Final Report

A Comparison of Mobile Scanning to a Total Station Survey at the I-35 and IA 92 Interchange in Warren County, Iowa

August 15, 2012

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16 Abstract

The purpose of this project was to investigate the potential for collecting and using data from mobile terrestrial laser scanning (MTLS) technology that would reduce the need for traditional survey methods for the development of highway improvement projects at the Iowa Department of Transportation (Iowa DOT). The primary interest in investigating mobile scanning technology is to minimize the exposure of field surveyors to dangerous high volume traffic situations.

Issues investigated were cost, timeframe, accuracy, contracting specifications, data capture extents, data extraction capabilities and data storage issues associated with mobile scanning. The project area selected for evaluation was the I-35/IA 92 interchange in Warren County, Iowa. This project covers approximately one mile of I-35, one mile of IA 92, 4 interchange ramps, and bridges within these limits.

Delivered LAS and image files for this project totaled almost 31GB. There is nearly a 6-fold increase in the size of the scan data after post-processing. Camera data, when enabled, produced approximately 900MB of imagery data per mile using a 2-camera, 5 megapixel system.

A comparison was done between 1823 points on the pavement that were surveyed by Iowa DOT staff using a total station and the same points generated through the MTLS process. The data acquired through the MTLS and data processing met the Iowa DOT specifications for engineering survey.

A list of benefits and challenges is included in the detailed report. With the success of this project, it is anticipate that additional projects will be scanned for the Iowa DOT for use in the development of highway improvement projects.

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A Comparison of Mobile Scanning to a Total Station Survey at the I-35 and IA 92 Interchange in Warren County, Iowa.

Project Team

Iowa DOT: Alice Welch, Norm Miller, Jonathan Miranda, Mike Rummelhart, Chad Hightshoe, Brian Smith, Kent Nicholson. REY Engineers, Inc.

Project Summary and Objectives

The purpose of this project was to investigate the potential for collecting and using data from mobile terrestrial laser scanning (MTLS) technology that would reduce the need for traditional survey methods for the development of highway improvement projects at the Iowa Department of Transportation (Iowa DOT). The primary interest in investigating mobile scanning technology is to minimize the exposure of field surveyors to dangerous high volume traffic situations. Additional benefits to explore were cost savings and reducing the time required to produce the survey information.

The definition of mobile scanning technologies for this project is a system that uses multiple light detection and ranging (LiDAR) scanners for data capture from a vehicle, while simultaneously recording positional data using a Global Positioning System (GPS), inertia measurement units (IMU), a distance measurement indicator (DMI), and cameras. The resulting data cloud will contain highly accurate 3-dimensional (3D) locations of topographic features of the roadway and associated features.

Issues to be investigated are the cost, timeframe, accuracy, contracting specifications, data capture extents, data extraction capabilities and data storage issues associated with mobile scanning. The project area selected for evaluation was the I-35/IA 92 interchange in Warren County, Iowa, as shown between the Yellow bars in the project overview image. This project covers approximately one mile of I-35, one mile of IA 92, 4 interchange ramps, and the bridges within these limits.

This interchange was selected because it represents a typical rural setting where engineering survey data is required and where the Iowa DOT is challenged with obtaining a significant number of field points in areas of high traffic volumes. This site was also selected because the Iowa DOT recently collected the survey data at this interchange using a total station and traditional survey methods. The traditional project data was be used for the comparison with the data collected through the mobile scanning process.

The mobile scanning survey firm was selected through a professional proposal process that focused on MTLS data collection, break line extraction and file delivery. R.E.Y. Engineers, Inc. of Folsom, CA in partnership with Foth Infrastructure & Environment, LLC of Johnston, IA were selected for this project.

Project Overview
I-35/IA 92 Interchange in Warren, County, Iowa
Preliminary Target Locations Shown in Red

Literature Search

"Kinematic Terrestrial Light-Detection and Ranging System for Scanning"
Craig Glennie, *Transportation Research Record*, No. 2105, 135–141, 2009.
Citation at http://dx.doi.org/10.3141/2105-17
Abstract: Highway corridor surveys are becoming more difficult and expensive to carry out because of the need to minimize lane closures, traffic disruptions, and safety hazards posed to the surveyors and public. Roadway surveyors are at risk when working in the traffic corridor if they are unable to move with the flow of traffic. Safety for the traveling public is also a concern when lanes are closed or blocked by slow-moving vehicles. Costs for the placement of safety features to protect a survey crew can in some instances be greater than the cost of the survey itself. To mitigate these problems, a survey data acquisition tool is needed that can collect topographic and infrastructure information without disrupting traffic flow. Terrapoint has developed a novel kinematic laser scanning system that can be deployed on a passenger vehicle or small watercraft. Light-detection and ranging (LIDAR) digital imagery and video are collected from the survey platform while it is moving at traffic speeds. The system is georeferenced with a high-accuracy Global Positioning System–inertial measurement unit. Terrapoint's mobile LIDAR scanner has successfully surveyed existing highway corridors all over North America. It has also proven sufficiently accurate for scanning airport runway surfaces so as to predict areas where water will pool. Moving with the traffic flow and not requiring an escort, the system scans a 360° swath that includes the pavement surface and objects to the sides and above the survey vehicle.

