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This report documents the research project "Evaluation of GPS-based Mountain Pass Road Opening for Tioga Pass." The primary goal of this project was to address porting of the GPS-based Mountain Pass Road Opening (MPRO) rotary plow Driver Assistance System (DAS) design and implementation from SR 108 to SR 120, and evaluate the system's performance in this new environment. Caltrans has eight mountain passes that are closed in the fall and opened each spring. Opening these passes is a difficult and dangerous job with few visual indicators or landmarks to guide experienced snowplow operators. Existing techniques include probing the snow pack with poles, path staking, and active embedded cable systems, which all have associated drawbacks. MPRO uses an infrastructure-free approach that uses the Global Positioning System (GPS) to provide a real-time in-cab mountain pass road opening system for rotary plow driver assistance. Under previous research, the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center developed MPRO to be portable, easy to install, and shareable among multiple vehicles. The MPRO system was originally developed for use on Sonora Pass (SR 108), and was tested there over five road opening seasons. The current project investigated porting the MPRO system to Tioga Pass (SR 120) and testing the system for one road opening season. The key task in porting the system, in addition to the physical installation of the hardware, was the development of a base map to support the GPS-based location of the vehicle. In the current project, a new approach was used based on Mobile Terrestrial Laser Scanning (MTLS). This approach allowed rapid generation of a highly accurate base map for use in the MPRO system. Testing on SR 120 was successful, demonstrating the portability of the MPRO system.

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# Advanced Highway Maintenance and Construction Technology Research Center

Department of Mechanical and Aerospace Engineering
University of California at Davis

## Evaluation of GPS-based Mountain Pass Road Opening for Tioga Pass

Kin Yen, Bahram Ravani &
Ty A. Lasky: Principal Investigator

Report Number: CA16-2337
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July 31, 2015

# California Department of Transportation

Division of Research, Innovation and System Information

## ABSTRACT

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ii

# TABLE OF CONTENTS

# LIST OF FIGURES

iv

# LIST OF TABLES

# LIST OF ACRONYMS AND ABBREVIATIONS

| Acronym | Definition |
| --- | --- |
| AHMCT | Advanced Highway Maintenance and Construction Technology Research Center |
| BOM | Byte Order Mark |
| Caltrans | California Department of Transportation |
| CORS | Continuously Operating Reference Stations |
| COTS | Commercial Off–The-Shelf |
| CRC | Cyclic Redundancy Check |
| CSV | Comma-Separated Value |
| DAS | Driver Assistance System |
| DC | Direct Current |
| DGPS | Differential GPS |
| DOD | Department of Defense |
| DOE | Caltrans Division of Equipment |
| DOP | Dilution-of-Precision |
| DOT | Department of Transportation |
| DR | Dead Reckoning |
| DRISI | Caltrans Division of Research, Innovation and System Information |
| DTM | Digital Terrain Model |
| EIA | Electronic Industries Alliance |
| EOP | Edge of Pavement |
| EPSG | European Petroleum Survey Group |
| ESC | Caltrans Equipment Service Center |
| GIS | Geographic Information System |
| GNSS | Global Navigation Satellite System |
| GPS | Global Positioning System |
| HMI | Human-Machine Interface |
| IGEB | Interagency GPS Executive Board |
| IMU | Inertial Measurement Unit |
| INS | Inertial Navigation System |
| KML | Keyhole Markup Language (used for Google Earth) |
| LCD | Liquid Crystal Display |
| MEMS | Micro-Electro-Mechanical Systems |
| MPRO | Mountain Pass Road Opening |
| MTLS | Mobile Terrestrial Laser Scanning |
| NAD83 | North American Datum of 1983 |
| NDGPS | Nationwide Differential GPS |
| NGS | National Geodetic Survey |
| NMEA | National Marine Electronics Association |
| OEM | Original Equipment Manufacturer |
| PM | Postmile |
| PNT | Position, Navigation, and Timing |
| R&D | Research & Development |
| RFP | Request for Proposals |
| RTK | Real-Time Kinematic |
| SA | Selective Availability |
| SBAS | Satellite-Based Augmentation System |
| SHP | Shapefile GIS format |
| SR | State Route |
| TAG | Technical Advisory Group |
| TLC | Time to Line Crossing |

| Acronym | Definition |
|---------|------------|
| TLS | Terrestrial Laser Scanning (fixed) |
| TSI | Transportation System Information |
| UNAVCO | University NAVSTAR Consortium |
| UTC | Coordinated Universal Time |
| UTM | Universal Transverse Mercator coordinate system |
| WAAS | Wide Area Augmentation System |
| WGS-84 | World Geodetic System |
| XML | eXtensible Markup Language |

# ACKNOWLEDGMENTS

# CHAPTER 1:
# INTRODUCTION

## Background and Motivation

### Problem

Under previous research, the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center developed the GPS-based Mountain Pass Road Opening (MPRO) Rotary Plow Driver Assistance System (DAS) [8]. MPRO was developed for use on Sonora Pass (SR 108), and was tested there over five road opening seasons [9]. AHMCT developed MPRO to be portable, easy to install, and sharable among multiple vehicles. The research results indicated that the system was ready for widespread use within California State Department of Transportation (Caltrans) Winter Maintenance Operations.

The primary goal of the current research project was to address porting of the MPRO design and implementation from State Route (SR) 108 to SR 120 (Tioga Pass), and evaluate the system's performance in this new environment. The key task in porting the system, in addition to the physical installation of the hardware, was the development of a base map to support the GPS-based location of the vehicle. In the current project, a new approach was developed based on Mobile Terrestrial Laser Scanning (MTLS). This approach, discussed in Chapter 4, allowed rapid generation of a highly accurate base map for use in the MPRO system.

### Background

Caltrans has eight mountain passes that it closes over each winter season due to large snow precipitation, and opens each spring[1]: Ebbets Pass (SR 4), Monitor Pass (SR 89), Lassen Loop (SR 89), Sonora Pass (SR 108), Tioga Pass (SR 120), June Lake Loop (SR 158), Mammoth Lakes (SR 203), and Lake Sabrina to Aspendell (SR 168). These locations are shown in Google Earth in Figure 1.1 and in Google Maps in Figure 1.2. Opening these passes in the spring is a difficult and dangerous job because of large snow accumulation over the entire winter season. It involves cutting the snow from the top down to the pavement using a small rotary snow blower driving on top of the snowpack. There are few visual indicators (e.g. terrain, snow stakes, trees) of road location, and over time some of these indicators may no longer be available (see Figure 1.3). For example, due to mandates, snow stakes may not be replaced when they are damaged or destroyed. Generally, experienced operators lead the road-opening effort, and identify the first cut paths in the snow build-up based on their experience and local terrain features and landmarks. For experienced operators, it can be difficult to reliably and repeatably determine the roadway location. For less experienced operators, this task is even more challenging and dangerous. If the rotary plow were steered off course, the vehicle could slide off a steep slope, sink into a creek bed, or damage the blower mechanism due to ingestion of rocks or running into rocks hidden in the snow along the roadside. Existing techniques to guide rotary plow operators include probing the snow pack with poles, path staking, and active embedded cable systems, which all have associated drawbacks.

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[1] For information on Caltrans winter pass closures see http://www.dot.ca.gov/hq/roadinfo/clsdlst.htm

These annual road opening operations, while difficult and hazardous, are also essential for public safety, mobility, and tourism. In conjunction with Caltrans Division of Research, Innovation and System Information (DRISI) and the Caltrans winter maintenance group, the AHMCT Research Center developed a field-ready and deployable GPS-based mountain pass road-opening rotary plow DAS to guide rotary plow operators to drive and stay over the roadway during the road opening operation. Primary system objectives are increased safety and snow-removal efficiency with minimal capital investment, and decreased environmental impact and costs associated with infrastructure repair. The system was developed to be portable and easily installed, with a small number of units sharable across Statewide mountain pass opening operations. Field-testing was continued under previous research through Spring 2009, and results indicated the system was ready for widespread use within Caltrans winter maintenance operations [9].
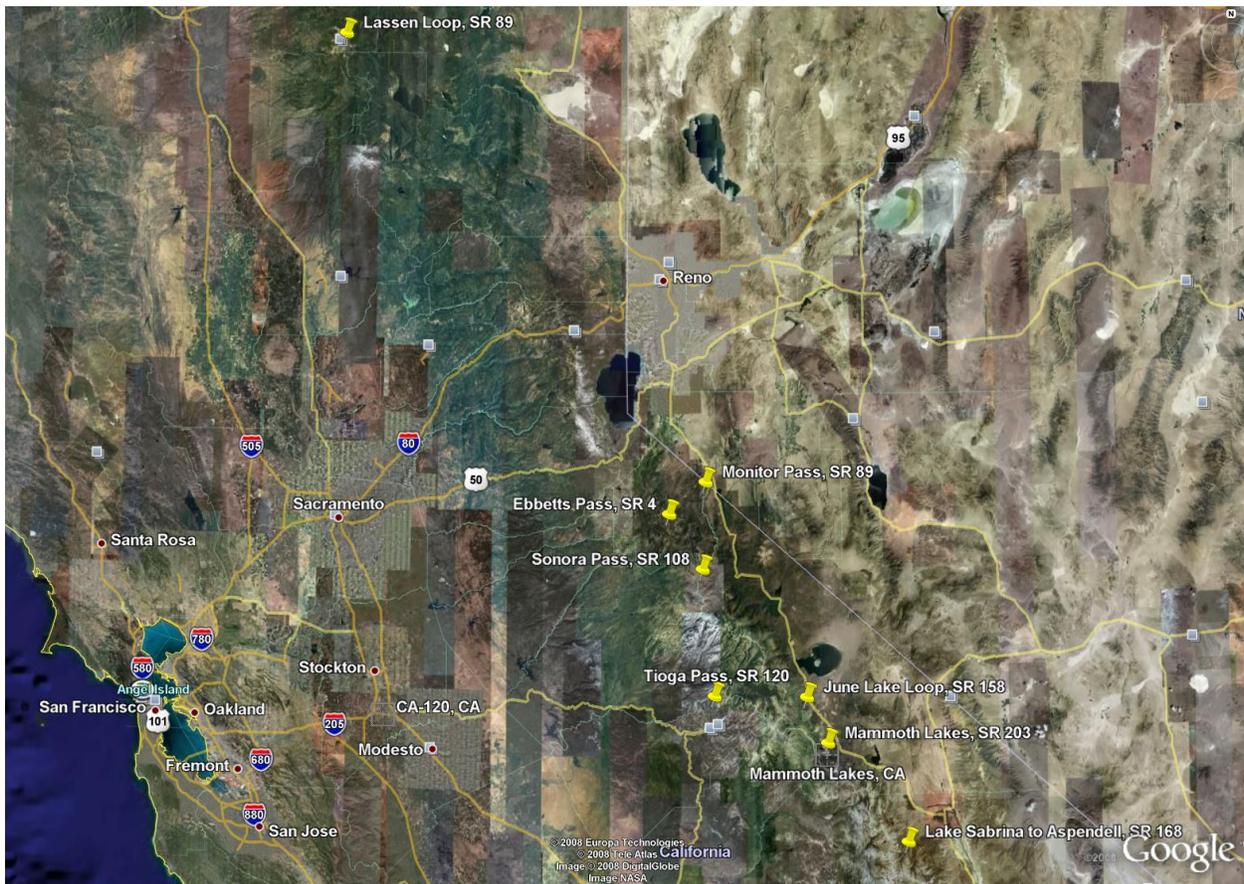


**Figure 1.1: Caltrans winter pass closures visualized in Google Earth**

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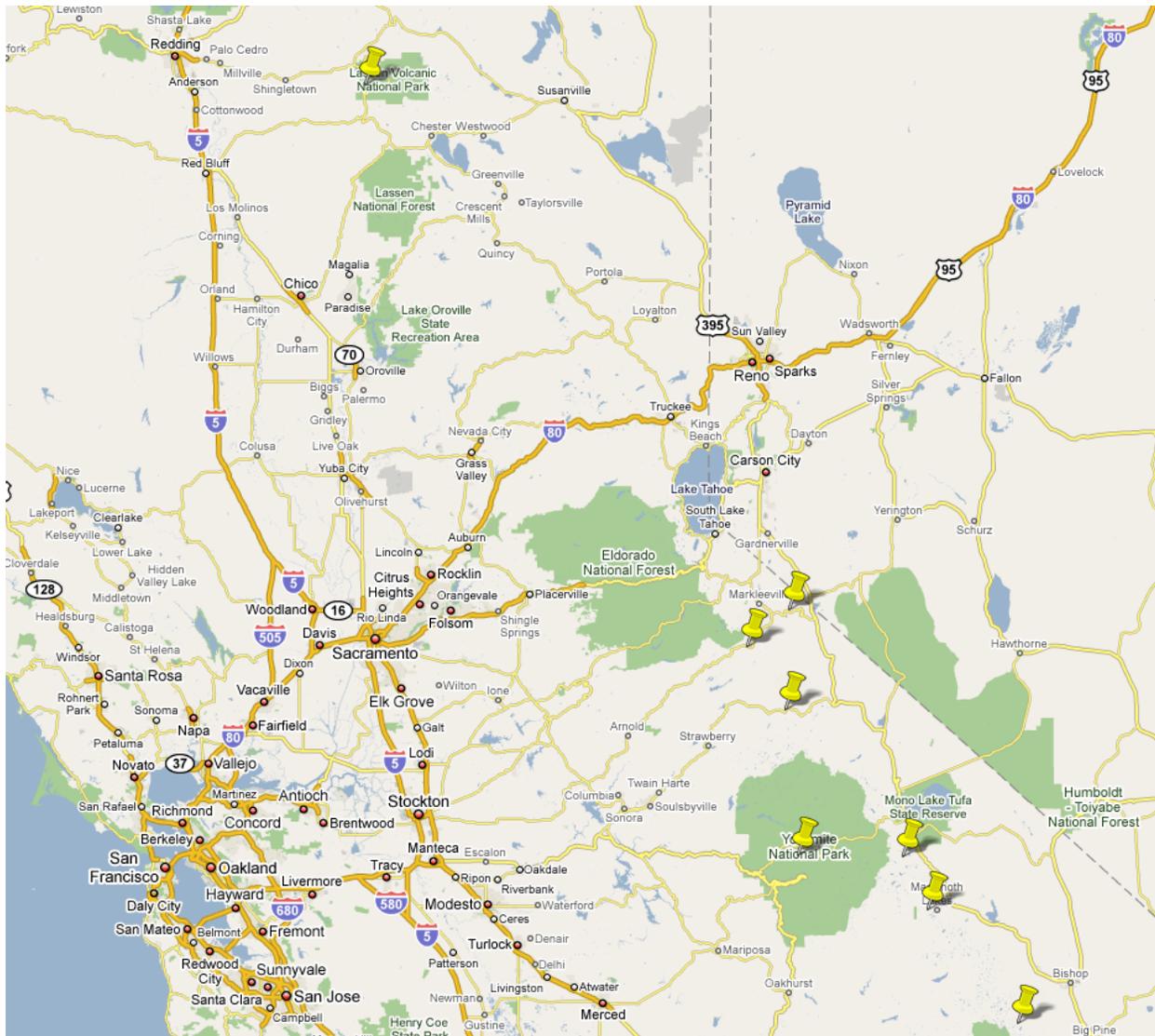
**Figure 1.2: Caltrans winter pass closures visualized in Google Maps**

