THE FEDERAL RAILROAD ADMINISTRATION'S AUTOMATED GRADE CROSSING SURVEY SYSTEM

Soheil Saadat
Staff System Engineer
Applied Technology and Engineering Division,
ENSCO, Inc.
5400 Port Royal Rd.
Springfield, VA 22151, USA
saadat.soheil@ensco.com

Tarek Omar
Program Manager, Train Control & Communications
Federal Railroad Administration,
Office of Railroad Policy and Development
1200 New Jersey Avenue SE
West Building, 3rd Floor
Washington, DC 20590, U.S.A.
tarek.omar@dot.gov

Edwin Olson
Associate Professor
Computer Science and Engineering
University of Michigan
2260 Hayward St.
Ann Arbor, MI 48109, USA
ebolson@umich.edu

Pradeep Ranganathan
Ph.D. Candidate
Computer Science and Engineering
University of Michigan
2260 Hayward St.
Ann Arbor, MI 48109, USA
rpradeep@umich.edu

Number of Words (including Figures) are 2,405

ABSTRACT

The Federal Railroad Administration's (FRA's) Office of Railroad Safety (RRS) reports that in calendar year 2014, there were more than 2,280 highway-rail accidents resulting in approximately 850 injuries and close to 270 fatalities. As part of FRA's mission to improve public safety, FRA is focused on the reduction of train-on-vehicle collisions at grade crossings and resulting fatalities through a variety of means. One such effort involves the efficient assessment of grade crossings as characterized by parameters such as grade crossing profile, track-road angle, sight lines as well as the presence and proper operation of gates through use of an automated system to survey grade crossings from full-size track inspection vehicle.

In order to realize this vision, FRA's Office of Research, Development and Technology (ORDT) has developed and deployed a LiDAR-based system that creates accurate, high-density point clouds of track and surrounding area in and around grade crossing at survey speeds of up to 55 mph. Data is analyzed in real-time to extract safety-critical grade crossing parameters and to identify high profile grade crossings that pose a risk for accidents in which low-clearance motor vehicles can become stuck on the tracks. This paper presents highlights of the FRA's development program as well as an overview of initial deployment and use of the resulting technology

INTRODUCTION

The improvement of safety of highway-rail grade crossings has been a long standing priority for FRA. FRA has targeted the reduction of hang-up incidents at grade crossings as part of its strategy. Hang-ups can occur when a low-clearance commercial motor vehicle bottoms out on a high profile, or humped, grade crossing and becomes stuck across the railroad right-of-way. These situations often result in collisions between trains and the highway vehicles due to the train's inability stop prior to the highway vehicle. Guidelines suggested by the American Association of State Highway and Transportation Officials (AASHTO) require that the change in elevation *"be [no] more than 3 [inches] higher or lower from the top of the nearest rail at a point 30 [feet] from the rails" (1)*. In the 2007 edition of the *Railroad-Highway Grade Crossing Handbook,* the Federal Highway Administration notes that several states employ alternative standards for crossing profiles *(2)*. Although the original configuration of crossings can meet one or more of these guidelines, the profile of a grade crossing can be altered by railroad or roadway maintenance.

Private crossings are subject to private contractual agreements, making the ability to assure the safe configuration of the crossing difficult at best.

To address these concerns, FRA initiated an effort to survey and classify grade crossings on a wide scale to identify unsafe conditions including the profile of the crossing. Following the survey of the crossing, unsafe crossings configurations can be identified and analyzed to make specific safety improvement or operational and functional suggestions to railroads and municipalities. FRA has developed a LiDAR-based system that creates accurate, high-density point clouds of grade crossings and their surroundings from a rail vehicle at survey speeds up to 55 MPH. This approach was based on FRA's successful demonstration of the use of LiDAR sensors on hi-rail vehicles to survey grade crossing elevation profiles *(3)*. FRA is in the process of establishing an approach that will allow for the efficient collection of survey data through grade crossings as part of its routine nationwide inspections. FRA intends to use this survey data to assess more than the profile of the crossing. Data collected during survey operations can be used to quantify the angle between the roadway and the tracks, characterize the intensity of pavement markings, identify malfunctioning gates and evaluate sight lines from the perspective of the train operator, motorists or pedestrians. The system automatically detects crossings, extracts key parameters and integrates results with location information gathered during the survey to provide railroads and FRA researchers with accurate information about grade crossings at a fraction of the cost of conventional surveying methods.

This paper describes the overall system and highlights early evaluations conducted over several surveys. The paper also described FRA's vision for the use of the data and how it will facilitate FRA's objective of improved public safety.

