Best Practices for Surveying and Mapping Roadways and Intersections for Connected Vehicle Applications

Task 2 Report: Mobile Mapping System Enhancements

Executive Summary: Connected vehicles require accurate and up-to-date maps both to allow coordination between vehicles and with the infrastructure. Such maps may also have utility for application aspects such as vehicle position estimation or control. As described in the Task 1 report (Mapping Methodology Assessment), there are several ways that maps can be acquired. But for purposes of connected vehicles, using a mobile terrestrial laser scanning (MTLS) method works best. Using this method, achieving accurate digital maps requires an elaborate field measurement process consisting of numerous integrated sensors performing three dimensional surveys of roadway infrastructure, attributes, and features. UC Riverside has previously participated in the development and operation of a Mobile Positioning and Mapping System (MPMS) deployed and tested at Turner Fairbanks Highway Research Center. This system met a number of key criteria including accuracy, robustness, efficiency, cost, safety, and usability.

The MPMS is part of a mobile test-bed platform which collects positioning and mapping data from a variety of sensors and combines them to provide accurate, available and continuous intelligence on the state of the MPMS moving vehicle and on the surrounding areas, yielding more accurate and precise location detail and associated feature maps. This is achieved through a combination of global positioning satellite (GPS) technology, feature-based aiding sensors (vision, RADAR, LIDAR) and high-rate kinematic sensors (INS, ENS) to capture and process multiple location and feature-based signals and to bridge data gaps whenever sensor reception is interrupted. The improvement to the MPMS hardware and software is the focus of Task 2 which will improve the systems functionality for subsequent tasks.

Table of Contents

I. Introduction

Detailed roadway feature maps will need to be developed, maintained, and communicated consistently to support Connected Vehicle (CV) applications. As a result, within the U.S. alone, hundreds of thousands of intersections and millions of miles of roadway will need to be surveyed, with application-relevant roadway features mapped to application-specific accuracies. The UC Riverside research team developed a Mobile Positioning and Mapping System (MPMS) platform that provides an accurate geometric representation of the roadway and relevant roadway features. The associated data processing interprets the relevant data and provides properties of the roadway and features in and digitally transmittable map message. Most mapping solutions relevant to the connected vehicle program involve the use of some combination of sensors and equipment, platforms, processes, and software.

The MMPS is a vehicle mounted technology involving the use of positioning and sensor Global Position System (GPS) technology, Inertial Measurement Units (IMU), Light Detection and Ranging (LIDAR), and video cameras mounted on vehicles to capture data required for characterizing roadway geometries as well as the features associated with each roadway. The map data integration involves the use of input sensor data from multiple sources and the subsequent manipulation, transformation, and integration of the data sources to create new map data that are more accurate, complete, detailed, and current than the individual data sources.

Although certain functions of connected vehicle applications may be performed without requiring the use of roadway maps, mapping provides some distinct advantages in that it can facilitate the improvement of positioning accuracy and provide details on roadway features. Connected vehicle applications use map data to establish vehicle location relative to a map, facilitate positional accuracy, and provide data on roadway features over a specified time frame with a level of reliability. The MPMS is part of a mobile test-bed platform which collects positioning and mapping data from a variety of sensors and combines them to provide accurate, available and continuous intelligence on the state of the MPMS moving vehicle and on the surrounding areas, yielding more accurate and precise location detail and associated feature maps. This current task addresses and details hardware, software, and configuration enhancements associated with the MMPS to achieve operational improvements for subsequent tasks.

II. Mobile Positioning and Mapping System

The University of California-Riverside's MPMS mobile test-bed platform collects positioning and mapping data from a variety of sensors and combines them to provide accurate, available and continuous intelligence on the state of the MPMS moving vehicle and on the surrounding areas, yielding more accurate and precise location detail and associated feature maps. This is achieved through a combination of GPS technology, feature-based aiding sensors (vision, RADAR, LiDAR) and high-rate kinematic sensors (INS, ENS) to capture and process multiple locations and feature-based signals and to bridge data gaps whenever sensor reception is interrupted. The MPMS is shown in Figure 1.