"Geometric validation of a ground-based mobile laser scanning system"
David Barber, Jon Mills and Sarah Smith-Voysey, *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol. 63, No. 1, 128–141, 2008.
Citation at http://linkinghub.elsevier.com/retrieve/pii/S0924271607000834
Abstract: This paper outlines a study, carried out on behalf of a national mapping agency, to validate laser scanned point cloud data collected by a ground-based mobile mapping system. As the need for detailed three-dimensional data about our environment continues to grow, ground-based mobile systems are likely to find an increasingly important niche in national mapping agency applications. For example, such systems potentially provide the most efficient data capture for numerical modeling and/or visualization in support of decision making, filling a void between static terrestrial and mobile airborne laser scanning. This study sought to assess the precision and accuracy of data collected using the StreetMapper system across two test sites: a peri-urban residential housing estate with low density housing and wide streets, and a former industrial area consisting of narrow streets and tall warehouses. An estimate of system precision in both test sites was made using repeated data collection passes, indicating a measurement precision (95 percent) of between 0.029 m and 0.031 m had been achieved in elevation. Elevation measurement accuracy was assessed against check points collected using conventional surveying techniques at the same time as the laser scanning survey, finding RMS errors in elevation in the order of 0.03 m. Planimetric accuracy was also assessed, with results indicating an accuracy of approximately 0.10 m, although difficulties in reliably assessing planimetric accuracy were encountered. The results of this validation were compared against a theoretical error pre-analysis which was also used to show the relative components of error within the system. Finally, recommendations for future validation methodologies are outlined and possible applications of the system are briefly discussed.

"**Close Photogrammetry and Laser Scanning Using a Mobile Mapping System for the High Detailed Survey of a High Density Urban Area"**
S. Gandolfi, M. Barbarella, E. Ronci, A. Burchi, *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B5. Beijing 2008*
Citation at http://www.isprs.org/proceedings/XXXVII/congress/5_pdf/158.pdf
Abstract: The realization of an urban underground is a key issue for the development of any city, and it has to regard all problems linked to the project phase and the connections with many other works like railways, bus-lines and, especially for an ancient city like Bologna, historical buildings. For these reasons the Municipality of Bologna has committed the ultimate design of the underground line with a high standard level of precision; this aspect forces the Project Group to choose a survey method that has to be both accurate and not too expensive. In order to achieve a precise high resolution survey in a short time, a Mobile Mapping System vehicle has been used. The Road-Scanner" system is equipped with 2GPS+IMU sensors for navigation (Applanix POSLV), four cameras for close range photogrammetric survey and a Laser scanner FARO LS880. Moreover, in order to obtain good and homogeneous results a geodetic network (performed using GPS and topographic survey) has been made in some area along the track. In this contribute the authors, starting from the municipality requirements, describe all the performed work and analyze the obtained results.

"Performance Characterization of a Mobile Lidar System: Expected and Unexpected Variables"
P. Valerie Ussyshkin, Mariusz Boba, ASPRS Annual Conference, Portland, Oregon April 28-May 2, 2008
Citation at:http://www.asprs.org/a/publications/proceedings/portland08/0081.pdf
Abstract: Achieving results that meet the requirements of any survey project requires knowledge and deep understanding of the performance capabilities of the survey equipment. Mobile lidar scanning, which has emerged as the preferred operational tool in remote sensing, surveying and mapping, is demonstrating outstanding capabilities in generating high-accuracy spatial data for a wide range of applications. Although manufacturers of mobile LiDAR systems provide accuracy specifications and other instrument characteristics in a spec sheet, such specifications are often potentially misleading due to the complexity of new technologies, and the interplay of factors affecting the quality of lidar derived end products. This paper represents a manufacturer's effort to clarify the issue of characterizing a mobile LiDAR system's performance.

"**Boresight alignment method for mobile laser scanning systems**"
P. Rieger, N. Studnicka, M. Pfennigbauer, *Journal of Applied Geodesy,*
Abstract: Mobile laser scanning (MLS) is the latest approach towards fast and cost-efficient acquisition of 3-dimensional spatial data. Accurately evaluating the boresight alignment in MLS systems is an obvious necessity. However, actual systems available on the market may lack of suitable and efficient practical workflows on how to perform this calibration. This paper discusses an innovative method for accurately determining the boresight alignment of MLS systems by employing 3D-laser scanners. Scanning objects using a 3D-laser scanner operating in a 2D-line scan mode from various different runs and scan directions provides

valuable scan data for determining the angular alignment between inertial measurement unit and laser scanner. Field data is presented demonstrating the final accuracy of the calibration and the high quality of the point cloud acquired during an MLS campaign.

"**A Study of Implementation of IP-S2 Mobile Mapping Technology for Highway Asset Condition Assessment"**
J. M. De la Garza1, C. G. Howerton2, D. Sideris2., May 13, 2010
Citation at http://www.champs.eng.vt.edu/Documents/Research/1.pdf
Abstract: The national highway infrastructure is continually deteriorating, and in need of reconstruction and repairs. This is revealed by national highways poor grades in the 2005 and 2009 ASCE report cards (ASCE 2005, ASCE 2009). As major arteries for the flow of goods and people in the United States, poor highways can lead to fatalities, economic distress, and frustration among motorists. Prior to performing maintenance, state DOTs need to assess damages and determine what highway assets need to be repaired. Data collection techniques have not been standardized in the United States, but most state DOTs make extensive use of manpowered collection crews. Manpowered crews' data collection efforts are time consuming, costly, and potentially unsafe. Mobile mapping enables DOTs to determine the condition and location of assets while increasing safety for surveyors. Positioning and visual recognition of assets is an important aspect while inspecting numerous dispersed assets along highways. This paper presents a preliminary study of Topcon's IP-S2 Mobile Mapping system. Two separate but interrelated projects were conducted. The first project's primary objectives are: (1) to measure the time it takes to collect data using the IP-S2 method versus the traditional method; and (2) to measure the accuracy of the data using the IP-S2 method versus the traditional method. These tests were conducted at two variable speeds: slow and highway.