**Figure 1.3: Terrain surrounding SR 120 after road-opening operations**

4

## Research Approach

The current work builds on AHMCT's experience with Mountain Pass Road Opening driver assistance, our strength in GPS sensing and vehicle integration, and our established Mechatronic hardware and software base [1,3-5,10,12-14].

The research methodology included:

- System evaluation and redesign,

- Development of new methodologies for base map generation,

- Development of test methods and data acquisition approach,

- Observation of MPRO use and test participation, and

- MPRO performance evaluation.

## Overview of Research Results and Benefits

The system provides safety benefits for Caltrans personnel working in particularly hazardous conditions. For the MPRO system, the roadway is obscured by many feet of snow, and there are few if any markers for the edge of the roadway. Snow stakes are not reliably available. Trees can provide a good indication; however, much of the road opening operation occurs above the tree line. Run-off road accidents are a risk, particularly for newer operators. The MPRO system provides clear and reliable indication of the vehicle's position above and heading along the roadway, thus greatly increasing the safety of the road opening.

The current project demonstrated a new approach for development of the base map to support the GPS-based location of the vehicle. This novel approach was based on Mobile Terrestrial Laser Scanning (MTLS). This approach allowed rapid generation of a highly accurate base map for use in the MPRO system. This approach will be widely applicable in other applications requiring a high-accuracy base map developed in a safe and efficient manner.

The key deliverables of this project include:

- Operational MPRO system for Tioga Pass,

- Methodology for MTLS-based generation of base maps,

- The base map for Tioga Pass,

- Field testing and operator feedback summary information, and

- Test results, analysis, and documentation.

5

# CHAPTER 2:
## BACKGROUND AND SUPPORTING SYSTEMS

The Human-Machine Interface (HMI) is the essential element in the MPRO system. From the operator's point of view, the HMI *is* the system. The HMI is based on a bird's eye view of the roadway. The HMI in general combines visual (screen-based), audible, and tactile feedback to the operator. In previous work, AHMCT developed simple and effective means to retrofit any existing driver seat with vibrating tactile feedback without compromising the safety and comfort of the driver's seat. AHMCT has also developed custom display technologies that are very well-suited to the maintenance vehicle environment in general, and to the low-temperature conditions of winter maintenance in particular.

## GPS and Related Technologies Background

Through numerous research efforts, AHMCT has developed significant experience and strength in the understanding and use of the Global Positioning System (GPS) in the highway environment. This includes previous research into vehicle guidance (related to snowplow driver assistance as well as mountain pass opening) with GPS as the primary sensor. AHMCT developed methodologies to survey and efficiently represent roadways and reference trajectories in a Geographic Information System (GIS), and refined these methods on SR 108 near Long Barn, CA. In separate research for the Caltrans Transportation System Information (TSI) (now part of DRISI), AHMCT designed and developed the GPS Advanced Travel Diary (GPS-ATD) for use in travel behavior studies. In this section, we will provide some of the relevant GPS background information and a summary of the state-of-practice and state-of-the-art in this area. We have also developed an extensive capability in the Mechatronic design and implementation of sensors, processors, and tightly-integrated solutions targeted for highway maintenance use (e.g. Donecker *et al* [1]).

Recent technological developments and improvements in GPS, low-cost small Micro-Electro-Mechanical Systems (MEMS) inertial sensors, and low-power embedded computers have converged to make GPS-based vehicle guidance the best choice for field-ready and deployable systems. Each of these technical areas will be discussed in brief detail in this section.

### Global Positioning System

The Global Positioning System (GPS) is a space-based radio-navigation system consisting of a constellation of satellites and a network of ground stations used for monitoring and control. A minimum of 24 GPS satellites orbit the Earth at an altitude of approximately 11,000 miles, providing land, sea, and airborne users with accurate information on position, velocity, and time anywhere in the world and in all weather conditions, with precision and accuracy far better than other radio-navigation systems available today or in the foreseeable future (see gps.faa.gov). Currently, there are 30 operational GPS satellites in orbit. They circle the Earth twice per day. The space and ground control GPS segments are operated and maintained by the Department of Defense (DOD). In 1996, a Presidential Decision Directive, later passed into law, transferred "ownership" from DOD to the Interagency GPS Executive Board (IGEB), co-chaired by senior officials of the Departments of Transportation and Defense to provide management oversight to assure that GPS meets civil and military user requirements. The President authorized a new

national policy on December 8, 2004 that established guidance and implementation actions for space-based positioning, navigation, and timing programs, augmentations, and activities for U.S. national and homeland security, civil, scientific, and commercial purposes. This policy supersedes Presidential Decision Directive/National Science and Technology Council-6, U.S. Global Positioning System Policy, dated March 28, 1996. Currently, the GPS program receives national-level attention and guidance from a joint civil/military body called the National Executive Committee for Space-Based Positioning, Navigation, and Timing (PNT).

GPS receivers collect signals from the satellites in view. They provide the user's position, velocity, and time, and some receivers give additional data, such as distance and bearing to selected waypoints or digital charts after further processing of the positional and time solutions. Without going into full detail, each satellite transmits an accurate position and time signal. The user's receiver measures the time delay for the signal to reach the receiver, which provides a direct measure of the apparent range (called a "pseudorange") to the satellite. Measurements collected simultaneously from a minimum four satellites are processed to solve for the three dimensions of position (latitude, longitude, and altitude in the WGS-84 geodetic reference system) and precise time. For more information, see Hoffmann-Wellenhof, *et al* [2].

Selective Availability (SA) was used to protect the security interests of the U.S. and its allies by globally denying the full accuracy of the civil system to potential adversaries. It was turned off at midnight on May 1, 2000. It is not the intent of the U.S. to ever use SA again. Currently, with removal of SA, accurate position (< 25 m), time, and speed can be obtained throughout the country using small and low-cost GPS receivers. GPS is continuously being modernized with additional radio frequency and transmission power resulting in more reliable and accurate positional and time solutions.

## Free Nationwide Differential GPS (DGPS) Services

GPS accuracy can be improved by additional information provided by fixed ground GPS monitoring stations. The Wide Area Augmentation System (WAAS) and the Nationwide Differential GPS (NDGPS) are two free differential GPS services available in the United States. Both systems provide improved GPS accuracy (1 to 3 meter) and integrity monitoring services. WAAS vertical accuracy over the United States is illustrated in Figure 2.1—horizontal accuracy (of most interest for vehicle guidance applications) is approximately three times better than vertical, due to geometric configuration. The West Coast has relatively excellent WAAS accuracy and coverage. While these services are not yet sufficient for the types of operations in the current research, they are noteworthy in that they illustrate the strong advances in freely available services. In addition, higher accuracy versions of some of these services have been proposed or are currently in development—such improved versions may be directly applicable in the future.
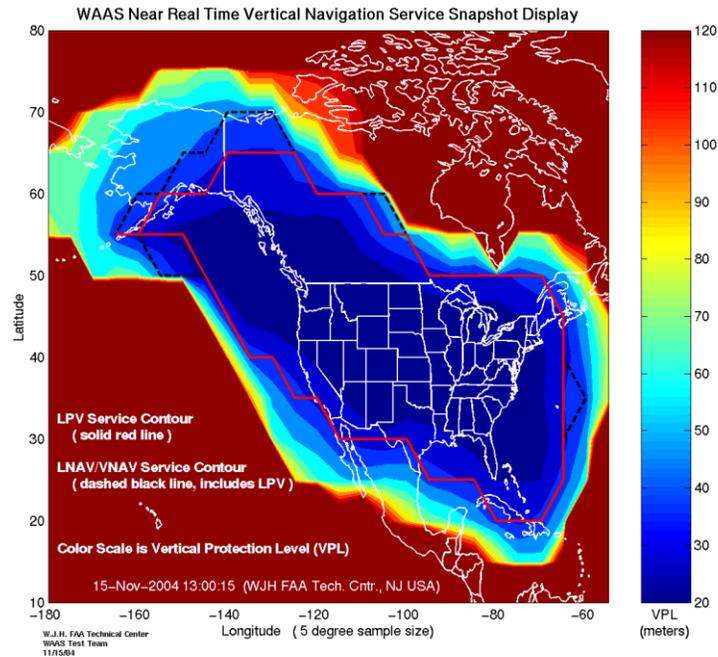
**Figure 2.1: WAAS GPS Vertical accuracy map
(http://www.nstb.tc.faa.gov/RT_VerticalProtectionLevel.htm)**

## Real-Time Kinematic GPS

GPS includes several sources of error. Many error sources are correlated between satellites and/or receivers, and can be removed via methods commonly referred to as differential corrections, or Differential GPS (DGPS). DGPS approaches can be broadly classified as code-based and real-time kinematic (RTK). For vehicle guidance applications, code-based approaches are typically not sufficiently accurate, so only RTK is considered in this discussion and in the research.

The RTK approach is based on carrier-phase tracking. The GPS satellites broadcast coded information on multiple frequencies. The carrier wave frequencies are precisely known, and RTK receivers can identify the phase of the incoming signal very accurately, so that the pseudorange can be determined for each satellite with very high precision (sub-wavelength). However, at system startup, the receiver only knows the phase and corresponding position within that wavelength. The receiver does not know the number of full wavelengths $n$ between the receiver and each broadcasting satellite. A key feature of the RTK approach is known as ambiguity resolution. Effectively, the receiver intelligently and (these days) rapidly resolves the ambiguity resolution for each satellite, and then knows each pseudorange to very high accuracy. Details will not be discussed here, but are commonly available in the literature [2]. The net result is that, with ambiguity resolution complete, the RTK GPS receiver can provide cm-level (or even sub-cm level) accuracy. There are a number of complicating factors (e.g. satellite signal loss, switchover from one satellite set to another, etc.) which must be carefully considered in vehicle guidance applications, but the key point is that RTK GPS can provide high-accuracy position (and velocity) information throughout most of the world, and, when thoughtfully integrated, is an

8

exceptional enabling technology for a wide range of applications in highway maintenance, general transportation, and many other areas.