Data captured through the MPMS integrated vehicle telematics is utilized to create a coordinate-based map of features accurately surveyed down to the decimeter level, enabling feature-based sensors to be more effectively used as navigation aids. This mobile mapping can be performed at normal arterial roadway speeds, enabling much faster data collection than what would be possible with conventional surveying techniques. Integration of data from high-rate and aiding sensors increase the accuracy and reliability of sensor fusion algorithms to accommodate asynchronous and latent sensor measurements. This Task 2 description provides details on the hardware and software improvements implemented to benefit the subsequent tasks.

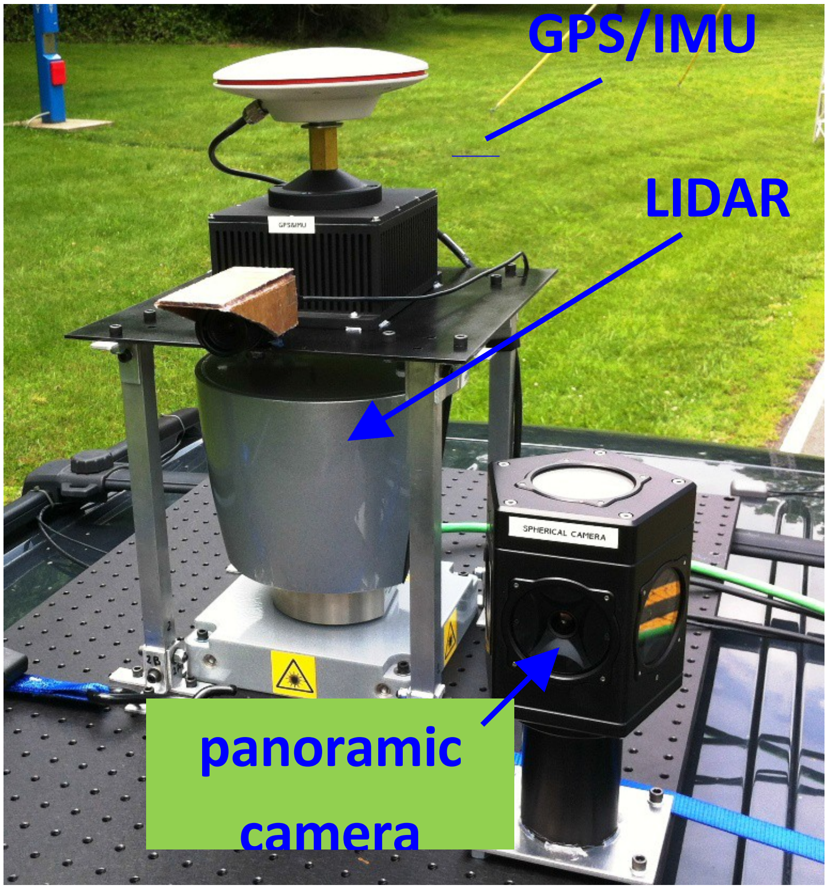

Figure 1: Mobile Positioning and Mapping System Platform

III. Data Collection Procedure Enhancement

The high-level steps sensor based mapping process is summarized in the Figure 2. The MPMS platform containing a suite of sensors is placed on the vehicle and moved through the environment for which a digital map is to be constructed. Sensor data are acquired and processed to produce a map of roadway features.

A variety of databases are involved in the above steps:

- The raw point cloud data set obtained from the LiDAR sensor is usually not distributed publicly prior to the georectification process, except by special request. Instead, it is maintained in a variety of formats within the databases of the entity that acquires the data. The database formats have been optimized to reduce size and improve handling in post-processing steps.
- The raw data from the LiDAR sensor goes through a calibration and georectification process which creates a point cloud containing all necessary information for map creation with high accuracy.

The accuracy of the final map representation is highly dependent on the accuracy of georectification process. Subsequent feature extraction techniques are improved as a result of enhanced calibration and georectification during the data collection and data processing steps.