"**Mobile Mapping Systems Overview**"
Lewis Graham, PERS_March 2010, Volume 76, Number 3, p. 222-228
http://digital.ipcprintservices.com/publication/?i=32898&p=&l=&m=&ver=&pp=

"**Mapping with Mobile Lidar**"
Federica Zampa, Dario Conforti, GIM International, April 2009, Volume 23, Issue 4
http://www.gim-international.com/issues/articles/id1306-Mapping_with_Mobile_Lidar.html

"**3D Scanning: Mobile Mapping for the Interstate**"
Scott Dunham, Professional Surveyor May, 2010, Volume 30, Issue 5
http://www.profsurv.com/magazine/article.aspx?i=70738

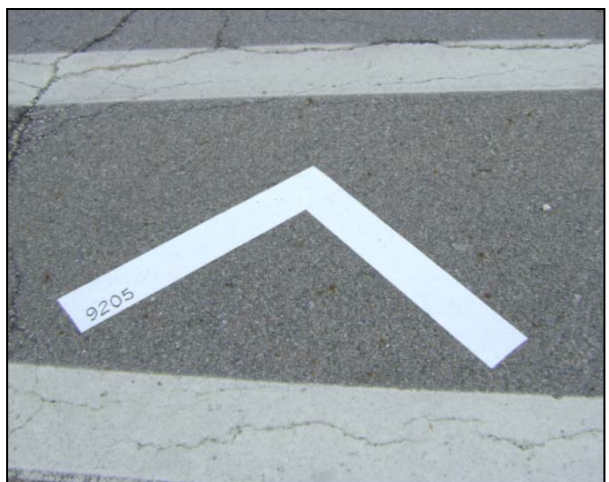
Project Details

Process Overview:
The following is a list of the step-by-step tasks needed to complete this project:

- Pre-Mission Planning
- Targeting & Control
- On-Site Planning & Safety
- Scan Data Acquisition
- Trajectory Processing & Reporting
- Scan Data Processing, Adjustment & Reporting
- LAS Data & Image Export
- LAS Data Q/C & Refinement
- Data Extraction
- CAD Formatting
- DTM Development
- Final Product Delivery

Scanning with Traffic Control

Scan Targets:
During the week of August 15, 2011, Iowa DOT survey staff set tape targets for use in the mobile scanning process. The 37 targets, shown as red triangles project overview image, were set in the both the right and left-hand shoulders of I-35 and IA 92, as well as along the five ramps within the project limits. The targets were made from 4" temporary pavement marking tape with the legs of the targets set at 2' in length. The coordinates of a point set into the pavement at the tip of the target were collected for use in data processing.



Mobile Scanning Target

Project Control:
The horizontal datum for this survey is the North American Datum of 1983 (NAD83/1996). The vertical datum is the North American Vertical Datum of 1988 (NAVD88). All units in this survey are US Survey Feet, defined as exactly 39.37/12 feet per meter.

Mobile scan data and trajectories were based on a GPS base station occupying control monument "G063" at the east end of the IA 92 bridge over I 35. Iowa South, State Plane

Coordinate values used were Y: 497,204.00, X:1,565,346.23, and an NAVD88 orthometric height of 843.314'.

Deliverable scan data was exported on Iowa South State Plane Coordinate then transformed to Local Project Plane (LPP) values using the following equations:

LPP y = [(State Plane y – 513,358.35) * 1.000086224] + 513,358.35

LPP x = [(State Plane x – 1,563,703.57) * 1.000086224] + 1,563,703.57

Data Acquisition:
Scanning Equipment
R.E.Y.'s Riegl VMX-250 mobile scanning system was used for data acquisition. The VMX-250 system consists of the following:

- 2 – Riegl VQ-250 line scanners
- 2 – Riegl CS6 5 MPx Cameras
- Applanix POS LV V4 Model 510 position and orientation system (IMU)
- Trimble BD960 GNSS receiver
- Trimble Zephyr Model 2 GNSS Antenna
- Applanix Distance Measurement Indicator (DMI)
- Riegl Control Unit (CU)

Specifications for Riegl VMX-250 System:

Technical Data Mobile Laser Scanning System *RIEGL* VMX®-250

Laser Product Classification	Class 1 Laser Product according to IEC60825-1:2007 The following clause applies for instruments delivered into the United States: Complies with 21 CFR 1040.10 and 1040.11 except for deviations pursuant to Laser Notice No. 50, dated June 24, 2007. CLASS 1 LASER PRODUCT

2 x VQ-250 Measurement Performance

Effective Measurement Rate[1]	100 kHz	200 kHz	300 kHz	400 kHz	**600 kHz**
Max. Unambiguous Measuring Range [2]					
natural targets $\rho \geq 10\%$	180 m	130 m	110 m	100 m	**75 m**
natural targets $\rho \geq 80\%$	500 m	380 m	340 m	300 m	**200 m**
Max. Number of Targets per Pulse	practically unlimited (details on request)				

Minimum Range	1.5 m
Accuracy [3] [5]	10 mm
Precision [4] [5]	5 mm
Max. Effective Measurement Rate [1]	600 000 meas./sec (2 x 300 000 meas./sec)
Line Scan Speed (selectable)	up to 200 lines/sec (2 x 100 lines/sec)

1) Rounded values, based on 2 *RIEGL* VQ-250 laser scanners.
2) The following conditions are assumed: target larger than the footprint of the laser beam, perpendicular angle of incidence, visibility 23 km, average ambient brightness.
3) Accuracy is the degree of conformity of a measured quantity to its actual (true) value.
4) Precision, also called reproducibility or repeatability, is the degree to which further measurements show the same result.
5) One sigma @ 150 m range under *RIEGL* test conditions.