**Satellite-Based Augmentation System**

Standard code-based and RTK DGPS systems typically require a fixed base station and some form of radio communication for real-time differential corrections. Of course, for surveying and similar operations, one can always post-process GPS data so that a real-time data link is not required; however, for vehicle guidance and control, real-time corrections are obviously essential. An alternative approach, a Satellite-Based Augmentation System (SBAS), also called Space-Based, can provide quite high-accuracy (~ 10 cm) differential GPS solutions without the need for a fixed base station, and with the real-time data link provided via a satellite-based system. SBAS subscription services are available from a number of vendors, with SBAS-enabled receivers available from multiple providers. Figure 2.2 and Figure 2.3 show test data for two SBAS services, and Figure 2.4 provides similar data for WAAS. SBAS is not appropriate for some applications which require the highest levels of accuracy; however, it is applicable in the Mountain Pass Road Opening (MPRO) system. Areas that typically would need such a road opening system are generally well-suited for SBAS DGPS—they are in high passes, often above the tree line (hence the need for some additional guidance), so that satellite signals will typically have high availability. In addition, SBAS has the strong advantage of removing the need for a fixed (or even temporary) base station, which is an important aspect given the portability and sharing potential of the MPRO system.
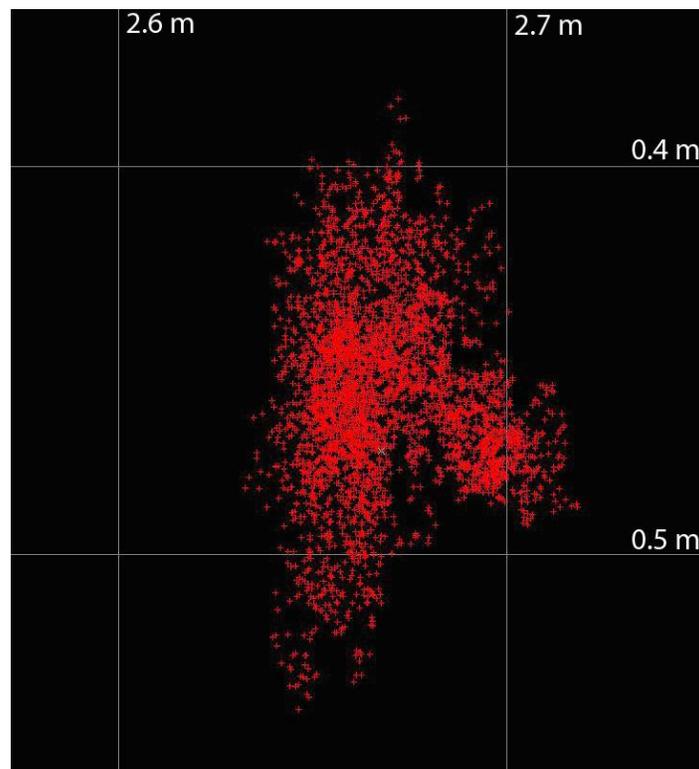


**Figure 2.2: Static OmniSTAR SBAS DGPS test result in Northern California.**

9
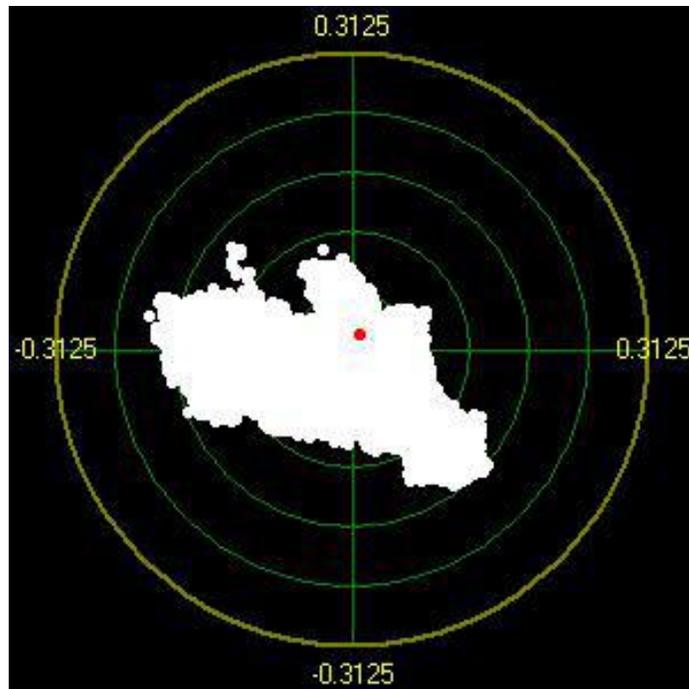
**Figure 2.3: Static StarFire SBAS DGPS test result in Northern California (meters)**
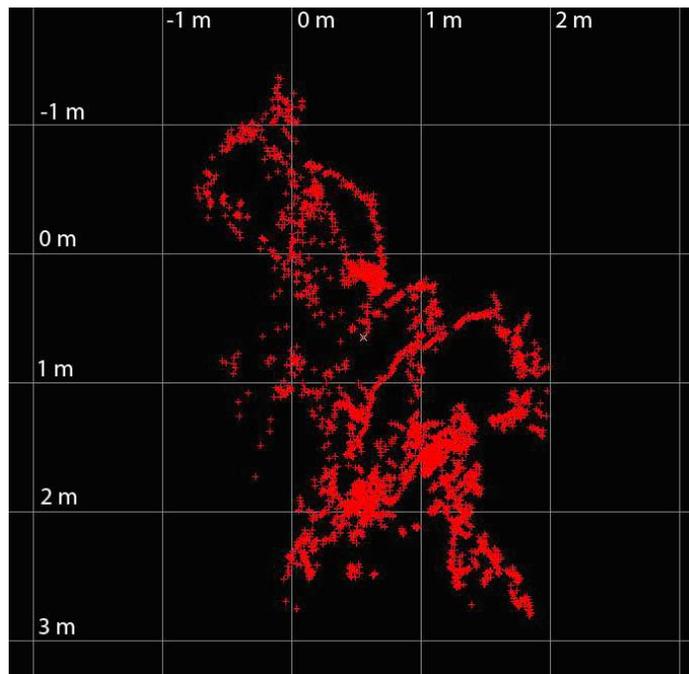


**Figure 2.4: Static WAAS DGPS test result in Northern California**

## GPS Vulnerability Issues and Mitigation

AHMCT is aware of the typical GPS vulnerabilities, and has developed methods to alleviate or mitigate these issues in the demanding winter maintenance environment. Many factors can degrade GPS performance. GPS receivers require a direct line-of-sight to the satellites in order to

10

obtain a signal representative of the true distance from the satellite to the receiver. Therefore, any object in the path of the weak GPS signal has the potential to interfere with its reception. Objects which can block a weak GPS signal include tree canopies, buildings, and terrain features. Similarly, the WAAS geostationary satellite signal can also be blocked. Furthermore, reflective surfaces can cause the GPS signals to bounce before arriving at a receiver, thus causing an error in the distance calculation. This problem, known as multipath, can be caused by a variety of materials, including water, glass, and metal. The water contained in the leaves of vegetation can produce multipath error. In some instances, operating under heavy and wet forest canopy can degrade the ability of a GPS receiver to track satellites. Typically, lower-elevation GPS satellites' signals are most likely to be blocked. In this situation, GPS receivers track only the highest satellites in the sky, as opposed to those satellites which provide the best Dilution-of-Precision (DOP)—a measure of the satellite geometry error sensitivity. Thus, the positional accuracy decreases. Unfortunately, there will be locations where the minimum four GPS satellite signals simply are not available due to obstruction, such as in urban canyon—in these cases, no general GPS solution can be obtained. Methods are available (e.g. combination with inertial measurement unit-based dead reckoning) to alleviate these issues and provide a robust solution with maximum availability.

For both Sonora and Tioga Pass, standard GPS satellites and the SBAS satellite signals have high availability, quite sufficient for the GPS-based systems in this research. For field-deployed systems, it is essential to provide fail-soft operation; i.e. if GPS signals are unavailable for an extended time such that complementary sensors (in particular dead reckoning via inertial sensing) can no longer provide a sufficient safety margin, the systems will alert the operator to resume manual operation without the aid of the driver assistance system. This is implemented in the MPRO system via watchdog timers and related health monitoring of the critical sensing components.
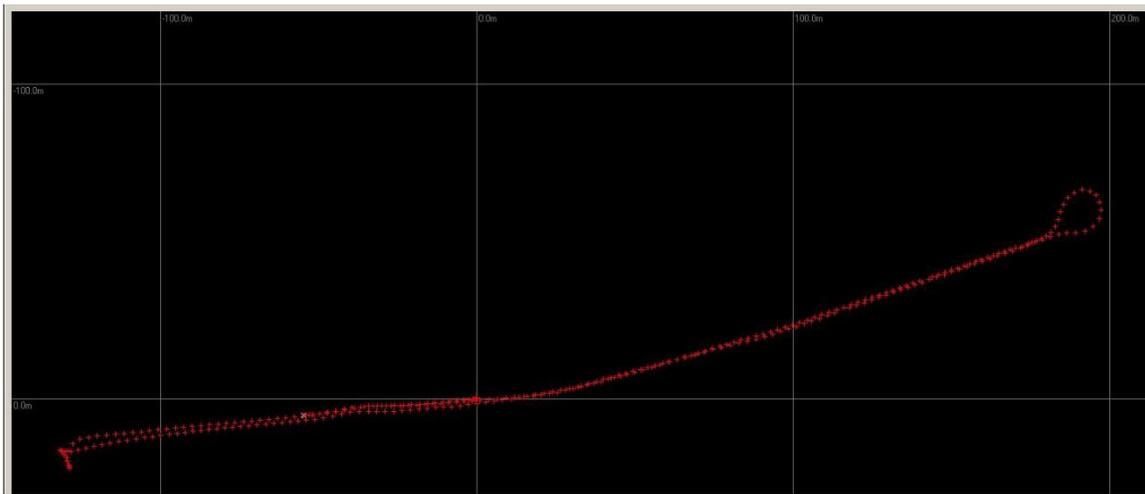


**Figure 2.5: Dynamic test result of OmniSTAR SBAS DGPS at Kingvale, California**

## GPS Sensors

Each manufacturer may have its own signal tracking, positional solution and filtering algorithms. Receivers may perform differently during startup, reacquisition of signal, and in

11

various terrains such as urban canyons and under tree canopies. Nevertheless, most GPS receivers output positional and time solution in ASCII text standard National Marine Electronics Association (NMEA) 0183 format via an RS232 serial port. NMEA output sentences contain Coordinated Universal Time (UTC) date and time, latitude, longitude, and altitude in the WGS84 coordinate system, geoidal separation, number of visible satellites, speed, heading, horizontal DOP, and solution status. Some GPS receivers give additional information such as estimated positional accuracy. Moreover, most receivers can also communicate solution data using proprietary binary communication protocols at a higher baud rate, allowing more data or more frequent updates.

Most GPS users would still not know where they are given their position in latitude, longitude, and altitude—with this raw data, most users can only tell whether they are in the northern or southern hemisphere. A digital map or a Geographic Information System (GIS) database is required to determine the user's state, city, and street location. In the special case of vehicle guidance, a centimeter-level accuracy digital map is required. The GIS component is an essential part of the research, as it provides the high-precision reference information to support GPS-based driver assistance and guidance. This component, also referred to as a base map, is discussed below, and in detail in Chapter 4, including methods to generate it.

Each GPS receiver has its own power-on sequence where it downloads almanac data (such as GPS satellite orbital information) before establishing a positional and time fix. This start-up time is referred as cold start time (typically between 45 sec to 5 min). Some receivers have a "sleep" mode in which the receiver keeps all the almanac data in memory using a low-power consumption mode. Thus, the long start time may be eliminated. Furthermore, keeping the receiver on may eliminate the cold start time. In addition, the reacquisition time, the time to reacquire the satellite signal lock when the signal was temporarily blocked, varies from 1 to 3 seconds for different manufacturers. Moreover, GPS receivers perform differently in GPS-challenged areas like urban canyons or heavily wooded areas. Their size and power consumption varies as well. These factors have been examined in this research, along with methods to alleviate these issues and provide a robust solution with maximum availability.

## Supporting Systems

The GPS-based approach of the current research does not require any added reference infrastructure in the pavement or on the guardrails. This provides a significant advantage in terms of maintainability and portability. This section overviews, the required support systems: base maps for position reference, and differential corrections. The system uses World Geodetic System (WGS-84) latitude / longitude / altitude coordinates.

### Accurate As-Built Roadway Base Map

The roadway base map provides the positioning reference for the GPS-based guidance system. This base map must be generated for each system installation site. The base map would need updates for any significant redesign of the roadway, i.e. anything that changes the roadway configuration. For the one-time generation and the needed updates, AHMCT has investigated appropriate and efficient methodologies, including simple driving and recording of lane

centerline positions (effective and used previously for the MPRO operation on SR 108), fixed Terrestrial Laser Scanning (TLS), and Mobile Terrestrial Laser Scanning (MTLS).