- A georectified point cloud contains a large amount of redundant information which makes its use and maintenance difficult and costly. Hence, after manual or automated processing of the georectified point could data, specific roadway features are extracted along with their locations and metadata descriptors (these steps are further detailed in Task 5) which remove a large part of redundant information and makes the map representation manageable.

Additional details regarding data calibration and processing are provided below.

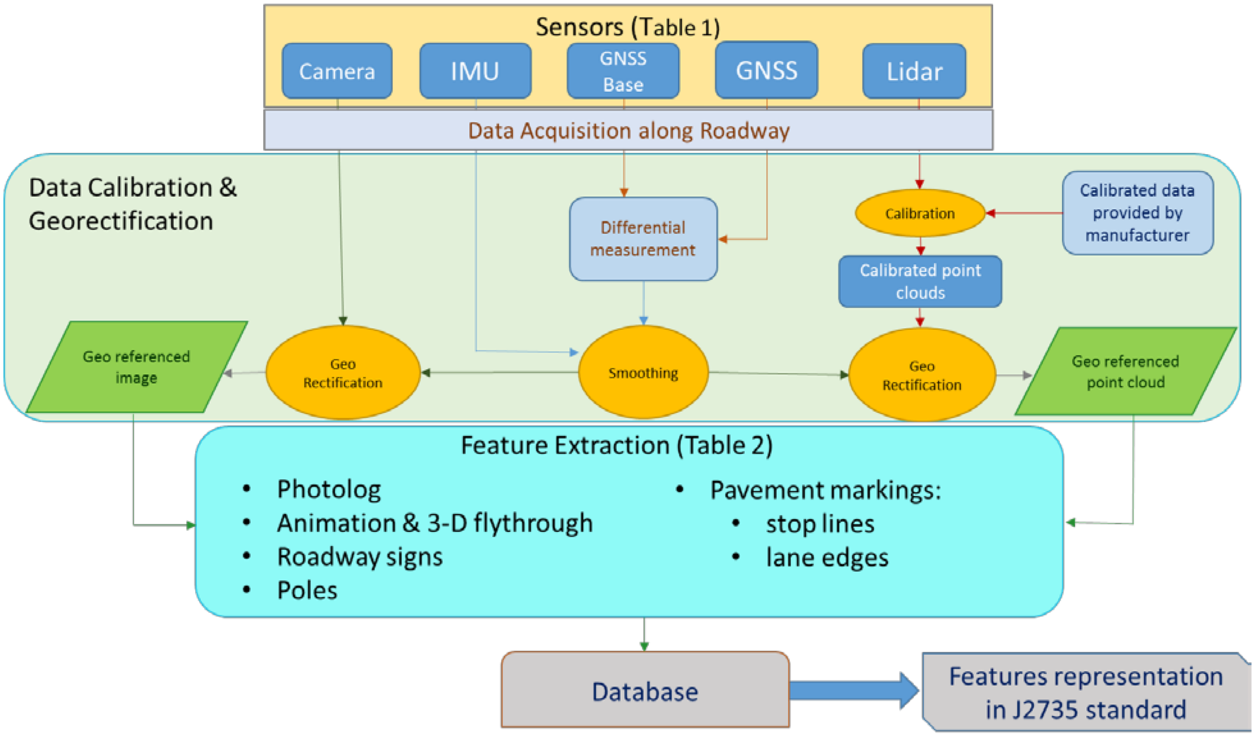

Figure 2: Data collection and processing flow chart Mobile Positioning Mapping System

IV. Calibration

Prior to the data collection in the field, the MPMS undergoes setup and calibration. The preparation involves two types of calibration, specifically intrinsic and extrinsic sensor parameter calibration. Intrinsic sensor parameter calibration involves calibrating the final output according to internal configuration of the sensor system. Extrinsic sensor calibration involves calibrating the final output based on the configuration of different sensors relative to each other on the same platform. To guarantee the accuracy of the final map attributes, the entire system calibration methodology has been refined, improving sensor alignment and providing measurement parameters established in a real-world setting.