INS/GNSS Performance[6]

Position (absolute)	typ. 20 - 50 mm
Position (relative)[7]	typ. 10 mm
Roll & Pitch	0.005°
Heading	0.015°

6) One sigma values, no GNSS outages, with DMI option, post-processed.
7) With a control point spacing < 300 m.

Specifications for Applanix POS LV V4 Model 510 INS:

PERFORMANCE SUMMARY - With GPS*

POS LV	210 PP	210 IARTK	210 DGPS	220 PP	220 IARTK	220 DGPS	420 PP	420 IARTK	420 DGPS	510/520 PP	510/520 IARTK	510/520 DGPS	610 PP	610 IARTK	610 DGPS
X,Y Position (m)	0.020	0.035	0.300	0.020	0.035	0.300	0.020	0.035	0.300	0.020	0.035	0.300	0.020	0.035	0.300
Z Position (m)	0.050	0.050	0.500	0.050	0.050	0.500	0.050	0.050	0.500	0.050	0.050	0.500	0.050	0.050	0.500
Roll and Pitch (°)	0.020	0.020	0.020	0.020	0.020	0.020	0.015	0.015	0.015	0.005	0.008	0.008	0.005	0.005	0.005
True Heading (°)	0.050	0.100	0.200	0.025	0.050	0.050	0.020	0.020	0.020	0.015	0.020	0.020	0.015	0.020	0.020

PERFORMANCE SUMMARY - GPS Outage (1km or one minute)*

POS LV	210 PP	210 IARTK	210 DGPS	220 PP	220 IARTK	220 DGPS	420 PP	420 IARTK	420 DGPS	510/520 PP	510/520 IARTK	510/520 DGPS	610 PP	610 IARTK	610 DGPS
X,Y Position (m)	0.320	1.270	2.510	0.240	0.690	0.880	0.120	0.340	0.450	0.100	0.300	0.420	0.100	0.280	0.410
Z Position (m)	0.130	0.350	0.610	0.130	0.350	0.610	0.100	0.270	0.560	0.070	0.100	0.530	0.070	0.100	0.510
Roll and Pitch (°)	0.060	0.060	0.060	0.060	0.060	0.060	0.020	0.020	0.020	0.005	0.008	0.008	0.005	0.005	0.005
True Heading (°)	0.060	0.100	0.200	0.030	0.070	0.070	0.020	0.030	0.030	0.015	0.020	0.020	0.015	0.020	0.020

* All accuracy values given as RMS. Assumes typical road vehicle dynamics for initialization.

INERTIAL MEASUREMENT UNIT (IMU)

Type	Origin	Operational Temperature	Models Used In	Maximum Data Rate	Dimensions	Weight
IMU-7	US	-54 °C to +71 °C	POSLV 420	200 Hz	L = 158mm, W = 158mm, H = 124mm	2.5 kg
IMU-17	US	-40 °C to +60 °C	POSLV 210, 220	100 Hz	L = 158mm, W = 158mm, H = 124mm	2.5 kg
IMU-21	US	-40 °C to +60 °C	POSLV 610	200 Hz	L = 213mm, W = 172mm, H = 172mm	4.8 kg
IMU-26	EU	-40 °C to +71 °C	POSLV 210, 220	200 Hz	L = 204mm, W = 204mm, H = 116mm	3.5 kg
IMU 31	EU	-20 °C to +55 °C	POSLV 510/520	200 Hz	L= 163mm, W= 130mm, H= 137mm	2.6 kg

Equipment Configuration:
The log rate of the onboard GPS is factory set at 5 Hz, which is supplemented by the IMU providing vehicle and sensor position and orientation updates at a rate of 200 Hz. Each scanner was configured for a measurement rate of 300 kHz (600 kHz combined). The scan vehicle travelled at an average speed of 40 mph, varying between 35 and 45 mph. Variation of the speed during acquisition assists in reducing IMU drift which tends to occur when constant direction, profile and speed are maintained over a period of time. At this speed and measurement rate, point density on the roadway surface ranges from approximately 600 points/m2 at 20 feet from the sensors, to over 2,300 points/m2 along the trajectory line, on a single pass.

Two passes were made on each roadway, including ramps, for redundancy and increased point density. A combination (or mosaic) of adjacent parallel passes are used for data extraction.

Scan data was acquired using Riegl's RiACQUIRE software, version 1.4.5 RiACQUIRE is installed on the Control Unit, and controls the laser sensors and INS data acquisition. At the end of the acquisition mission, the INS and scan data is immediately transferred to a laptop or office workstation.

Scan Processing:

- Vehicle Trajectory Processing
  Trajectory processing was performed using Applanix's POSPac MMS version 5.3, Service Pack 3. Two base stations were fixed at their NAD83 (NAD83/1996) latitude and longitude. Base station ellipsoid heights were fixed at their Geoid 09 modeled values, based upon their NAVD88 orthometric heights.