In general, the base map must be as accurate as the machine control requirements. For MPRO operations, the requirement is to keep the operator over the roadway; for this application, it is sufficient to drive the route and record a lane centerline, although the higher precision MTLS approach would certainly be applicable as well. The MTLS approach was used for SR 120, as discussed in Chapter 4. The new geo-referenced mobile 3D laser scanning technology (MTLS) provides the most suitable survey solution for future applications. Data is collected at approximately highway speed and provides the level of accuracy needed. The dense geo-referenced 3-D point clouds capture all features of the roadway area accurately and rapidly, thus a surveyor can go back to the point clouds and perform virtual survey of any point and surveys of any dimension that was not conceived before the physical survey, all in the safety of the office. The 3-D point clouds may be used to generate a 3-D terrain model for use in any machine guidance applications. Other data may be extracted to produce current survey deliverables such as a Digital Terrain Model (DTM). In summary, the geo-referenced 3-D laser approach will provide the detail and accuracy required for the GPS-based guidance applications, and it will provide data needed by Caltrans for other envisioned applications, including the demanding requirements of Caltrans Design.
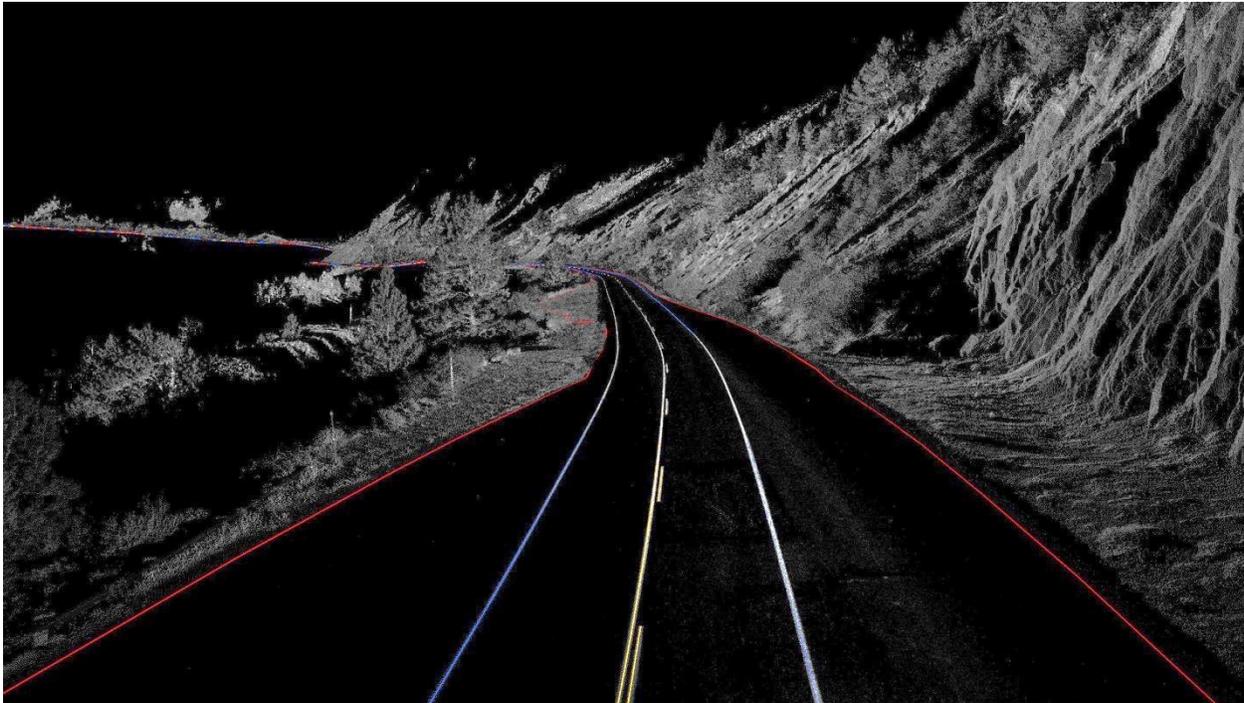


**Figure 2.7: Example 3D laser scan point cloud with extracted base map overlay**

The existing industry 3-D laser scanning survey standards (including scan density) in conjunction with the accuracy requirements of Digital Terrain Model (DTM) survey (7 mm vertical and 10 mm horizontal) would yield more than adequate base map survey requirements. The final point cloud density depends highly on range and geography. The laser scanner operators are experienced in setting the proper scan density for the required accuracy. Higher

scan density may be required for proper registration and geo-referencing. Caltrans now has the in-house ability and equipment to perform both fixed TLS and MTLS. In addition, the Caltrans Surveys Manual now includes a chapter for TLS and MTLS.

**Differential GPS**

For the required sensing accuracy, different GPS-based guidance systems require varying levels of differential GPS corrections. The accuracy requirements differ significantly between different applications, pointing to different solutions in each case. Here, the needs of the MPRO system are addressed.

The MPRO operation requires relatively low accuracy, with a 10 cm correction being more than sufficient. This can be conveniently provided via a Satellite-Based Augmentation System (SBAS). This removes need for any differential base station infrastructure at the pass opening site, and maximizes system portability and minimizes site requirements. However, the system does require an SBAS subscription service, and Caltrans must maintain an annual license for each MPRO system it operates. On the other hand, as the system is portable, and pass opening operations may occur at different times in each pass, one consideration is sharing of the MPRO system among multiple passes, to maximize benefits.

## CHAPTER 3:
## MOUNTAIN PASS ROAD OPENING (MPRO) DAS DETAILS

### **Overview**

The Mountain Pass Road Opening (MPRO) DAS was developed and field-tested in a previous research project [8]. The system was further ruggedized based on prior testing results and operator feedback. In another research project, the system was field-tested during the opening of SR 108, Sonora Pass, over four seasons [9].

The MPRO DAS system allows the operator of a small rotary plow to safely and efficiently work on top of deep (30 – 40 feet) snow build-ups, in order to reopen mountain passes that are allowed to close over each winter. This system provides a bird's-eye view of the roadway with the vehicle location and heading clearly illustrated. Additional information, e.g. landmarks, is provided to help operators have a context for their location along the route. This system is portable, with easy field installation, calibration, use, and removal. As such, it is feasible to share the system between passes and between districts within Caltrans, yielding cost advantages. The system uses GPS as the primary sensor for driver mountain pass road opening driver assistance. Refer to Figure 3.1 for a system configuration diagram, which includes:

- A GPS receiver to provide accurate (~10 cm) vehicle location in WGS-84 latitude / longitude / altitude coordinates, suitable for integration with the GIS discussed below. The mountain pass opening operation is suitable for GPS incorporating SBAS differential corrections, i.e. no base station is required. For SBAS, currently an annual service fee is required, but there are significant advantages due to removing the need for establishing and maintaining a fixed base station at each site.
- A GPS-based compass to determine vehicle heading. The pass opening operation is typically too slow to effectively derive heading from single antenna GPS data. In addition, the large steel vehicle body would generate large interference to a magnetic compass. However, the system has been augmented to include a dual-antenna vector GPS unit that directly provides accurate heading data that is not subject to magnetic interference.
- A high-accuracy GIS database representation of the roadway (lane centerlines, relevant roadside infrastructure, on and off-ramps, etc.) which provides a reference to determine the vehicle's location above the road, heading vs. the road direction, and approximate height above the road.
- An in-vehicle display to provide the bird's-eye view of the vehicle location and heading vs. the roadway, along with landmark information to provide a sense of overall position along the route.
- The required embedded computing, real-time software, and power systems to support this mountain pass road opening driver assistance system.

15

**GPS Antenna**    **GPS Antenna**

**GPS Antenna**

**NovAtel ProPak LB OmniSTAR or NavCom StarFire**

**GPS-Based Compass**

**LCD Display**

**RS232 10Hz**

12 VDC Power In

**Computer**
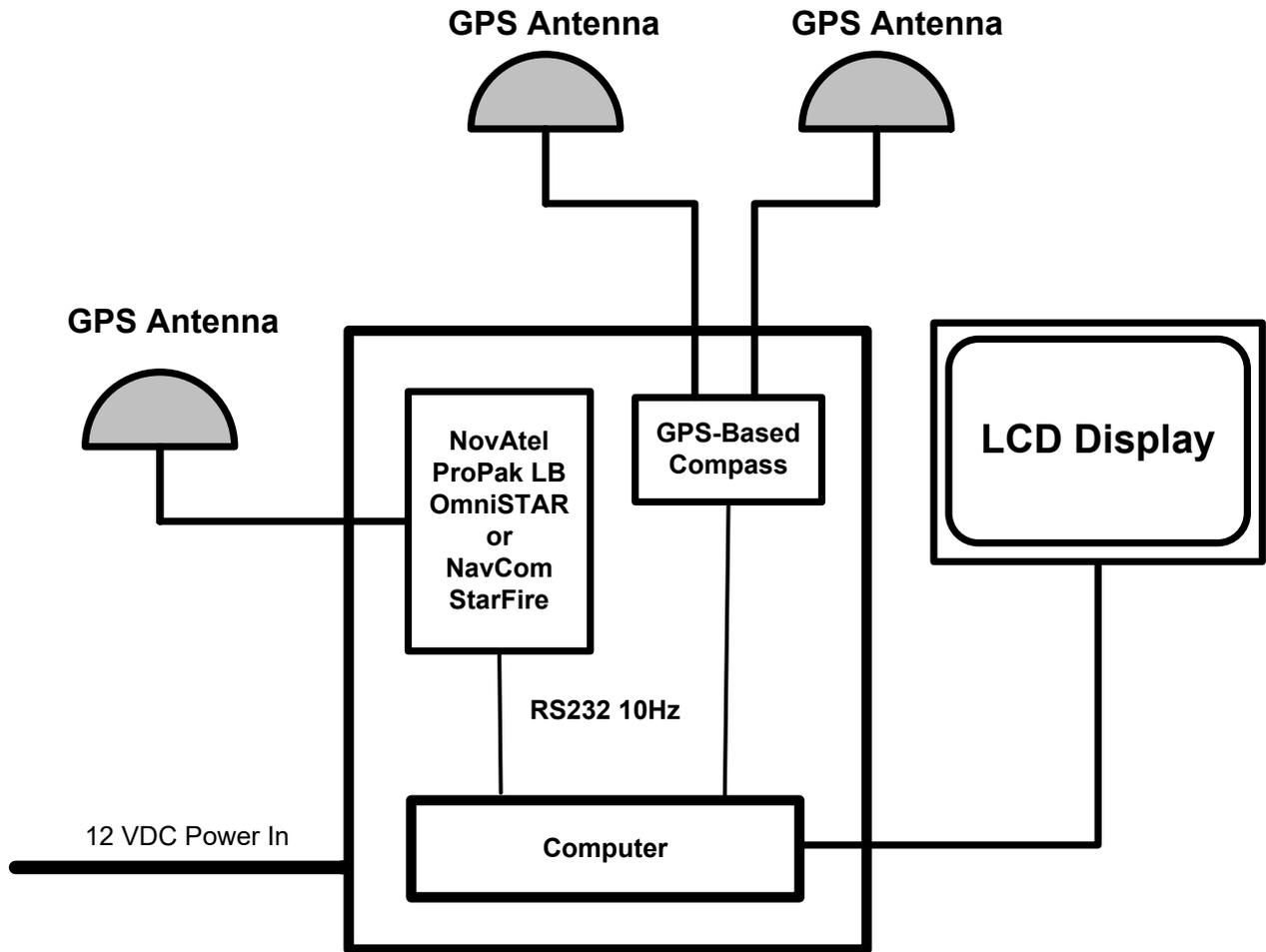
**Figure 3.1: MPRO system configuration**

## System Architecture and Hardware

This section provides an overview of the MPRO architecture and hardware. Software details were presented in the final report of related previous research [8].

The overall MPRO architecture is provided in Figure 3.1. An example screen shot of the MPRO DAS display is shown in Figure 3.2. The derivation of the information content from the sensing systems is discussed below.
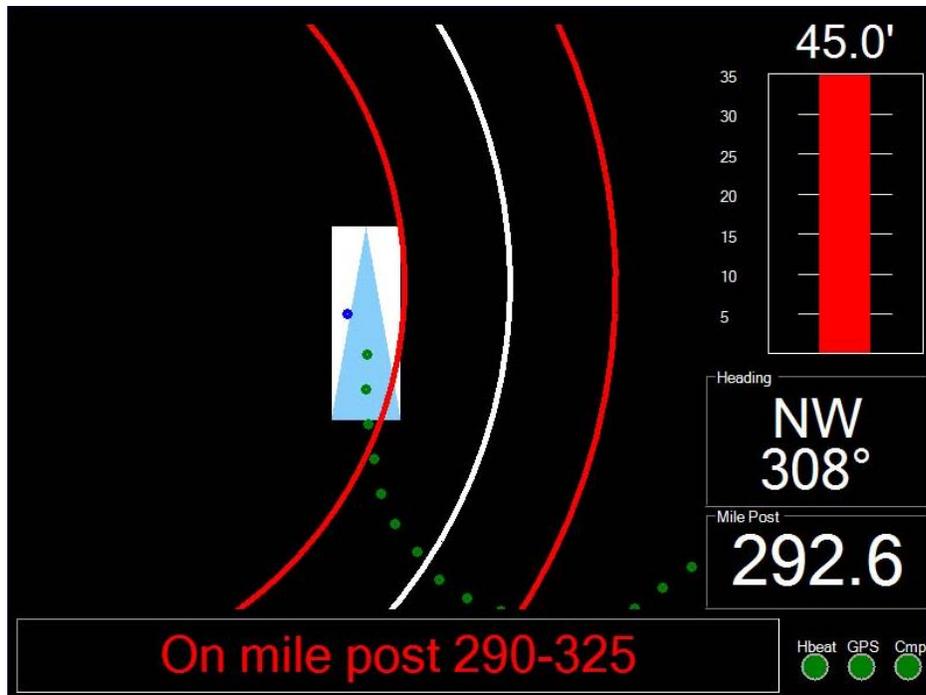
**Figure 3.2: The MPRO DAS display**

The system determines vehicle location using the Global Positioning System (GPS). Accuracy of uncorrected GPS is not sufficient for this application. To safely find the road center and keep the vehicle over the road, sub-meter accuracy is crucial. However, many locations do not have the necessary differential base station to provide this level of accuracy. To achieve the accuracy desired while avoiding additional infrastructure, the current system uses a Satellite-Based Augmentation System (SBAS) to provide differential corrections, and achieves 4 inch (10 cm) accuracy. This is more than sufficient for the current task, and the SBAS signal is available continent-wide. Use of SBAS instead of a base station for differential corrections also makes the system more portable.

Vehicle heading vs. the road heading is also essential, so that the blower operator can continue moving along the road. A dual-antenna vector GPS-based compass provides the heading of the vehicle, which allows display of vehicle vs. road heading.

The system also provides height above the roadway, as well as text-based information indicating how far along the current pass opening has advanced, e.g. milepost readings. The GPS again provides this information. Underlying the GPS sensing, a key part of the system is the Geographic Information System (GIS) base map, which includes information on the roadway location (centerline, shoulders, lanes), as well as roadside features, including signs. From this GIS, the system can determine location along the road, and provide the operator with milepost numbers, as well as text messages for familiar local landmarks, upcoming intersections, and system status.

