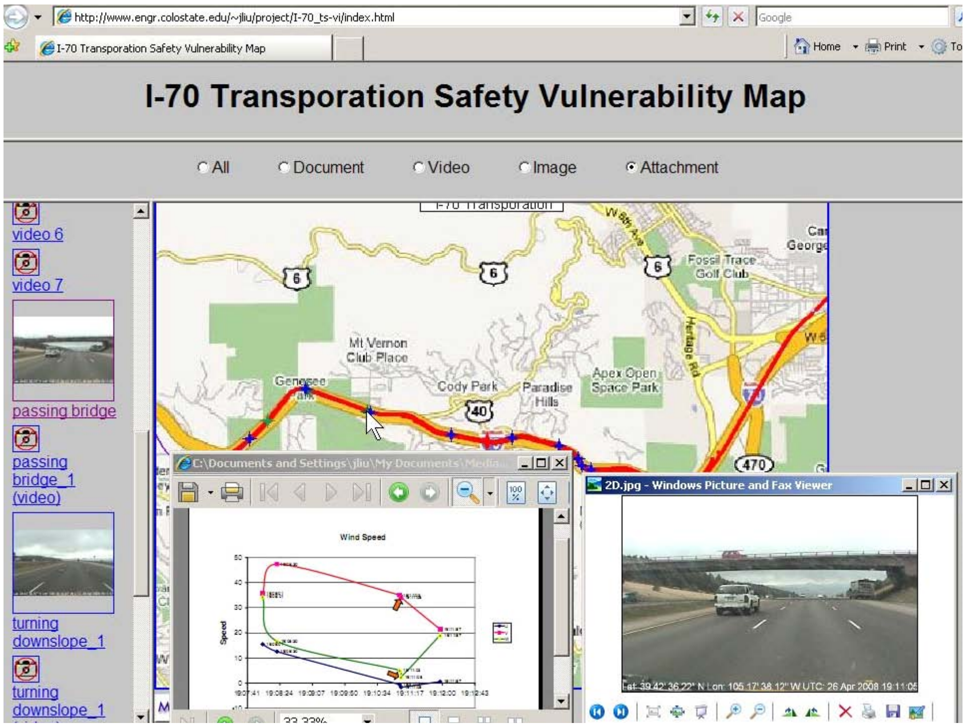


Figure 4.17 A Demo Web-based Platform for TS-VIP
http://www.engr.colostate.edu/~jliu/project/I-70_ts-vi/index.html

After VMS data and wind speed as well accelerations are synchronized together via MediaMapper, the georeferenced results can be exported into a Web-based demo TS-VIP and published in Web server. The figure 4.17 presents a screen shot of the Web platform with georeferenced still images and feature at the clicked point on the map. The georeferenced still image shows the scenario where the tested vehicle was located at the time. The feature chart indicates the wind speed at the highlighted time and location with arrows. The detail information of the TS-VIP demo platform is published at http://www.engr.colostate.edu/~jliu/project/I-70_ts-vi/index.html (best effect via IE 6.0 or higher).

5. CONCLUSIONS AND RECOMMENDATIONS

This study integrates geospatial multimedia information technology with the mobile measurements of wind speed and acceleration. Together, these allow investigations of traffic vulnerability with the future goal of mitigation of risk. The results 1) have demonstrated a promising approach to promote the transportation safety with advanced geospatial information technology, 2) can be beneficial to transportation agencies for better management and implementation and 3) provide spatial information for highway designers and researchers to improve highway design and safety research.

As a proven technique from this study, many future studies may be conducted based on the new mobile testing techniques, geo-multimedia technology and GIS-based information system. As the first step to test the new technology, many further studies can be conducted, such as mobile wind measurements and intelligence transportation systems. Detailed data analysis and studies will also be conducted on the collected data, which will be the future work of the writers.

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