The MPMS has been transported to a variety of test sites, mounted on a test vehicle, and recalibrated for procedural validation. Several data collections are then performed in a controlled environment with known objects to refine the calibration parameters. Following the improved calibration process, data are collected for comparison purposes. The vehicle with the system is then driven repeatedly over the test site at different times of the day, with varying levels of congestion. At the end of each data run, the raw data are examined to determine the data validity which guides the subsequent data collection process. Once enough data are gathered for a test site, the raw data collection is complete.

V. Data Handling

The logged raw data processing has been refined as shown by three major blocks in Figure 3. Raw GPS, IMU, LiDAR and/or camera measurements are input to the offline processing system. The data preparation block is the common step for all road feature extraction algorithms. In this block, the vehicle trajectory is estimated by smoothing the whole log of GPS and IMU measurements. Subsequently, the raw LiDAR data are calibrated with the factory parameters, filtered by distance, and then converted to global coordinate frame using the optimized vehicle trajectory and extrinsic parameters with respect to IMU, known as the georectification process. Finally, the time-series of LiDAR point clouds are stored into 151m by 151m blocks based on the North and East coordinates. The second block generates the bird's eye view intensity image of selected intersection regions and then enhances the intensity image using morphological operations. In the third block, image processing algorithms are utilized on the intensity image to extract the stop bars as straight lines and then find the ends of each stop bar.