To assure safety, the system includes a watchdog feature, and status indicators for all sensing systems. The status indicators provide an immediate indication of the function of the system, e.g. whether the GPS receiver sees enough satellites, whether differential correction information is

17

available, etc. The watchdog subsystem monitors the overall code execution, and provides a pulsing heartbeat. In the rare circumstance of a system freeze, this heartbeat would also stop, and the operator could tell that the system was no longer reliable. In normal conditions, if the sensing degrades (e.g. due to loss of satellites) beyond an acceptable level, the operator is notified and the system will not provide faulty guidance information.

**Figure 3.3: Liquid Crystal Display (LCD) and system box containing computer and GPS receivers**

The MPRO hardware is responsible for providing sensor data to software applications, executing DAS software applications, and displaying driver assistance information for the operator. The MPRO hardware includes the system box and display installed inside the rotary plow cab (Figure 3.3), and the antenna bar (Figure 3.4 and Figure 3.5). The computer, power backup battery, power supplies, GPS receiver for position, and GPS receiver for heading were packaged together into a single system box. Inside the system box, the GPS receivers and computer are connected using Electronic Industries Alliance (EIA) standard (RS-232) serial communication, and the GPS protocol is the National Marine Electronics Association GPS

18

communications standard (NMEA-0183) with an 8-bit Cyclic Redundancy Check (CRC) to verify message integrity. The system box was mounted on a platform attached to a display boom arm (see Figure 3.3), and installed inside the rotary plow cab. NovAtel and Hemisphere GPS receivers were used, along with OmniSTAR XP SBAS service for decimeter-level corrections. The GPS antennas were mounted onto a single antenna bar (see Figure 3.4 and Figure 3.5) to be installed on the roof of the rotary plow cab as a single unit with the included magnetic mount. The antenna bar ensures that the spacing of the GPS antennas for heading determination is fixed on every installation. The only cabling connection between the vehicle and the DAS is for the 12-Volt Direct Current (DC) power supply. Hardware model numbers are shown in Table 3.1. The final system is usually installed in the field in a couple of hours. The only field software configuration is to input the vehicle dimensions and antenna location relative to the vehicle.



**Figure 3.4: GPS antenna bar with magnetic mount**



**Figure 3.5: Caltrans rotary snow blower with GPS antenna bar**

19

**Figure 3.6: System installation showing LCD screen location**

**Table 3.1: Implementation hardware details**

| Hardware | Model | Manufacturer |
|---|---|---|
| GPS receiver 1 (SBAS, position) | OEM-4 ProPack-LB-HP | NovAtel |
| GPS receiver 2 (heading) | Crescent Vector | Hemisphere GPS |
| Computer | MB890 | IBASE |
| LCD screen | Tflex-G212P | Argonaut |
| LCD arm | RAM- VB-122-SW1 | Ram Mount |
| GPS 1 antenna | GPS-600-LB | NovAtel |
| GPS 2 antenna | CDA-3RTK | Hemisphere GPS |
| GPS antenna bar | Custom | AHMCT |
| System box | Custom | AHMCT |

# CHAPTER 4:
# DEVELOPMENT OF THE GIS BASE MAP

## **Base Map Requirements**

The MPRO system requires a centimeter-level horizontal accuracy base map consisting of three different shapefiles in NAD83 UTM11N EPSG: 26911 (Universal Transverse Mercator coordinate system). One shapefile contains the roadway centerline and postmile information; the second shapefile encompasses the fog line positions; and the third shapefile includes the location data of edge of pavement and fixed infrastructure such as signs, guard rails, and rest stop facilities.

## **Creating the Base Map**

A new map had to be created for Tioga Pass (SR 120 east of the Yosemite National Park gate). The map creation method is different from the previous method used at Sonora Pass (SR 108). In the past, GPS data was logged when a vehicle equipped with GPS was driven at the centerline to collect the centerline positions. Known offsets are added to the fog line, as well as the centerline if the GPS was not driven directly above the centerline. A new method, Mobile Terrestrial Laser Scanning (MTLS) [7,11], was used to create the Tioga Pass map. The MTLS method is faster, less demanding on the vehicle operator, and provides high-resolution data to extract roadway features such as signs, guard rails, and rest area facilities.
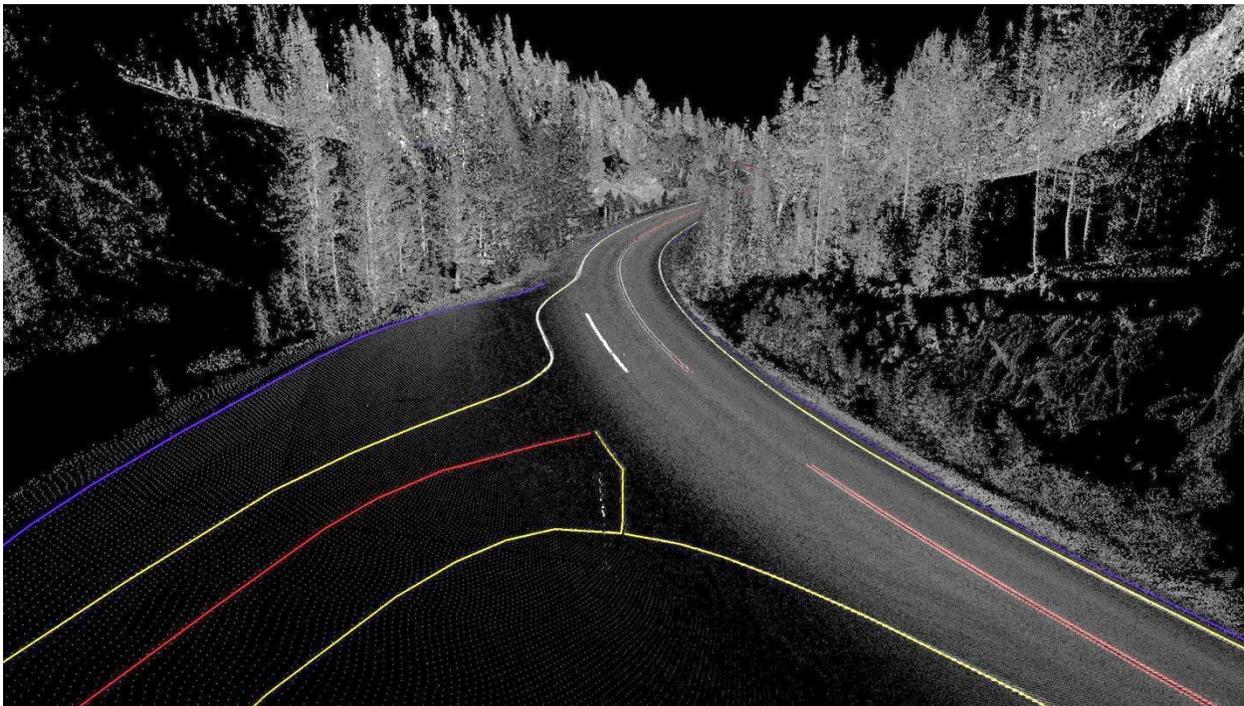


**Figure 4.1: Example 3D laser scan point cloud with extracted base map overlay**

The Caltrans MX8 Mobile Laser Scanner was used to scan the area on 10/17/2013. The data was collected at about 35 MPH with both laser scanners running at 100 Hz scan rate. Detailed

data collection procedures may be found in the final report of a previous research project [11]. With assistance from Caltrans staff and University NAVSTAR Consortium (UNAVCO) personnel, the Continuously Operating Reference Stations (CORS) base stations P636 and P628 logged GPS data at 1 Hz for 24 hours on the same day as the scan. The data was subsequently post-processed to generate the point cloud using CORS base station P636.

**Applanix POSPac Post-processing and results**

The Global Navigation Satellite System / Inertial Measurement Unit (GNSS/IMU) data was then post-processed twice with CORS station P628 or P636 GNSS base station data using the Single Base Station post-processing method to produce the best estimate vehicle trajectory solution. The results using each CORS base station were compared to each other. The vehicle trajectory solution using the P636 yielded better accuracy because it is closer to the initial vehicle starting point, where a 5-minute static session was preform at the intersection of SR 120 and US 395.



**Figure 4.2: CORS station P636 location on map (http://www.ngs.noaa.gov/CORS_Map/)**

22

**Figure 4.3: CORS station P636 setup (Image from http://www.ngs.noaa.gov/cgi-cors/corsage.prl?site=P636)**

The final vehicle trajectory is plotted in Figure 4.4. The starting point (intersection of SR 120 and US 395) is located on the far right of the light green curve. The end of the light green curve (left side of figure) represents the location of the Yosemite National Park gate. The estimated position errors (X, Y, and Z) vs. time of the vehicle trajectory determined from GNSS/IMU post-processing with CORS P636 base station data are shown in Figure 4.4. The estimated vertical error is less than 0.06 meters, and the estimated horizontal (X and Y) errors are less than 0.025 meters.
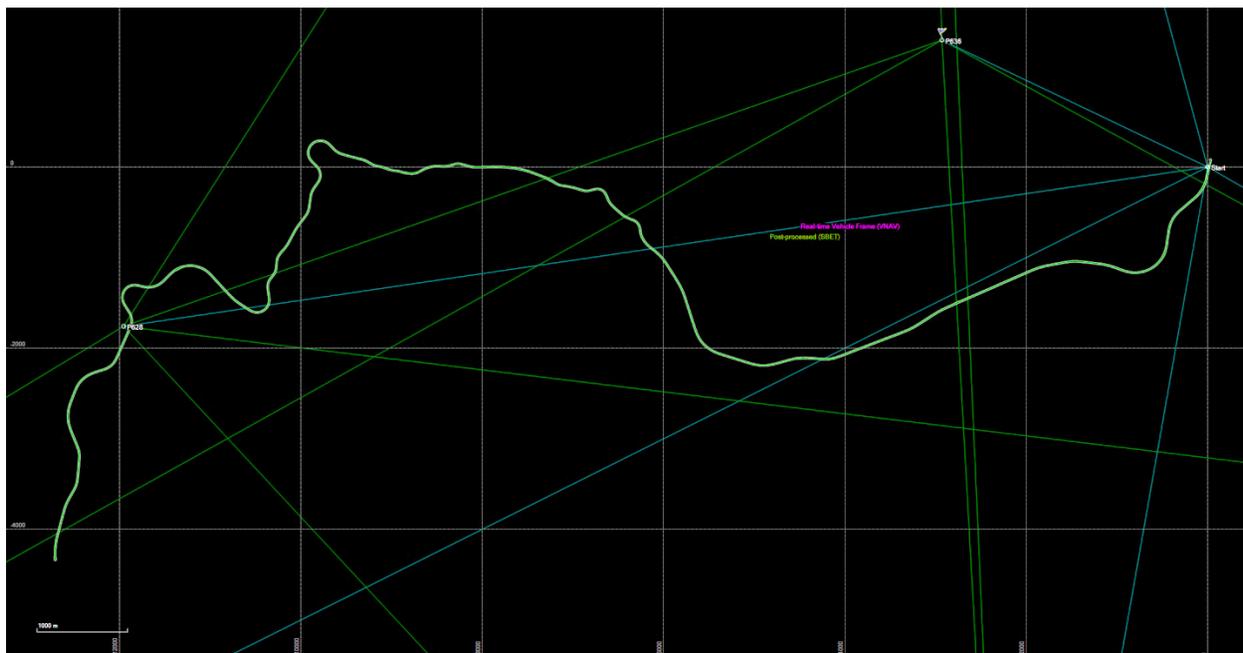


**Figure 4.4: Vehicle trajectory resulted from GNSS/IMU post-processing with CORS station P636 base station using POSPac software**