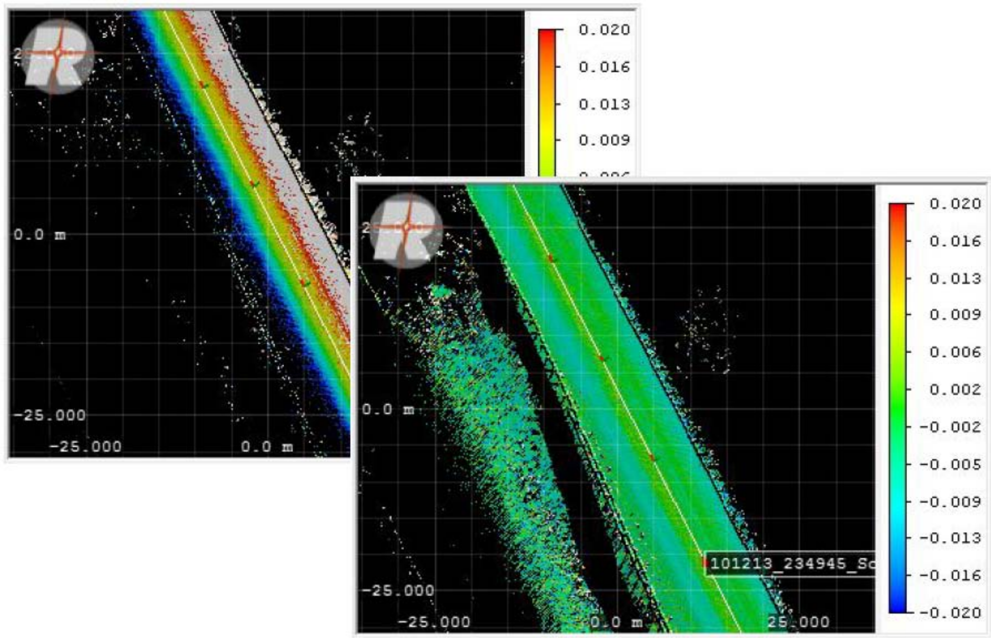
  Two methods of processing are available within the POSPac MMS suite, tightly or loosely coupled. In both solutions, the data is processed in both forward and backward directions to produce the optimal solution, smoothing the effect of GPS outages and other aberrations in the data. In a tightly coupled solution the IMU data is used together with the GPS data to produce a smoothed best estimate of trajectory (SBET) for the scan vehicle. During a complete GPS outage, the IMU data is not only used to carry the vehicle position, but also assists in regaining the GPS integer count when satellite reception is regained. A successful tightly coupled solution is always preferable to a loosely coupled solution. However, the tightly coupled solution currently only uses GPS data and does not make use of any GLONASS data that may be available. The loosely coupled solution does make use of GLONASS data if available. However, the vehicle trajectory is based entirely upon the GNSS derived trajectory, with IMU data only being used during a GNSS outage and in determining the orientation of the scanner. This solution would be used in the event that GPS data was of insufficient quality and a tightly coupled solution was not possible. For these reasons, GPS and GLONASS data for both the mobile platform and the base station(s) are always logged as a backup.

  Vehicle trajectories from the primary base station processed successfully as tightly coupled solutions. As such, the backup base station data was not used in this survey. Trajectory quality reports are contained in Section 2 of this report. The reports are presented as an overall trajectory, and further broken down by individual scan collection segments.

- Scan Data Processing
  Scan data was processed using Riegl's RiPROCESS software, version 1.4.15. In RiPROCESS raw scan data is time-matched with the SBET to produce trajectory-based, geo-referenced scan data. Scan records are typically collected in one mile segments on the mainline, and for each ramp individually to allow for manageable data file sizes.

  Initially, each scan Record, consisting of overlapping data from Scanner 1 and Scanner 2, is compared by laser data height differencing. The laser difference range was set to +2 cm to -2 cm. This allows visual verification that scan records contain readily usable data.

  The image below-left, showing a rainbow effect of the laser differencing, is an example of data that is "scissored". This scan record would be rejected in favor of the data in the second image below-right. Laser differencing in the second image indicates overlapping scan data is well within 2cm, and closer to 5mm of relative difference. Further processing is required for those scan Records that show laser differencing approaching and in excess of 2cm. *(The images below are examples only, and are not representative of the data collected on this project.)*



Scan Data Adjustment is a tool in RiPROCESS to improve the calibration of the system and the relative fit of the scan data. It allows the adjustment of several parameters such as the orientation and position offsets per laser data, per laser device, per navigation device and of the trajectory. Scan Data Adjustment is an iterative process whose results are based on interactive judgment and decisions as to when scan Records have reached their optimal relative adjustment.

Experience has proven that over-adjusting scan data is possible and scan data relativity can be degraded. Allowing too much freedom in the Roll, Pitch and Heading adjustment parameters can cause initially good data to drift out of tolerance.

In RiPROCESS scan data was adjusted using a two-step process. The first process is cloud-to cloud adjustment using a routine called “Manual Tie Planes”. Overlapping scan data is allowed to “float” within certain defined parameters. This reduces horizontal and vertical offsets between overlapping data, while improving the data’s absolute position based on the initial trajectories. Second, the resulting data was related to the scan targets by editing the position and orientation file by use of “Manual Tie Objects”. This method allows the trajectories, and dependent scan data, to adjust to the field surveyed transformation and validation points.

At the conclusion of adjustment in RiPROCESS, LAS 1.2 files were exported, in Iowa South coordinates and NAVD88 elevations, for further analysis and final adjustment in MARS Explorer 7 and TopoDOT.

- LAS File Transformation and Adjustment

MARS Explorer 7, from Merrick & Company, was used for transforming the LAS files from Iowa South coordinates to Local Project Plane (LPP) coordinates. This exercise was also used to combine Scanner 1 and Scanner 2 data into composite LAS files for each pass. Additionally, if necessary, MARS can be used to apply final X,Y, or Z shifts to the LAS data. Shifts in the X and Y directions are based on visual observation of the scan targets to the surveyed value of the point. Shifts in the Z direction are determined in an automated fashion by comparing a TIN face to the surveyed value of the scan target point.

The final step is developing accuracy reports, by comparing the scan targets to the finished point cloud data. For final accuracy reporting we used TopoDOT's "*Control Point to Data Analysis*", which compares the Z of the scan target point to an average Z of all scan data within a user defined radius. The TopoDOT Control Point to Data Analysis Report is contained in Section 3 of this report. The purpose of the report is to illustrate the overall accuracy of the final point cloud data, relative to the project control. Below is a summary of the relative accuracy's between the scan targets and the point clouds.