LiDAR-BASED SURVEYING SYSTEM OVERVIEW

FRA's LiDAR-based surveying system is installed on FRA's DOTX 218 Gage Restraint Measurement System vehicle shown in Figure 1 This system consists of five major subsystems - the measurement beam mounted on the rear end of DOTX 218, a high-resolution axle-mounted encoder to provide accurate distance measurements, a GPS antenna and receiver to accurately tag survey data with geo-location information, a Right-of-Way (ROW) camera for capturing imagery, and an operator's station for data storage and system operation. The survey system was built and developed by researchers at the Autonomy, Perception, Robotics, Interfaces, and Learning (APRIL) Robotics Laboratory at the University of Michigan and ENSCO, Inc.

Figure 1. FRA's LiDAR-Based Surveying System on DOTX 218

The measurement beam located at the rear end of the vehicle, shown in Figure 2, houses five SICK LMS 511 Pro Standard Resolution LiDAR sensors and a custom-made Inertial Measurement Unit (IMU) to capture the movement of the measurement beam. The LiDAR sensors feature built-in heaters for operations below freezing temperatures and reports intensity in a similar manner to monochromatic line scan cameras. The number of LiDAR sensors, as well as their locations and orientations, were calculated through a parametric study using three-dimensional simulations. In these simulations, the height of the measurement beam above rail was fixed while number, locations and roll/yaw/pitch of the LiDAR sensors were varied. For each simulation, the average and minimum LiDAR point densities were measured as number of points per square meter using ray casting methods. Simulation results indicated that employing five specifically oriented LiDAR sensors could achieve the required spatial sampling density.

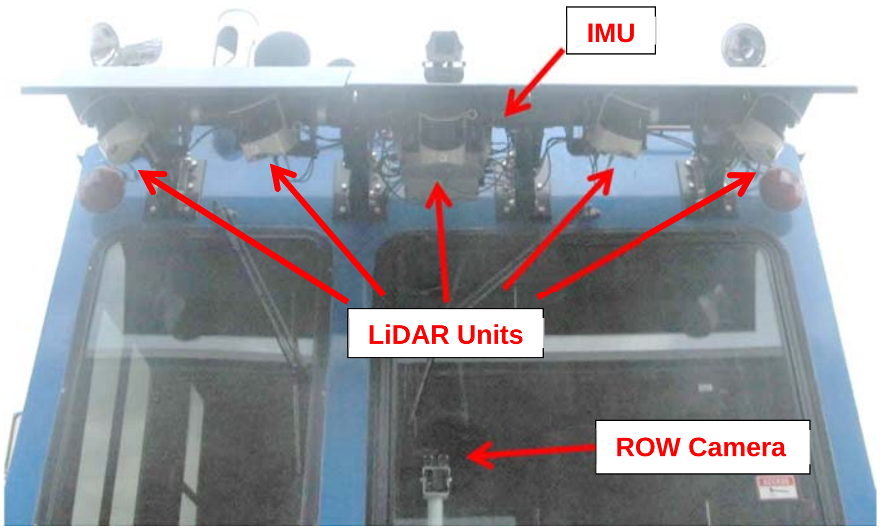

Figure 2. LiDAR-Based Surveying System Measurement Beam

Data is continuously streamed from all LiDAR sensors, as well as the IMU, encoder and GPS receiver, and recorded in real-time. The system can be operating in “continuous” mode during which all survey data is recorded and data around grade crossings can be extracted through automated feature recognition algorithms developed by University of Michigan researchers *(4)*. The data can also be buffered and recorded when events such as grade crossings are tagged manually by observers on the car. For each tagged event, LiDAR data, ROW images, location and railroad information available from survey data are recorded onto onboard storage devices for subsequent transfer to storage servers. Developers employed a message parsing and data handling scheme employed in robotic applications known as Lightweight Communications and Marshalling (LCM) to meet the demands of the number of data channels and high capture rates *(5)*. Figure 3 illustrates the LiDAR system software architecture established on DOTX 218. Real time or offline viewing of LiDAR data and ROW imagery is facilitated through a user interface, shown in Figure 4 that provides tools necessary for viewing of individual sensor outputs, representations of LiDAR data from any angle and playback of recorded data.