23
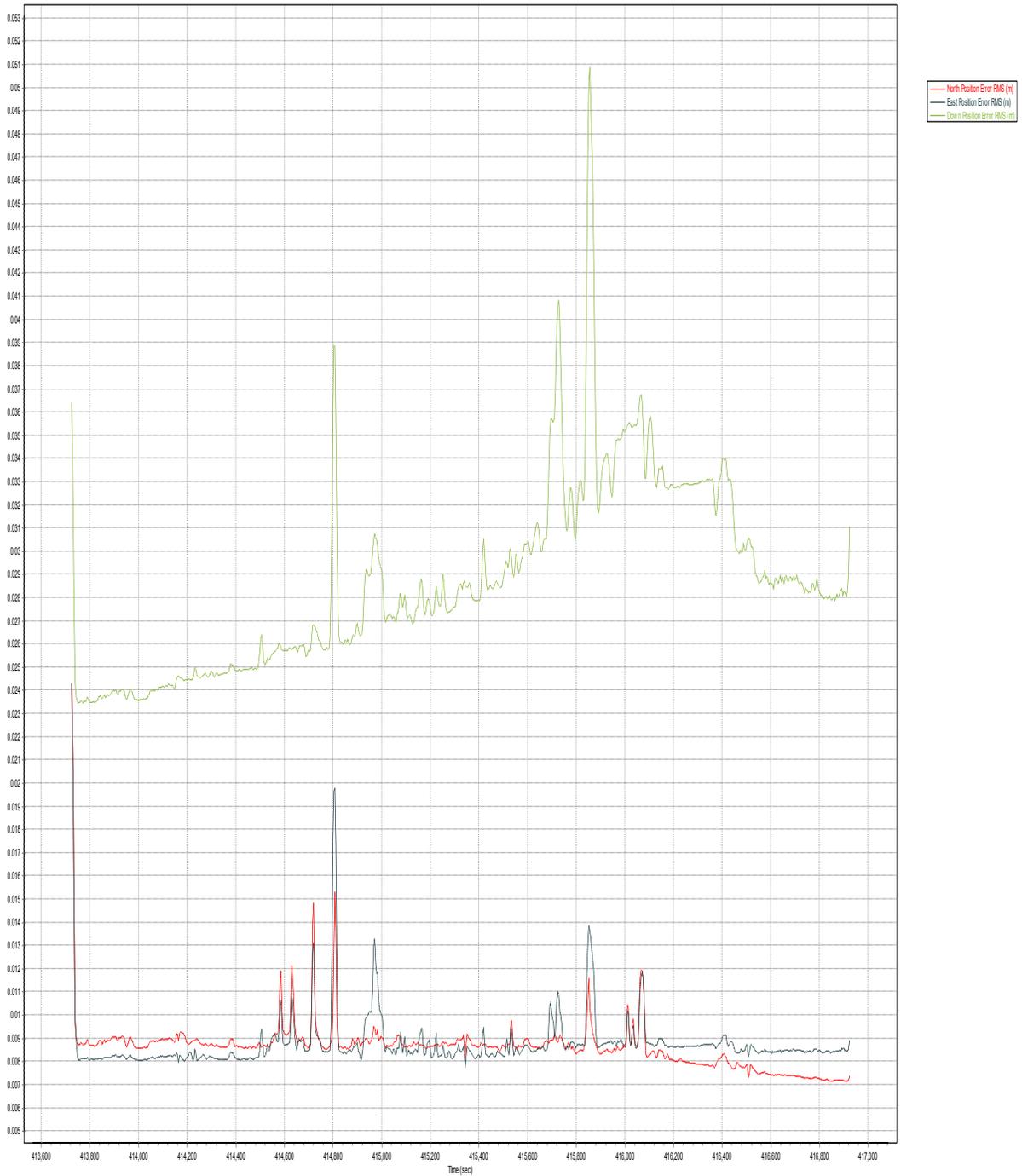
**Figure 4.5: Estimated position errors (X, Y, and Z) vs. time of the vehicle trajectory determined from GNSS/IMU post-processing with CORS P636 base station using POSPac software. The green line represents the estimated vertical error (< 0.06 meters). The red and black lines represent the estimated horizontal (X and Y) errors (< 0.025 meter).**

24

Figure 4.6 shows the number of GPS satellites available during the MTLS data collection. The data shows that the vehicle can receive signal from 5 or more GPS satellites for the majority of the SR 120 route. The plot also shows that there are area of mountainous GPS-challenged terrain where 4 or fewer GPS satellites were observed. This data demonstrates that the MPRO system should work well in over the large majority of the SR 120 route.
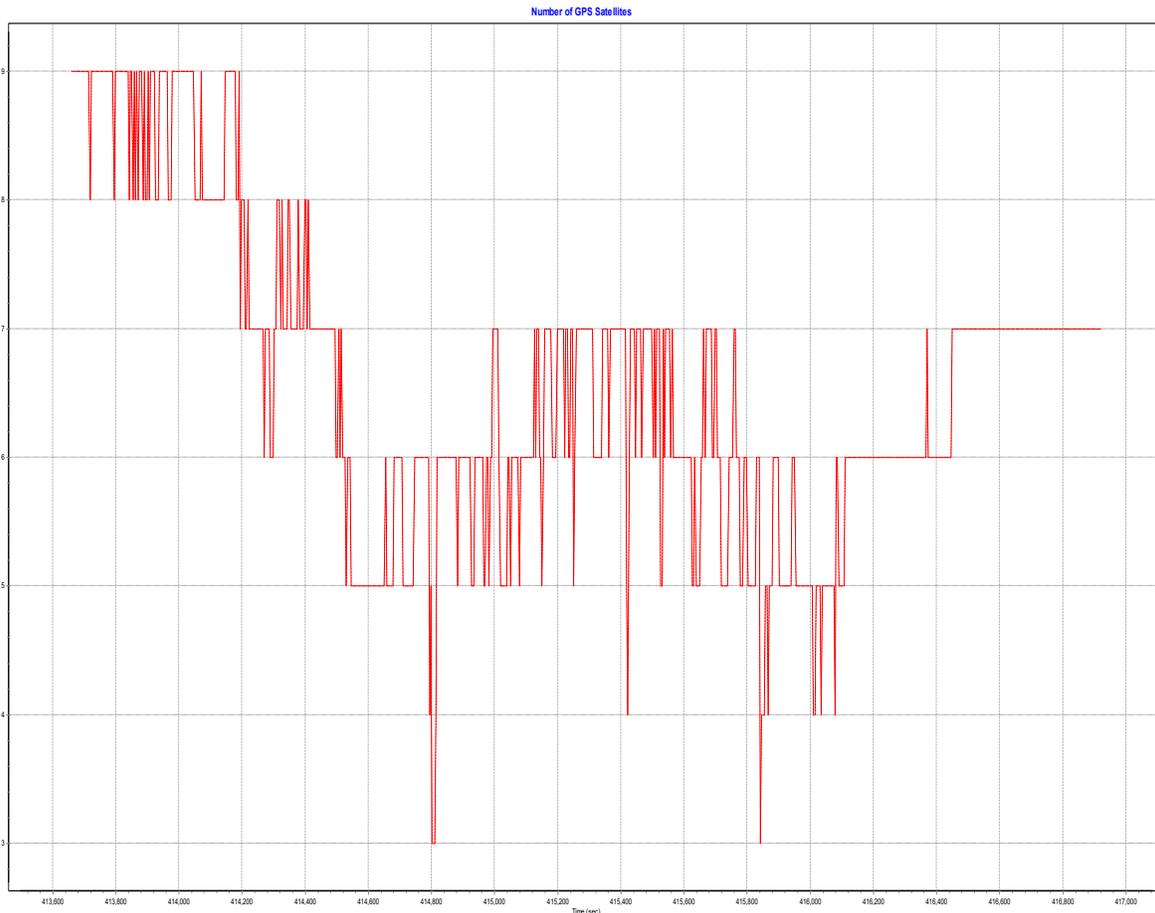


**Figure 4.6: Number of available GPS satellites (from 3 to 9) vs time.**

**Trimble Trident MTLS data post-processing**

Trimble Trident software was used to combine the best estimated vehicle trajectory solution from POSPac with the laser scanner and camera data to produce the colorized point cloud for feature extraction. The point cloud data were colorized and exported to WGS84 UTM11N with Continental US 99 Geoid LAS 1.2 files for subsequent feature extraction in Leica Cyclone and PolyWorks software. The intensity value was rescaled to facilitate semi-automated lane line extraction. This approach is very effective, and is recommended for future locations' map creation.

25

**Feature extraction using Leica Cyclone Software**

Manual extraction is faster with Cyclone; however, PolyWorks lane line and centerline auto-tracking extraction is faster. However, edge of pavement currently needs manual extraction. There may be an issue with the PolyWorks DXF export which resulted in a scaling error in the shapefile. This requires more investigation. Ultimately, the majority of the data were extracted using Leica Cyclone. Efficient shortcut key setup enabled us to extract all necessary features for 12 miles of point cloud data in one week.

Cyclone feature extraction steps:

1. Import LAS 1.2 files in Cyclone.
2. Set up layers for centerline, fog line, and edge of pavement (EOP).
3. Draw polyline for given feature using multi-point selection.
   a. Click on the "multi-point selection" tool.
   b. Click on the points in the middle of the center line, fog lane line, or edge of pavement.
   c. Click on "Create Object" -> "From Pick Points" -> "Polyline" to activate polyline construction tool (see Figure 4.7). A short cut key was created to speed up this procedure.
   d. Assign the polyline to the appropriate layer.
   e. De-select the polyline and points using "De-select all".
   f. Repeat for other lines.
4. Export all three line layers to three individual DXF files.
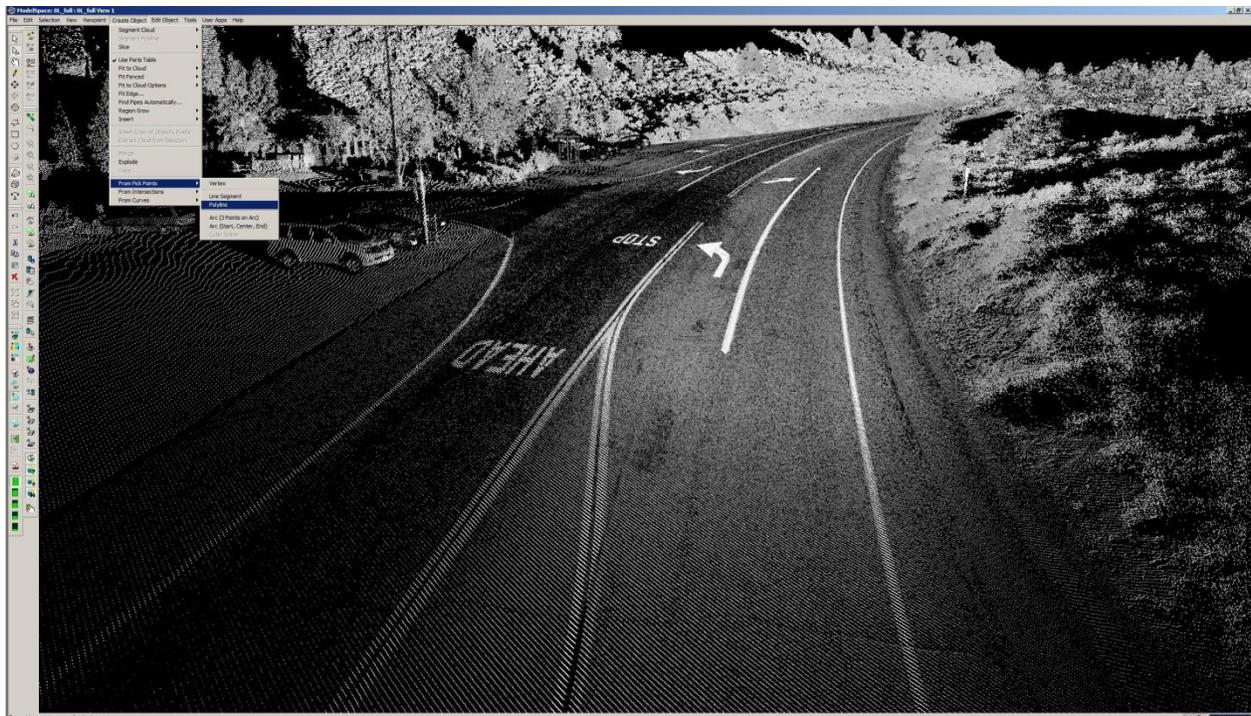


**Figure 4.7: Cyclone feature extraction user interface**

**Figure 4.8: Point cloud with extracted feature lines overlaid in Cyclone. The red, blue, and yellow lines denote the edge of pavement, fog line, and centerline, respectively.**

## Shapefile merging and editing using QGIS

QGIS, open source free software for GIS application available at http://www.qgis.org/, was used to merge and edit the exported DXF files. ESRI ArcGIS could also be used instead of QGIS. QGIS was also used to transform the shapefiles from WGS84 UTM 11N to NAD83 UTM11N EPSG: 26911 datum.

1. Import DXF into QGIS using "add layer" and select WGS84 UTM 11 for datum.
2. Using the "layer save as" function in QGIS to export DXF data to SHP files.
3. Edit polylines as needed, such as deleting extra nodes or joining lines.
4. Merge all appropriate SHP files into three different SHP files (Centerline, Lane line, and EOP).
5. Use the QGIS "Save as" function to export the SHP files to a new datum NAD83 UTM11N EPSG: 26911. The final output SHP files must be NAD83 UTM10N for Davis testing, or NAD83 UTM11N EPSG: 26911 for SR 108 Sonora Pass and SR 120 Tioga Pass.