LAS File Coverage	RMSE (Ft)	95% Conf. (Ft)
Overall Project	**0.013**	**0.026**
Northbound I-35	0.013	0.026
Southbound I-35	0.007	0.013
Eastbound IA-92	0.022	0.043
Westbound IA-92	0.016	0.030
I-35 NB Offramp	0.008	0.016
I-35 NB Onramp	0.007	0.014
I-35 NB Loopramp	0.007	0.014
I-35 SB Offramp	0.006	0.012
I-35 SB Onramp	0.006	0.011

- MTLS Feature Extraction & Formatting
  Final LAS files were loaded into Certainty 3D's TopoDOT (version 4.3.12.4) product. TopoDOT is a high performance MicroStation (version 8i, Select Series 2) application for extracting 3D deliverable topography, planimetrics and models from point clouds, calibrated images and related 3D data.

  In real-time, 3D line and point features were traced and draped directly into the appropriate Iowa DOT seed file, using the Iowa DOT specific color table, line-style library and cell library. Upon completion of feature extraction, no CAD translations or formatting is required.

  Adjusted mobile LiDAR hard surface data typically lies within a band of points ranging from .02' to 0.08' in thickness. The draping method used for developing data on hard surfaces is taking the average elevation of all points within a user defined radius for the point being extracted. The radius used is dependent on the density of the points in the area of the feature being delineated.

The final step in the delivery process was developing a GEOPAK surface (TIN). The process we elected to use for this project is to first create an InRoads surface (DTM) from the 3D graphic elements we compiled in MicroStation from the LAS files, then export to GEOPAK TIN format by use of the data acquisition feature in MicroStation. Both TIN and DTM formats were delivered to the Iowa DOT.

Note: Supplemental survey data will typically be required in areas of ground cover and vegetation. Also, since the mobile scanner is a line-of-sight instrument, if it can't be seen with the naked eye, chances are it will need to be surveyed conventionally. Again, areas subject to flat grazing angles may require supplemental surveys, via aerial mapping, field surveys or airborne LiDAR. In areas of vegetation, the advantage airborne LiDAR has over ground-based LiDAR is the nearly perpendicular perspective the airborne sensors have to the ground. This allows for better penetration which results in more "last returns" off the bare earth surface. However, airborne data is typically not as accurate on hard surfaces as ground-based data due to range, altitude and attitude (roll, pitch, and yaw) of the aircraft.

Data sets can be seamlessly merged using GEOPAK or InRoads surface creation tools/techniques as well as the Data Acquisition functionality in MicroStation®. Data from different sources should reside in different models in the MicroStation file, so the data source can be followed when determining which data is best in a given area. Supplemental survey data will typically be required in areas of ground cover and vegetation. Also, since the mobile scanner is a line-of-sight instrument, if it can't be seen with the naked eye, chances are it will need to be surveyed conventionally. Again, areas subject to flat grazing angles may require supplemental surveys, via aerial mapping, field surveys or airborne LiDAR. In areas of vegetation, the advantage airborne LiDAR has over ground-based LiDAR is the nearly perpendicular perspective the airborne sensors have to the ground. This allows for better penetration which results in more "last returns" off the bare earth surface. However, airborne data is typically not as accurate on hard surfaces as ground-based data due to range, altitude and attitude (roll, pitch, and yaw) of the aircraft.

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Results

The following is a summary of topics discussed at the completion of the project.

Data Storage and Computer Issues

Computing and storage requirements need to be separated into two distinct categories; Data processing and extraction, versus end-user usage, and tend to be software dependent. Delivered LAS and image files for this project totaled almost 31GB.

Data Processing

Acceptable performance can be achieved with modest hardware such as a dual-core processor (hyper-threading a plus), 32-bit operating system, 4GB RAM, mid-level graphics board, 500GB internal hard drive and the ability to attach external drives via eSATA or USB 3.0 interfaces when needed. However, higher-end hardware does achieve measurable performance gains and reduced time expenditure. The size of the project data files is subject to many variables such as scan density, vehicle travel speed, etc. The Riegl VMX-250 produces approximately 500 to 700MB of raw scan data per mile of scanning when set for a scan density of 600,000 points per second and travelling at 40 mph. The raw scan data is stored in a compacted format. There is nearly a 6-fold increase in the size of the scan data after post-processing. Camera data, when enabled, produces approximately 900MB of imagery data per mile using a 2-camera, 5 megapixel system.

Data Extraction

Data extraction is performed using the final, adjusted LAS files. The Riegl VMX-250 system, configured as described, produces approximately 1.0 to 1.4GB of LAS data per mile of scan. Extraction tools are capable of segmenting the LAS data into more manageable working-file sizes. Experience will determine the maximum manageable data-set size for a particular hardware platform. Systems are capable of loading one mile of LAS data at a time while maintaining acceptable performance during extraction. Clipping of the LAS data outside of the area of interest allows for longer, wider or multiple segments to be loaded. The primary limitation in our environment is the fact that MicroStation, at this time, is still 32-bit platform. Certain Microsoft Windows system settings will allow MicroStation to access more than 2GB RAM, but MicroStation's access to this additional memory is via way of memory paging. When MicroStation offers a 64-bit platform; manageable data set sizes as well as overall performance should increase.

End-User Usage

The typical finished products from a scan mission are the CAD design files and the LAS point cloud files. The CAD files typically produced are indistinguishable from conventionally derived products. Hardware platforms currently providing satisfactory performance will suffer no adverse impacts from the incorporation of scan-derived products. Several free and commercial utilities are available for the viewing of the LAS files. One example is the free-ware software viewer Quick Terrain Reader, developed by Johns Hopkins University's Applied Physics Lab. Suitable performance is achieved using the lower-end systems described above, although larger models will see substantially increased performance when viewed on higher end, 64-bit platforms with greater than 4GB RAM and professional grade graphics boards.