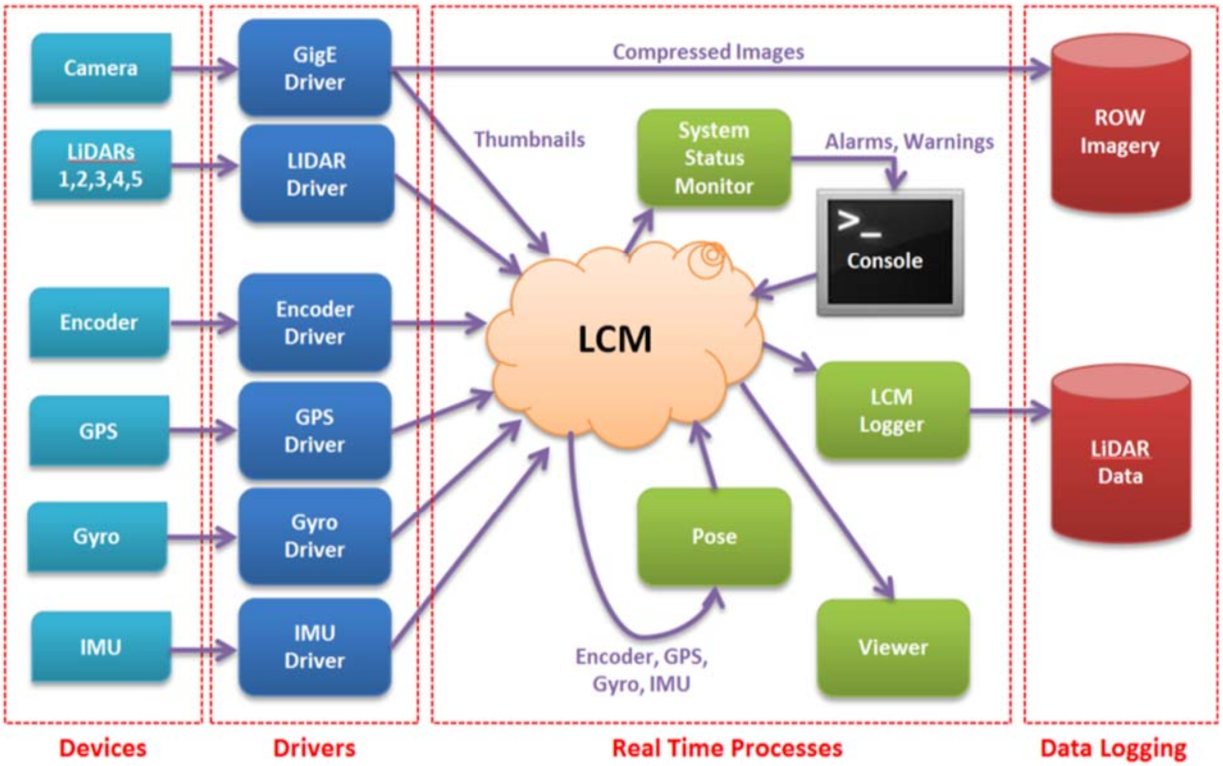

Figure 3. System Architecture of LiDAR-Based Survey System

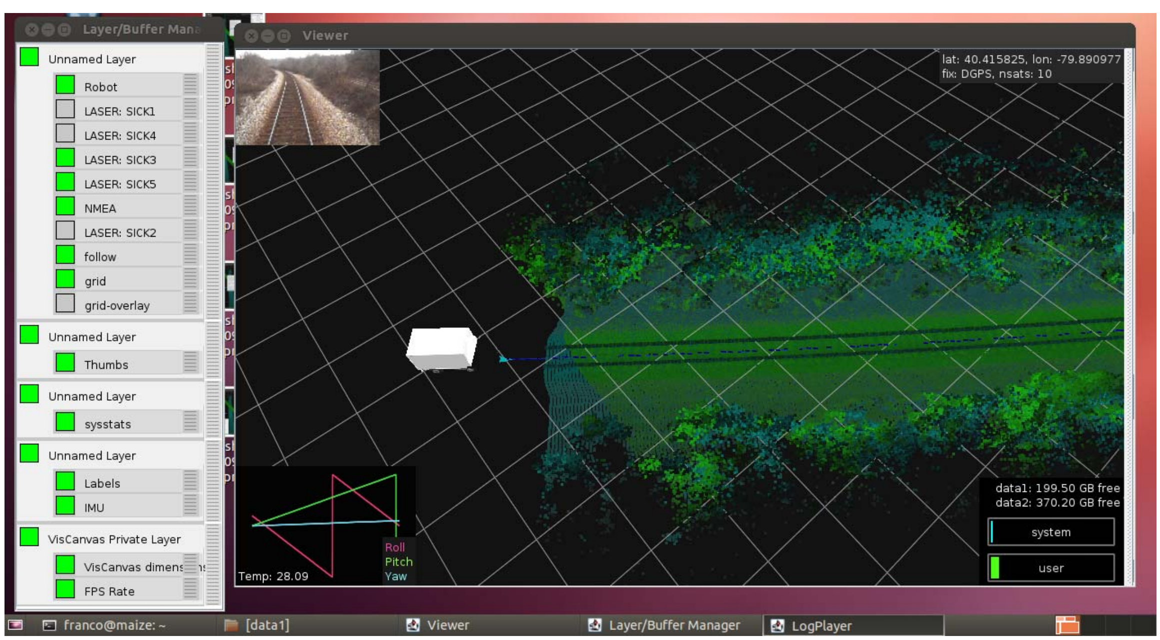

Figure 4. LiDAR-Based Survey System Onboard User Interface

A typical three-dimensional contour map of a crossing collected in an urban area is illustrated in Figure 5. The colors on the contours produced by the system in the vicinity of the crossings are indicative of near-grade elevation changes and reflectivity of objects and road markings.

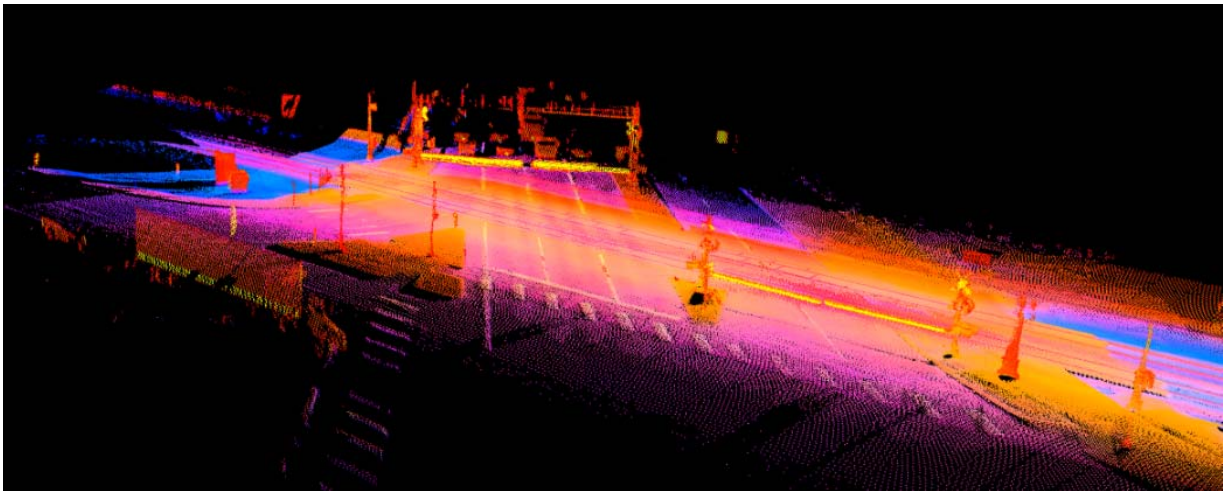

Figure 5. Three-Dimensional Map of Urban Grade Crossing Captured with LiDAR-Based System

The following data/parameters are identified for automatically detected grade crossings:

- Three-dimensional map of the crossing;
- A scalar parameter referred to as “planar deviation” that represents the profile of the crossing;
- Roadway/track crossing angle;
- Railroad/subdivision;
- Location of crossing expressed with GPS coordinates and milepost information;
- Track class;
- Track number;

In addition, a feature that identifies the presence of gates and whether the gates are working at the time of train passage is being integrated into the system at the time of paper publication.

During the ongoing development of this technology, survey data is transferred to a server hosted by the University of Michigan. Users can search for crossings of interest based on GPS location, planar deviation or measure of crossing evaluation or survey identification number. The user interface to the database is shown in Figure 6.