27
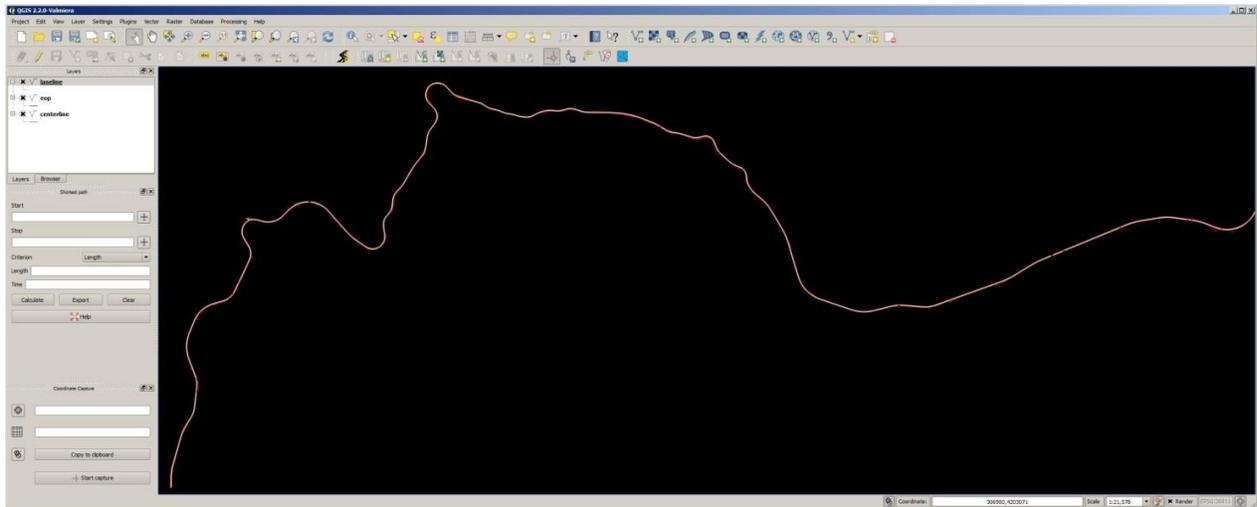
**Figure 4.9: Entire SR 120 Tioga Map displayed in QGIS**
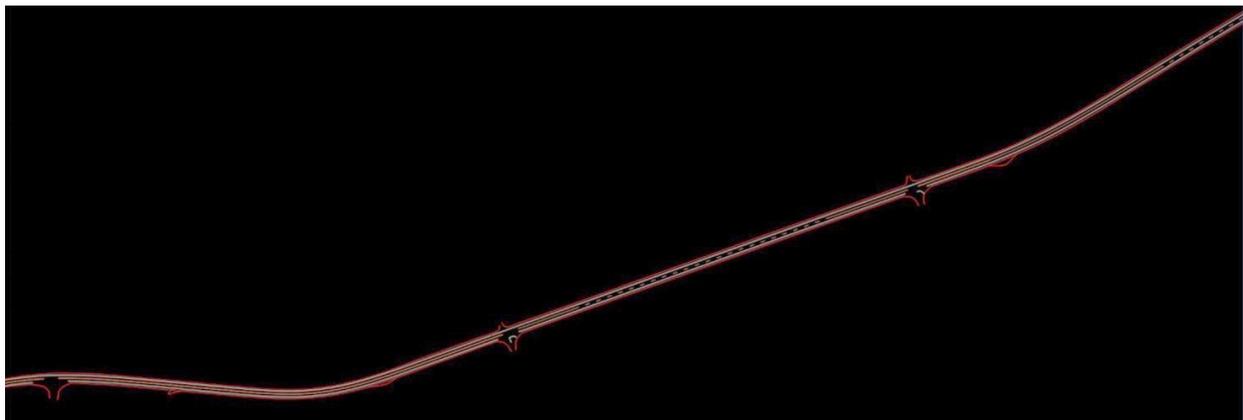


**Figure 4.10: Zoom-in view of SR120 Tioga Map in QGIS**

## Adding postmile (PM) information

The MPROConfigure program was used to convert the developed SHP files into the eXtensible Markup Language (XML) files required by the MPRO software for fast and efficient display of data. The postmile information was added to the centerline XML file (search layer and layer #1 in MPRO software) using the latitude and longitude data.

**Table 4.1 SR 120 landmarks and points of interest**

| Postmile | Land Mark Name |
|----------|----------------|
| 12.0 | North Junction US 395 & SR 120 West |
| 10.8 | Lee Vining Ranger Station |
| 8.6 | Bottom Gate |
| 3.1 | Ellery Lake Dam |
| 2.1 | Saddle Bag Road |
| 2.0 | Tioga Lodge |
| 0.0 | Yosemite Gate |

## Postmile generation process

The GIS route data collected by the MTLS scan after post-processing includes two sets of location coordinates for every point: WGS-84 latitude / longitude, and UTM coordinates in East (X) and North (Y) values, along with elevation (Z). The specific UTM coordinate system is also indicated in the input data. These coordinates are necessary for the GPS-based driver assistance. However, they are meaningless to the operator.

To provide the operator with a sense of absolute position along the roadway, the system needs postmile information for each point in the base map. This section details the approach used to generate and store postmile information from the input latitude/longitude for use in the MPRO system.

First, an input CSV file with no heading row is created, with each line in the form:

*coordSys, lineID, numPoints, EX, NY,Z, M, Lat, Long*

where *coordSys* is the UTM coordinate system, *lineID* is the current line's identification number, *numPoints* is the number of points in the current line, *EX* is the East (X) location, *NY* is the North (Y) location, *Z* is the elevation, *M* is the milepost, *Lat* is the latitude, and *Long* is the longitude. For the input file, *M* is not set, and can be any value. This input file is typically generated using Excel, but could be created by any program capable of generating CSV output.

This input file, e.g. named *tioga_centerline.in.csv*, is then processed using Perl script, to generate an output file, e.g. named *tioga_centerline.out.csv*, using the command

*perl postmile.pl tioga_centerline.in.csv  tioga_centerline.out.csv*

The Perl script is quite simple. It reads each line of the input file, makes a call to the Caltrans postmile web service (discussed in Chapter 6 of [11]), which returns a data structure containing the corresponding county, route, and postmile for the input latitude/longitude. The script outputs to the  *tioga_centerline.out.csv* output file, one line at a time, in the form of

*county, route, postmile*

The next step is somewhat manual. It could easily be automated, but since the base map generation was a one-time process in this research project, a manual approach here was sufficient. The output CSV file is opened in Excel, along with the original input CSV file. The user then selects the milepost column from the output CSV file, copies it, and pastes it into the milepost column of the input file. The user then saves this as a final CSV file, e.g. named *tioga_centerline.final*. This final CSV file now has all the information that is needed for the MPRO system GIS base map. However, it must be converted into the appropriate XML format before it can be imported into the MPRO system.

This CSV file is converted into XML using a simple Python script, yielding XML data of the form:

```
\Uffffffff<?xml version="1.0" encoding="utf-16"?>
<LayerArray CoordSys="11">
 <Line ID="200392" NumPoints="10">
  <Point X="314332.9585" Y="4202390.167" Z="2084.284919" M="12.04" />
  <Point X="314332.3585" Y="4202387.791" Z="2084.363621" M="12.04" />
  <Point X="314331.7514" Y="4202385.417" Z="2084.440526" M="12.03" />
  <Point X="314331.1401" Y="4202383.044" Z="2084.532387" M="12.03" />
  <Point X="314330.5125" Y="4202380.676" Z="2084.627253" M="12.03" />
  <Point X="314329.8859" Y="4202378.307" Z="2084.721651" M="12.03" />
  <Point X="314329.2831" Y="4202375.932" Z="2084.818265" M="12.03" />
  <Point X="314328.6967" Y="4202373.553" Z="2084.912957" M="12.03" />
  <Point X="314328.1025" Y="4202371.176" Z="2085.006512" M="12.03" />
  <Point X="314327.5103" Y="4202368.799" Z="2085.106597" M="12.02" />
 </Line>
 <Line ID="200439" NumPoints="10">
  <Point X="314333.1316" Y="4202389.968" Z="2084.291803" M="12.04" />
  <Point X="314332.7586" Y="4202388.518" Z="2084.343803" M="12.04" />
  <Point X="314332.3885" Y="4202387.083" Z="2084.387996" M="12.04" />
...
 </Line>
...
</LayerArray>
```

The conversion and the corresponding code is very simple. The one issue that requires some care is ensuring that the file's Byte Order Mark (BOM) is correctly set. Here, the *\Uffffffff* is the BOM. If this is not properly set, the MPRO XML file load will fail, as noted in Chapter 5.

## Map update based on user feedback

Based on the Lee Vining maintenance yard supervisor's feedback on the importance of mapping buildings (rest stop bathrooms), guardrails, and signs at visitor points, the map was updated in 2015. More details are provided in Chapter 5. The SR 120 base map was updated to include signs, guardrails, and buildings. Since the area was mobile scanned using the MTLS system, the resulting point cloud allows us to perform survey on demand without returning to the SR 120 site. The additional features (buildings, guardrails, and signs at visitor points) were

30

located and extracted from the original point cloud following the same steps listed above. After that, these additional map features were merged into the edge of pavement shapefile layer. The new edge of pavement shapefile was then converted to the XML file format using the MPROconfigure tool developed by AHMCT. The augmented base map, including these new features, was successfully demonstrated to Lee Vining Maintenance personnel, as discussed in Chapter 5.

# CHAPTER 5:
# SYSTEM TESTING AT TIOGA PASS

AHMCT researchers tested the MPRO prototype during the Spring 2005 and 2006 openings (under a prior contract) of Sonora Pass on State Route 108, north of Yosemite, CA [8]. Additional field testing by Caltrans Maintenance personnel occurred in the spring of 2007, 2008, and 2009 with support of AHMCT [9]. Based on results and operator feedback, providing GPS-based driver assistance for mountain pass opening is feasible and effective, and holds great promise for enhancing the safety and efficiency of this operation. The MPRO system was installed on a research vehicle and driven on both the eastbound and westbound lanes of SR 120 route in April 2014 to collect data and test the system. OmniSTAR XP service was activated for one year for the NovAtel GPS receiver. OmniSTAR was acquired by Trimble. Both of their XP or HP services are available only in a full-year subscription. The test objectives are:

1. **Verify map accuracy and functionality.** After loading the new SR 120 base map onto the MPRO system, the map accuracy was checked visually as the vehicle was driven on SR 120. The maps (X, Y and elevation) matched well with the real-time GPS location data throughout the Tioga pass from PM 1.0 (Yosemite Gate) to PM 12 (SR 120 and US 395 junction). The system performed well as expected without any anomaly. Initially, there was a problem loading the XML file with postmile. There is a Unicode Byte Order Mark (BOM) in the beginning of the XML file that was not preserved when the postmile information was added. This error was corrected after the on-site testing. Microsoft Internet Explorer can be used to test the file format compliance.

2. **Create sensor (GPS receivers) log files for system performance evaluation, simulation, and demonstration.** The GPS receivers' output data were logged when the vehicle was traveling on SR 120. The log files were used to determine GPS availability as well as to run the system in simulation mode where the log data are played back to demonstrate the system's functionality without being on Tioga Pass. This mode can also be used to examine and modify the system performance in the office repeatedly.

3. **Determine GPS and SBAS availability on SR 120 Tioga Pass and locations where GPS availability is limited.**

### GPS and SBAS availability analysis and result

The GPS location log was used to plot the vehicle path with valid GPS position solution. The areas without valid GPS position solutions are areas with limited GPS availability due to the mountainous terrain. The GPS positions log file is in XML format. The XML file was first imported in Microsoft Excel, and the 10 Hz positional data was then decimated to produce 1 Hz positional data for ease of data handling by QGIS and Google Earth in the subsequent phase of data analysis. The decimated data was exported in Comma-Separated Value (CSV) format for QGIS to import for visualization and comparison with the SR 120 road centerline map created in the Chapter 4 map making process. When the GPS signal is limited, the GPS receiver may provide positional solution with large error. By overlaying the vehicle position with the SR 120 road centerline map, these erroneous position solutions may be identified and deleted from the

CSV file. After that, the data was exported in Keyhole Markup Language (KML) format for visualization in Google Earth. The PM locations were determined manually using Caltrans Earth.



**Figure 5.1: Mountainous terrain of SR 120 Tioga Pass. The majority of the roadway has the northern sky view blocked by the mountain.**

Figure 5.2 is a Google Earth screen capture with the vehicle path (in red) overlaid on SR 120. The end of the red trail located on the right is the intersection of SR 120 and US 395, and the end of the red trail located on the left is the Yosemite National Park entrance gate. Figure 5.2 shows two large positional data gaps, highlighted with a yellow and blue circle, along the SR 120 route. In these two locations, the GPS signal was blocked by the mountain, such that no positional data were available from the GPS receiver.

33

**Figure 5.2: Google Earth screen capture with the vehicle path (in red) overlaid on SR 120. The yellow and blue circled areas are locations with very limited GPS availability.**

Figure 5.3 is a close-up view Google Earth screen capture of the yellow circled area in Figure 5.2. The red dots represent the available GPS position solution of the vehicle travel path from both westbound and eastbound travel on SR 120. The absence of red dots indicates that a GPS solution is not available. The bird's-eye view of the yellow circled area is shown in Figure 5.4, which provides the general terrain in the area.



**Figure 5.3: Google Earth screen capture of the yellow circled area where GPS availability is very limited (aerial view), from PM R5.46 to R5.24 (~ 0.3 miles long)**

34

**Figure 5.4: Close-up Google Earth screen capture of yellow circled area (bird's-eye view)**

Figure 5.5 is close-up view Google Earth screen capture of the blue circled area in Figure 5.2. The bird's-eye view of the blue circled area is shown in Figure 5.6, which provides general terrain in the area. The mountainous terrain blocks the majority of the northeastern sky view.

**Figure 5.5: Google Earth screen capture of the blue circled area where GPS availability is very limited (aerial view), from postmile R3.63 to R3.36 (~0.3 miles long)**



**Figure 5.6: Google Earth screen capture (bird's-eye view) of the blue circled area**

36

**Figure 5.7: Ground view of the blue circled area**



**Figure 5.8: Google Earth screen capture of another GPS-challenged area
from PM 0.68 to 0.47**

Figure 5.8 shows another GPS-challenged area from PM 0.68 to 0.47. The GPS receiver failed to provide valid solution when the vehicle was traveling eastbound, where it is closer to the mountain north of the roadway. AHMCT experimentally verified satellite signal availability on SR 120 at Tioga Pass in 2014, as well as availability of the essential SBAS differential correction service. There are two areas that the GPS may not provide valid positional solution

37

due to limited sky view for GPS signal. However, the GPS and SBAS work well for the large majority of the SR 120 Tioga Pass area.