Accuracy

The data acquired through the MTLS and data processing meets the Iowa DOT specifications for engineering survey. The adjacent table summarizes the accuracy of the 76 control points that were covered by the scanning.

Project Units	US Survey Feet
Control Points with LiDAR Coverage	76
Average Control Error Reported	-0.001
Maximum (highest) Control Error Reported	0.027
Median Control Error Reported	0.000
Minimum (lowest) Control Error Reported	-0.050
Standard deviation (sigma) of Error for sample	**0.013**
RMSE of Error for sample (RMSE(z))	**0.013**
FGDC/NSSDA Vertical Accuracy (Accuracy(z))	**0.026**
NSSDA Achievable Contour Interval	0.046
ASPRS Class 1 Achievable Contour Interval	0.040

The following table is an example of the accuracy for 16 of the 76 control points.

Point	Easting	Northing	Surveyed Elevation	LiDAR Elevation	Elevation Deviation	Location
3502	1563579.190	494246.620	850.060	850.080	-0.020	Northbound I-35
3503	1563608.080	494245.600	849.940	849.940	0.000	
3504	1563643.910	494246.700	849.950	849.932	0.018	
3506	1563521.550	495553.140	847.750	847.769	-0.019	
3507	1563549.680	495554.430	847.690	847.663	0.027	
3508	1563603.500	495556.140	847.210	847.221	-0.011	
3509	1563546.090	496387.180	844.900	844.896	0.004	
3511	1563478.100	496538.040	844.840	844.832	0.008	
3512	1563491.570	496878.350	845.330	845.328	0.002	
3513	1563534.350	496880.880	845.090	845.090	0.000	
3515	1563414.710	497958.330	851.010	851.039	-0.029	
3516	1563443.000	497959.930	850.940	850.938	0.002	
3517	1563493.300	497962.540	850.410	850.404	0.006	
3519	1563361.910	499226.310	877.080	877.079	0.001	
3520	1563390.160	499223.650	876.990	876.995	-0.005	
3521	1563426.530	499225.020	876.960	876.961	-0.001	

A comparison was done between 1823 points on the pavement that were surveyed by Iowa DOT staff using a total station and the same points generated through the MTLS process. The results of that comparison are shown below.

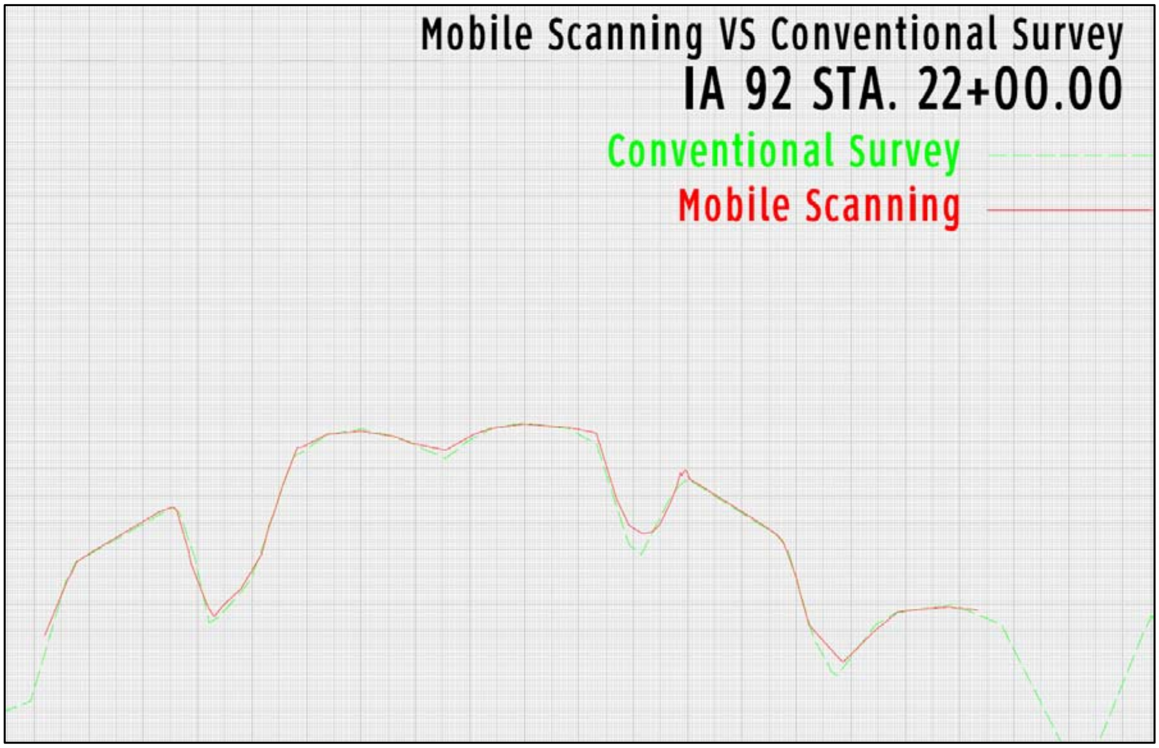
1823 Total Number of Points
497 Points Below the TIN Surface
1325 Points Above the TIN Surface
1 Points Equal to the TIN Surface