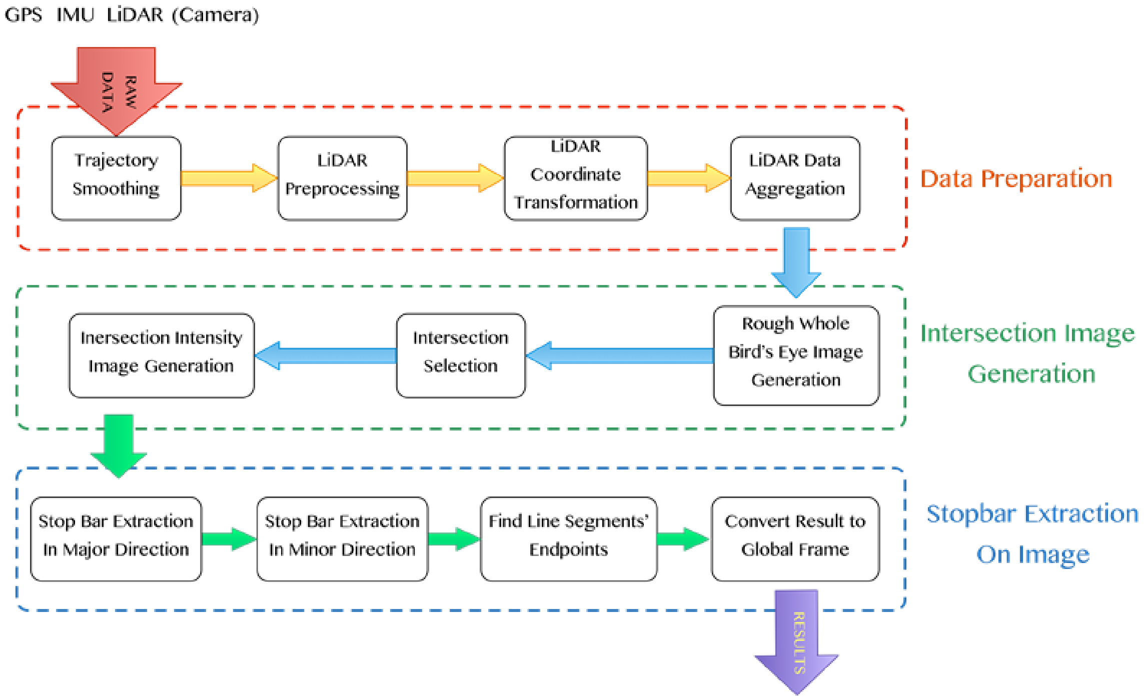

Figure 3: Data processing flow chart of our LiDAR based Mobile Mapping System

VI. Data Preparation

The first fundamental step for all mobile mapping systems is the acquisition of an accurate mobile platform trajectory. Most commercial systems rely on a real time positioning solution by integrating GPS with IMU or Dead Reckoning using EKF. Post processing kinematic solutions (PPK) of GPS and inertial data provides improved positional accuracy in the popular MMS systems. Additionally, commercial systems utilize expensive and advanced IMUs for most accurate positioning.

In the LiDAR preprocessing block of Figure 3, the raw LiDAR measurements are converted to 3D Cartesian coordinates with reference to the LiDAR frame using the calibration parameters and methods provided by the manufacturer. Before the transformation, a simple distance filter is applied to remove detections that are closer than 1m or farther than 75m from the LiDAR. The 3D coordinates are then passed into the next block to be transformed to global coordinate frames.

The LiDAR points in LiDAR coordinate frame are stored as a list with the time reference when the laser point detection took place. To convert the LiDAR measurement to global coordinate frame, we need to find the corresponding vehicle pose of the specific laser detection. The pose is obtained by interpolation of the two states in the smoothed trajectory whose times are closest to the given LiDAR time step. The extrinsic calibration parameters between LiDAR and body frame must be applied to every data point prior to subsequent processing steps. The preprocessed data of the entire run is around 4 gigabytes, which hardly fits the computer memory. It is partitioned to pieces of 40 megabytes which contains 1000 cycles. Each partition is converted to global frame separately, and then passed into the next block. The data storage methodology onboard has been improved to allow for extended data collection events. Figure 4 details data collected upon completion of improved calibration and data storage.