## System Evaluation on SR 120, Tioga Pass

Due to the recent drought in California, there was very little snow on the SR 120 Tioga Pass in 2014 and 2015. The Caltrans crew was able to clear snow on the SR 120 roadway relatively quickly, without getting on top of snow and using a blower. Figures 5.9 and 5.10 show area photographs taken in 2014 and 2015 where the snow accumulations were highest on the roadway. The accumulations were less than 4 feet. The snow accumulation was very small in 2015. There was no snow until near the Yosemite park gate. Due to the lack of snow, the equipment was not installed in any of the Caltrans road opening snow removal equipment for user evaluation in 2014 and 2015.



**Figure 5.9: Pictures taken on 4/21/2014 after road opening completion near the Yosemite Nation Park gate (near highest elevation point of the Tioga Pass). The snow accumulation is less than 4 ft.**

38

**Figure 5.10: Picture taken 4/21/2015, showing that the highest snow accumulation on the roadway is less than 4 ft. The AHMCT research vehicle in view provided scale.**

In 2014, we interviewed Thomas Clark, the Lee Vining maintenance yard supervisor, who is responsible for SR 120 springtime road opening, for his input and feedback. According to Mr. Clark:

- Typically, there could be up to 10 ft to 12 ft of snow accumulation. However, there are sections that are a couple of hundred feet long that can have snow drift accumulation up to 80 ft, but the specific coordinates of these drift locations were not recorded.

- For SR 120, their blowers stay on the pavement. They use a loader to get up on the snow to push snow down to the blower. The loader clears a wide path (wider than the road) so that snow will not cave in to the road. This operation differs from that on SR 108, where the blower is used on top of the snow.

- He would like to map buildings (rest stop bathrooms), guardrails, and signs at visitor points. Snow could completely cover them. The loader can damage them when clearing snow from above. Figures 5.11 and 5.12 shows example signs and buildings near the roadway that would be covered by high snow. Subsequently, the SR 120 base map was updated to include signs, guardrails, and buildings. The ability to modify the base map from the scanned point cloud without returning to the field for additional surveys is an important feature of the methodology used in this research.

- Road opening usually starts on the 1st of April.

- Road opening starts at the lower gate at PM 8.6.

- In the past, they have used handheld GPS to mark the location of the road.

39

**Figure 5.11: Sign and building locations need to be mapped to reduce accidental damage during snow clearing (picture taken 4/21/2014)**



**Figure 5.12: Building locations need to be mapped to reduce accidental damage during snow clearing (picture taken 4/21/2014)**
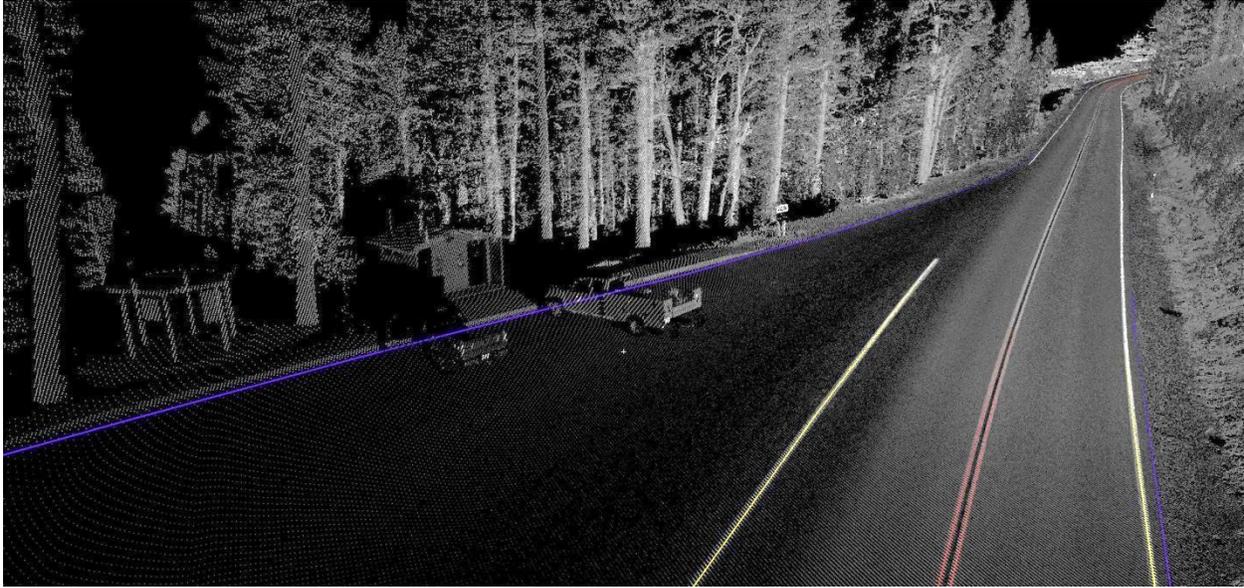
**Figure 5.13: Building locations need to be mapped. Coordinates can be determined from the point cloud.**

In April 2015, the MPRO system was demonstrated to the new Lee Vining yard supervisor, Randy Walker, for his input and feedback. Using the SR 120 data log file, we simulated system driving on SR 120 and show the system features and its usage. He echoed his predecessor's feedback, and is hopeful that there will be enough snow next year to test the system.

# CHAPTER 6:
# CONCLUSIONS AND FUTURE RESEARCH

Key contributions of this research project included:

- Demonstration of the portability of the MPRO system across vehicles and sites.

- Development of a novel method for GIS base map development.

- Generation of the GIS base map for Tioga Pass (SR 120).

The safety improvement of the MPRO system can be significant. Operator feedback from the MPRO field testing has been quite positive. Over the previous several years' testing, the system was easily integrated into a variety of snow-blower cabs without interference with the equipment operation or the operator's visibility. Thus the system meets the "do no harm" criteria. The white snow and sunlight created a bright background that can produce significant glare on the LCD. The current high-brightness LCD model can be easily viewed under such challenging conditions. It is fairly compact, so it does not obstruct the operator's field of view. Users found the information on the vehicle position and heading relative to the road and absolute position along the road (postmile location) useful. They found the vehicle height above the road / elevation information and system health indicators to be interesting but not critical. From a safety perspective for regular use, the researchers still recommend inclusion of the system health indicators.

User expectations were formed, in part, by the recent availability of consumer hand-held navigation devices. These devices, tailored for the mass consumer market, are inexpensive, very small and robust, and provide sufficient accuracy for effective consumer navigation. The MPRO system should integrate these recent advances in packaging and processing power to meet these user expectations, in addition to providing existing MPRO GPS precision. User expectation can also be managed through better user training, to a certain extent. The system size and power could be reduced using the latest generation of CPU and smaller form-factor computer boards. Size reduction also requires enhanced integration with the Original Equipment Manufacturer (OEM) GPS board to reduce wasted space.

The remaining area of improvement is the GPS positional accuracy and robustness—this presents a significant challenge due to signal blockage by tall trees and terrain. Due to the mountainous terrain, GPS systems typically can only receive signal from 4 to 6 GPS satellites, compared to 7 to 9 satellites in areas with open sky. The reduced number of satellite signals degrades positional accuracy and availability. As a result, the user can occasionally observe a discrepancy between the vehicle position relative to the road as shown by the system vs. what they can detect with their own eyes. The positional solution availability will improve as overall GNSS systems are modernized and/or deployed, and as more satellites and signal frequencies are added. However, this modernization process will take about a decade to complete.

## **Future work**

There are technological advances commercially available since the last MPRO system hardware design.

- The new generation of computers and/or tablets could be used to reduce power consumption and size of the hardware resulting increased ease of installation and portability. An Android app may easier to use.

- Google Glass or similar user interface devices may be used instead of the bulky sunlight-readable LCD display.

- There have also been new advances in subscription SBAS services. OmniSTAR has introduced its OmniSTAR G2 Service. OmniSTAR G2 is a L1/L2 dual-frequency solution, offering 5-10 cm (2-4 in) repeatable horizontal accuracy (see http://www.omnistar.com/SubscriptionServices/OmniSTARG2.aspx). It includes GLONASS satellites and GLONASS correction data in the solution, which significantly increases the number of satellites available. Short-term accuracy can be 1-2 inches, and long-term repeatability is better than 10 centimeters, 95% CEP. The subscription cost is $1,500 (as of 2015), which is the same as the current OmniSTAR XP subscription used by the MPRO system. To take advantage of the G2 service, a new GNSS receiver is required. Trimble also provides a Trimble CenterPoint RTX SBAS that may be suitable for MPRO applications.

43

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# APPENDIX A:
# NGS P636 DATA SHEET

## **The NGS P636 Data Sheet**

```
PROGRAM = datasheet95, VERSION = 8.7
1      National Geodetic Survey,   Retrieval Date = APRIL 21, 2015
 DM7575 ************************************************************************
 DM7575  CORS       -  This is a GPS Continuously Operating Reference Station.
 DM7575  DESIGNATION -  LOGCABINRFCS2007 CORS ARP
 DM7575  CORS_ID    -  P636
 DM7575  PID        -  DM7575
 DM7575  STATE/COUNTY-  CA/MONO
 DM7575  COUNTRY    -  US
 DM7575  USGS QUAD  -  MOUNT DANA (1994)
 DM7575
 DM7575                        *CURRENT SURVEY CONTROL
 DM7575  _____
 DM7575* NAD 83(2011) POSITION- 37 57 45.96231(N) 119 08 48.09052(W)   ADJUSTED
 DM7575* NAD 83(2011) ELLIP HT-  2739.678 (meters)       (12/??/11)   ADJUSTED
 DM7575* NAD 83(2011) EPOCH   -  2010.00
 DM7575* NAVD 88 ORTHO HEIGHT -        **(meters)          **(feet)
 DM7575  _____
 DM7575  NAD 83(2011) X  - -2,453,321.719 (meters)                   COMP
 DM7575  NAD 83(2011) Y  - -4,399,308.726 (meters)                   COMP
 DM7575  NAD 83(2011) Z  -  3,903,871.853 (meters)                   COMP
 DM7575  GEOID HEIGHT    -       -24.08  (meters)               GEOID12B
 DM7575
 DM7575.Formal positional accuracy estimates are not available for this CORS
 DM7575.because its coordinates were determined in part using modeled
 DM7575.velocities. Approximate one-sigma accuracies for latitude, longitude,
 DM7575.and ellipsoid height can be obtained from the short-term time series.
 DM7575.Additional information regarding modeled velocities is available on
 DM7575.the CORS Coordinates and Multi-Year CORS Solution FAQ web pages.
 DM7575
 DM7575.The coordinates were established by GPS observations
 DM7575.and adjusted by the National Geodetic Survey in December 2011.
 DM7575
 DM7575.NAD 83(2011) refers to NAD 83 coordinates where the reference
 DM7575.frame has been affixed to the stable North American Tectonic Plate.
 DM7575
 DM7575.The coordinates are valid at the epoch date displayed above
 DM7575.which is a decimal equivalence of Year/Month/Day.
 DM7575
 DM7575.The PID for the CORS L1 Phase Center is DM7576.
 DM7575
 DM7575.The XYZ, and position/ellipsoidal ht. are equivalent.
 DM7575
 DM7575.The ellipsoidal height was determined by GPS observations
 DM7575.and is referenced to NAD 83.
 DM7575
 DM7575. The following values were computed from the NAD 83(2011) position.
 DM7575
 DM7575;                    North         East    Units Scale Factor Converg.
 DM7575;SPC CA 3    -   663,200.135 2,118,912.702   MT  0.99993598   +0 49 42.7
 DM7575;SPC CA 3    - 2,175,849.11  6,951,799.42   sFT  0.99993598   +0 49 42.7
 DM7575;UTM  11     - 4,203,857.730   311,420.108   MT  1.00003802   -1 19 15.3
 DM7575
 DM7575!          - Elev Factor  x  Scale Factor =   Combined Factor
 DM7575!SPC CA 3  -  0.99957029  x  0.99993598 =   0.99950630
 DM7575!UTM  11   -  0.99957029  x  1.00003802 =   0.99960829
 DM7575
 DM7575                        SUPERSEDED SURVEY CONTROL
 DM7575
 DM7575  NAD 83(CORS)- 37 57 45.95981(N)    119 08 48.08812(W) AD(2002.00) c
 DM7575  ELLIP H (05/??/11) 2739.644  (m)                       GP(2002.00) c c
 DM7575
 DM7575.Superseded values are not recommended for survey control.
```

```
DM7575
DM7575.NGS no longer adjusts projects to the NAD 27 or NGVD 29 datums.
DM7575.See file dsdata.txt to determine how the superseded data were derived.
DM7575
DM7575_U.S. NATIONAL GRID SPATIAL ADDRESS: 11SLC1142003857(NAD 83)
DM7575
DM7575_MARKER: STATION IS THE ANTENNA REFERENCE POINT OF THE GPS ANTENNA
DM7575
DM7575                          STATION DESCRIPTION
DM7575
DM7575'DESCRIBED BY NATIONAL GEODETIC SURVEY 2011
DM7575'STATION IS A GPS CORS. LATEST INFORMATION INCLUDING POSITIONS AND
DM7575'VELOCITIES ARE AVAILABLE IN THE COORDINATE AND LOG FILES ACCESSIBLE
DM7575'BY ANONYMOUS FTP OR THE WORLDWIDE WEB.
DM7575'   ftp://cors.ngs.noaa.gov/cors/README.txt
DM7575'   ftp://cors.ngs.noaa.gov/cors/coord/coord_08
DM7575'   ftp://cors.ngs.noaa.gov/cors/station_log
DM7575'   http://geodesy.noaa.gov/CORS

*** retrieval complete.
Elapsed Time = 00:00:02
```

46