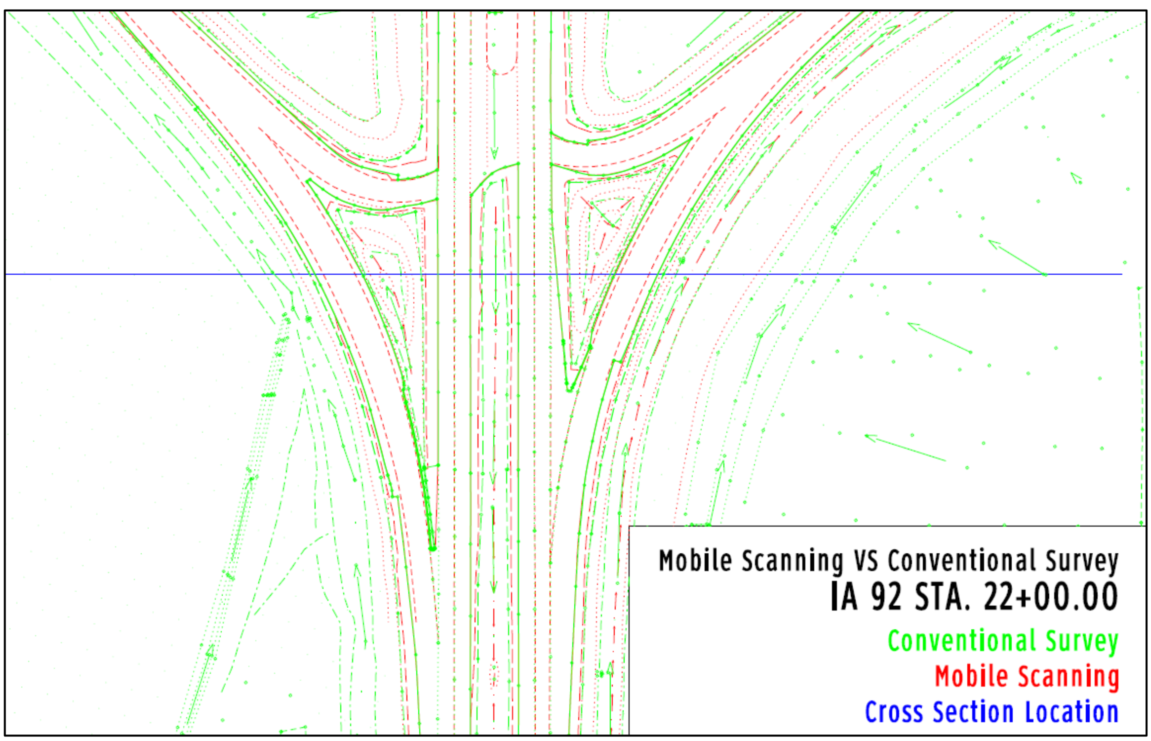
Sum of the Elevation Difference Squared = 8.8101
Average of Elevation Difference Squared = 0.0048
Root Mean Square Error = 0.0695
National Standard for Spatial Data Accuracy (NSSDA) = 0.1363
Points PASS the 95% confidence test based on 1.96 Chi Square Value.

The difference in the 1823 points compared is shown below.

Tolerance	No. of Pts.	Percent				
> 0.25	3	0.16%				
0.20 to 0.25	5	0.27%	99.67%			
0.15 to 0.20	30	1.65%		99.07%		
0.10 to 0.15	168	9.22%			96.54%	
0.05 to 0.10	492	26.99%				86.51%
-0.05 to 0.05	1012	55.51%	+/- 0.25'	+/- 0.20'	+/- 0.15'	+/- 0.10'
-0.05 to -0.10	73	4.00%				86.51%
-0.10 to -0.15	15	0.82%			96.54%	
-0.15 to -0.20	16	0.88%		99.07%		
-0.20 to -0.25	6	0.33%	99.67%			
> -0.25	3	0.16%				
TOTALS	**1823**	**100.00%**				

The following is a typical example of a cross section showing the surface resulting from the original Iowa DOT surface and the surface produced through the MTLS process. The results of the scanning are very good on the roadway pavement.





Survey Time Comparison:
The hours listed below are approximate but are useful in comparing time used to capture the roadway data using MTLS and a total station survey.

MTLS:
The number of hours per work task for all activities for the MTLS process:

Planning		22 hours
Travel & Logistics		34 hours
On-Site Planning		16 hours
Scan Data Acquisition		16 hours
On-Site Pre-Processing		12 hours
Trajectory Processing & Reporting		8 hours
Scan Data Processing, Adjustment & Reporting		16 hours
LAS Data& Image Export		12 hours
LAS Data Q/C & Refinement		16 hours
Data Extraction		140 hours
CAD Formatting		16 hours
DTM Development		6 hours
Final Reports		24 hours
Data Assembly & Delivery		8 hours
	Total	318 hours

Total Station Survey:

All field and office activities	Total	260 hours

Benefits

The following is a listed of MTLS process and product benefits:

- The density of data points collected is significantly greater than traditional survey and provides the highway designer with a much better understanding of the existing roadway and associated features.
- Improved safety for the survey crew members by significantly reducing the amount of time they need to send in close proximity to the traveling public.
- Improved safety to the traveling public by reducing the amount of time that survey vehicles are present near the roadway as well as reducing the possible distraction of survey activities.
- The accuracy of the MTLS products meets the requirements for highway design.
- The rate of data collection in the field is much greater than traditional methods.
- More Data Features like Super Structures

Challenges

The following is a list of challenges to overcome with the MTLS process:

- Development of specifications, similar to those found in Chapter 15 of the Caltrans Surveys Manual, will be essential for the Iowa DOT to receive data meeting the needs of highway and bridge designers.
- Advancement in the software that aid highway designers in fully utilizing the full benefits on the MTLS produced data.

Summary/Implementation

With the success of this project, it is anticipate that additional projects will be scanned for the Iowa DOT for use in the development of highway improvement projects.