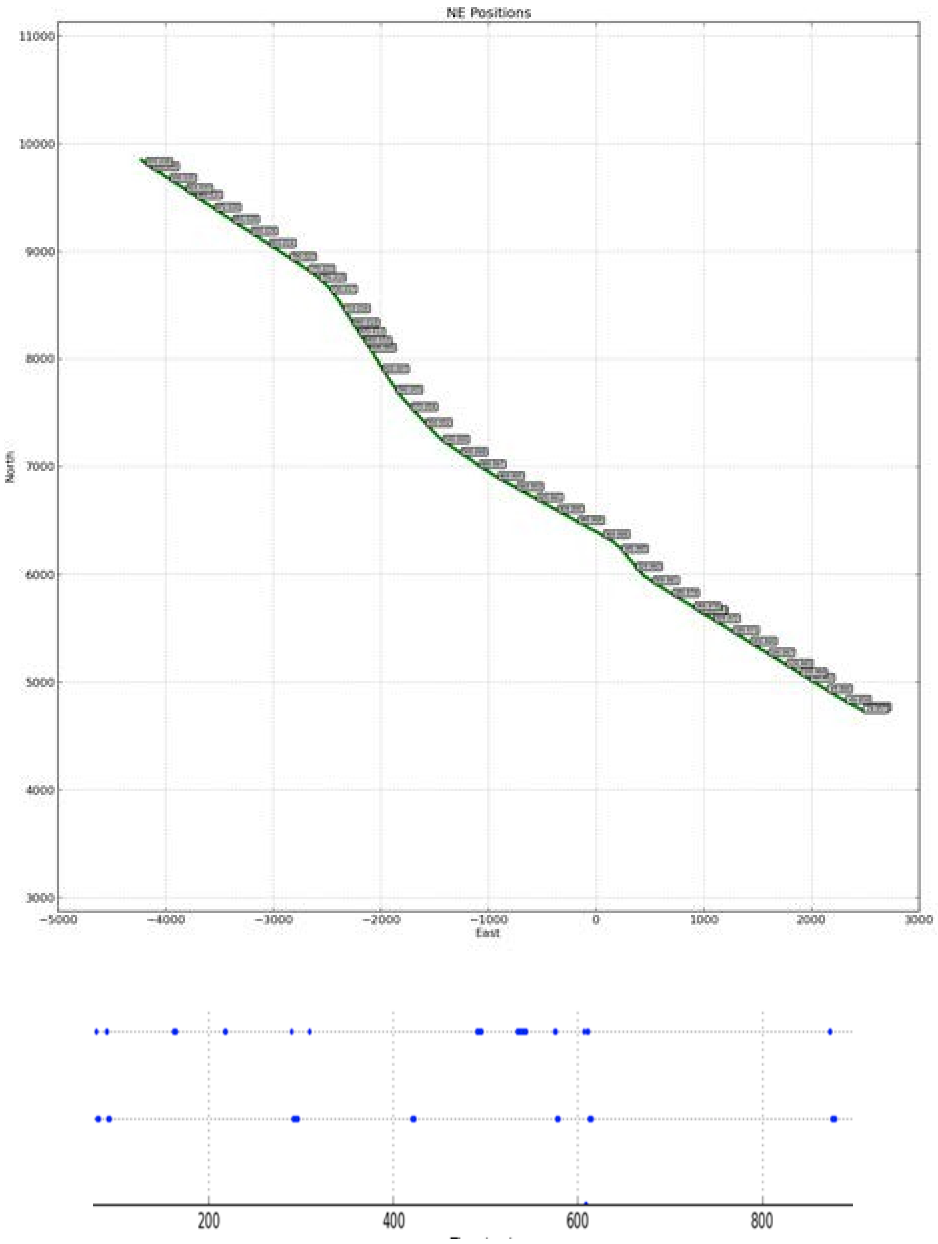

Figure 4: The first plot (a) is the plot of the estimated north and east coordinates of the trajectory. The second plot (b) is the number of satellites above predefined elevation.

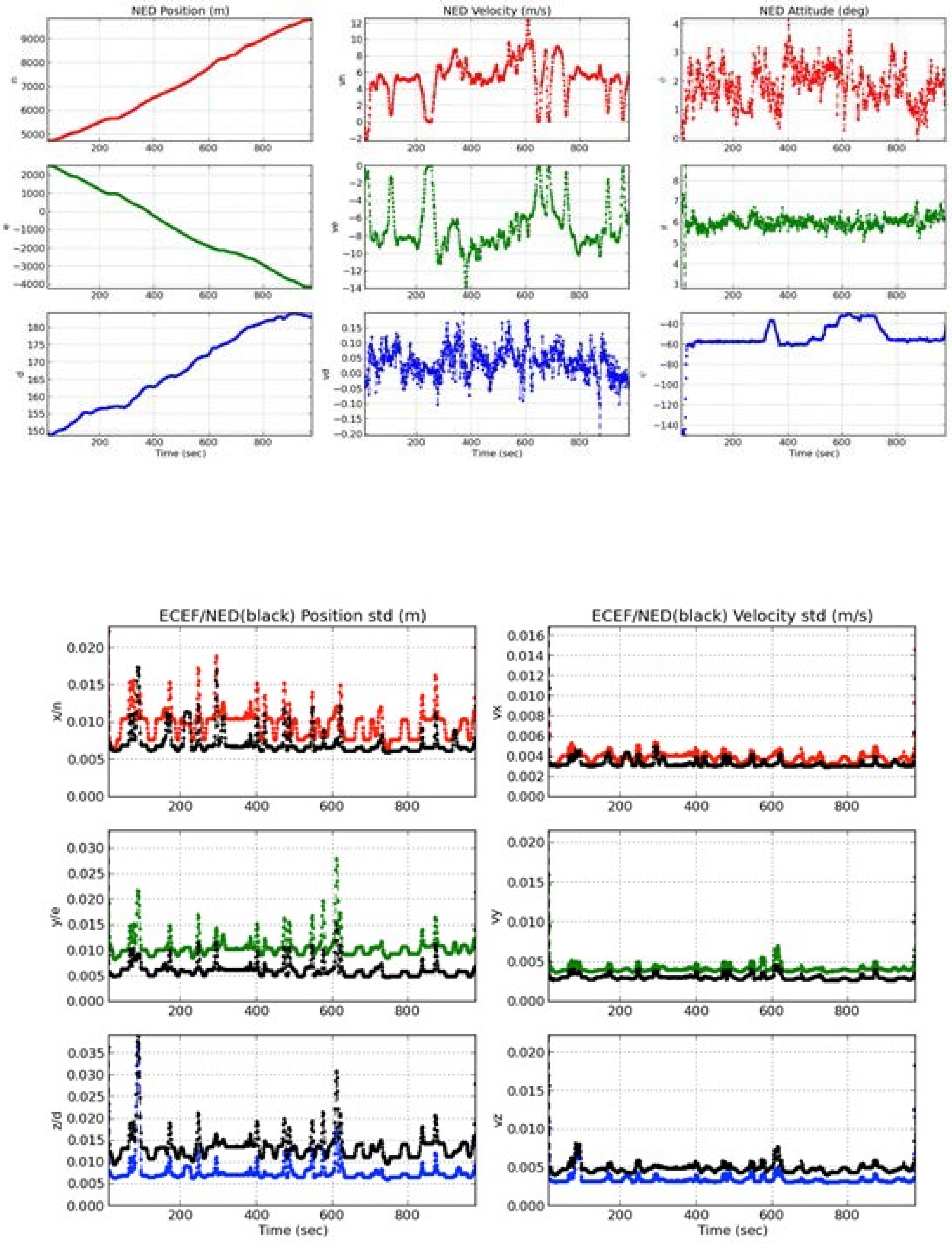

Figure 5: The first three rows are the smoothing results of the position, velocity and attitude in NED frame. The bottom three rows show the standard deviations of the position and velocity estimates. In general, the overall positioning standard deviation is below 2cm. If we refer to Figure 4, it can be seen that the large position standard deviation happens when the number of usable satellites are low.

The LiDAR dataset in global frame from the previous block needs to be stored into a database or simply data files on hard drive, because different applications could implement different algorithms on these preprocessed data. Instead of using the whole trajectory of LiDAR data, the feature extraction algorithms usually process only small sections of data to fit the limited memory. The simple way of storing all LiDAR data into a single file has several disadvantages. Firstly, the file would be too large in size due to the large amount of LiDAR data, so that it could not easily be loaded into memory, and it also takes too long. Secondly, obtaining specific LiDAR point requires traversing the whole file, which requires unnecessary time cost. So a distributed storage architecture is designed and implemented in our system.

To support the following procedures which extract the intersection region, the LiDAR data are stored into several non-overlapping blocks of data files. Each block contains all the LiDAR points that falls into the north and east boundaries of the block. In our system, each block is a box with infinite length along down- axis. The box covers 151m by 151m region in North-East plane. The size of the box is selected such that the LiDAR points from each LiDAR scan cycle (full 360°) would fall into at most four such blocks in the worst scenario to make reduce the memory usage. The index of each block is the coordinate of its North and East corner. Figure 5 details the trajectory and vehicle state information that is coupled with the 3D point cloud. The improved partitioning procedure allows for advanced feature extraction as detailed in following tasks.

VII. Conclusions

In this Connected Vehicle Mapping project task, the MPMS hardware and software was successfully improved and enhanced to allow for improved data collection procedures. The MPMS was deployed on an instrumented vehicle to map a segment of the California Connected Vehicle testbed corridor. The intrinsic and extrinsic parameters of the sensor platform were calibrated using factory provided information and accurate estimation process. After calibrating the sensor platform, the instrumented vehicle was driven repeatedly up and down the corridor of interest, collecting raw point cloud data on the on-board data servers. Then, after a sufficient amount of data was collected, the raw point cloud data was processed as a validation of system modifications. Completion of this task has allowed for greater improvement to the data processing the feature extraction techniques.