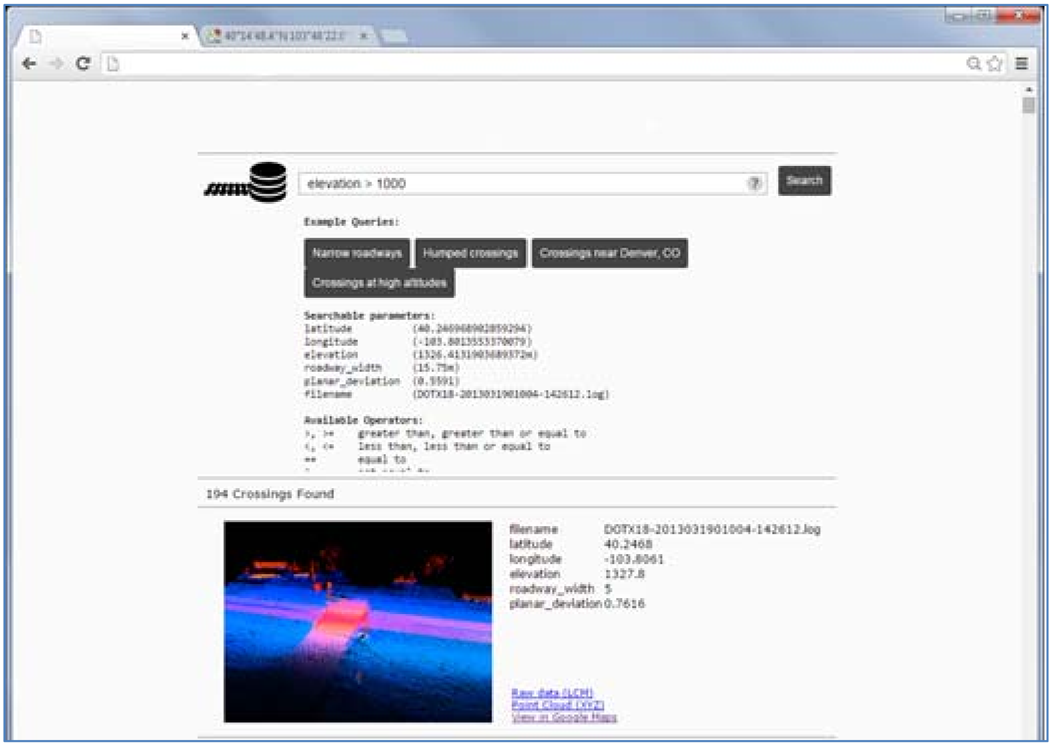

Figure 6. Grade Crossing Database Interface

Users can open a three-dimensional map similar to that shown in Figure 5 for viewing or download from the database interface. Crossings can also be viewed through satellite imagery available from Google services. As data is collected during ongoing FRA surveys, it is uploaded to the storage server for use by FRA or any FRA-designated party. FRA is in the process of migrating data storage from this temporary development server to a system that will be integrated with other FRA data management systems.

SYSTEM OPERATIONS

Following installation of the system in March 2013, FRA has evaluated the performance of the system while conducting several surveys as part of ongoing ORDT tests. Well over one-thousand grade crossings have been scanned during initial testing. Data from these crossing have been used to improve feature detection algorithms to enhance automated processing. In November 2014, FRA supported the comparison of survey data collected over a previously identified high profile grade crossing by both DOTX 218 and a ground-based survey crew using high-density LiDAR scans. RMS levels between the two surveys were very comparable. It should be noted that the DOTX 218 survey data was collected at no additional cost to survey operations being conducted at the time while the ground-based survey required trained surveyors several hours to collect and process the data, resulting in survey costs on the order of $3000. The relative cost differential of the survey methods demonstrates the value of the collected safety-related datasets.

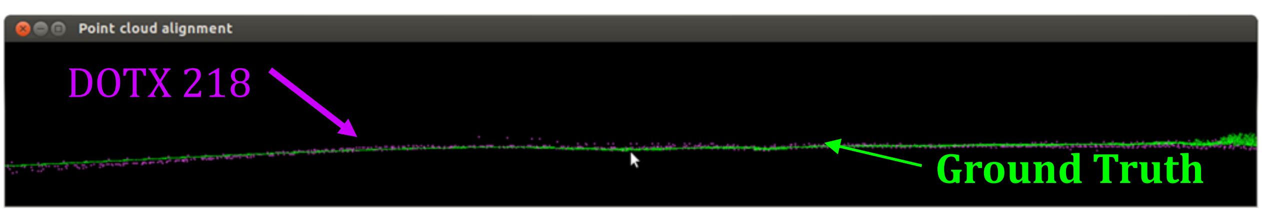

Figure 7. Cross-Section through DOTX 218 and Ground Survey Data Overlay

Preliminary assessment of the several thousands of grade crossing scans collected while passing through over one thousand crossings indicate that rural crossings exhibit the highest elevations observed to date. Several examples are illustrated in Figure 8. The planar deviations for the crossings shown in Figure 8 are on the order of 1.3; this should be compared to relatively "flat" crossings that have planar deviations on the order of 0.3. Although rural grade crossings do not present the same level of risk for train-motor vehicle collisions as high-traffic volume public crossings, a safety risk remains. As data of this nature is captured and analyzed, FRA is taking steps to integrate this data into regular operations and establish a mechanism for communicating crossings of concern to local municipalities and other stakeholders.

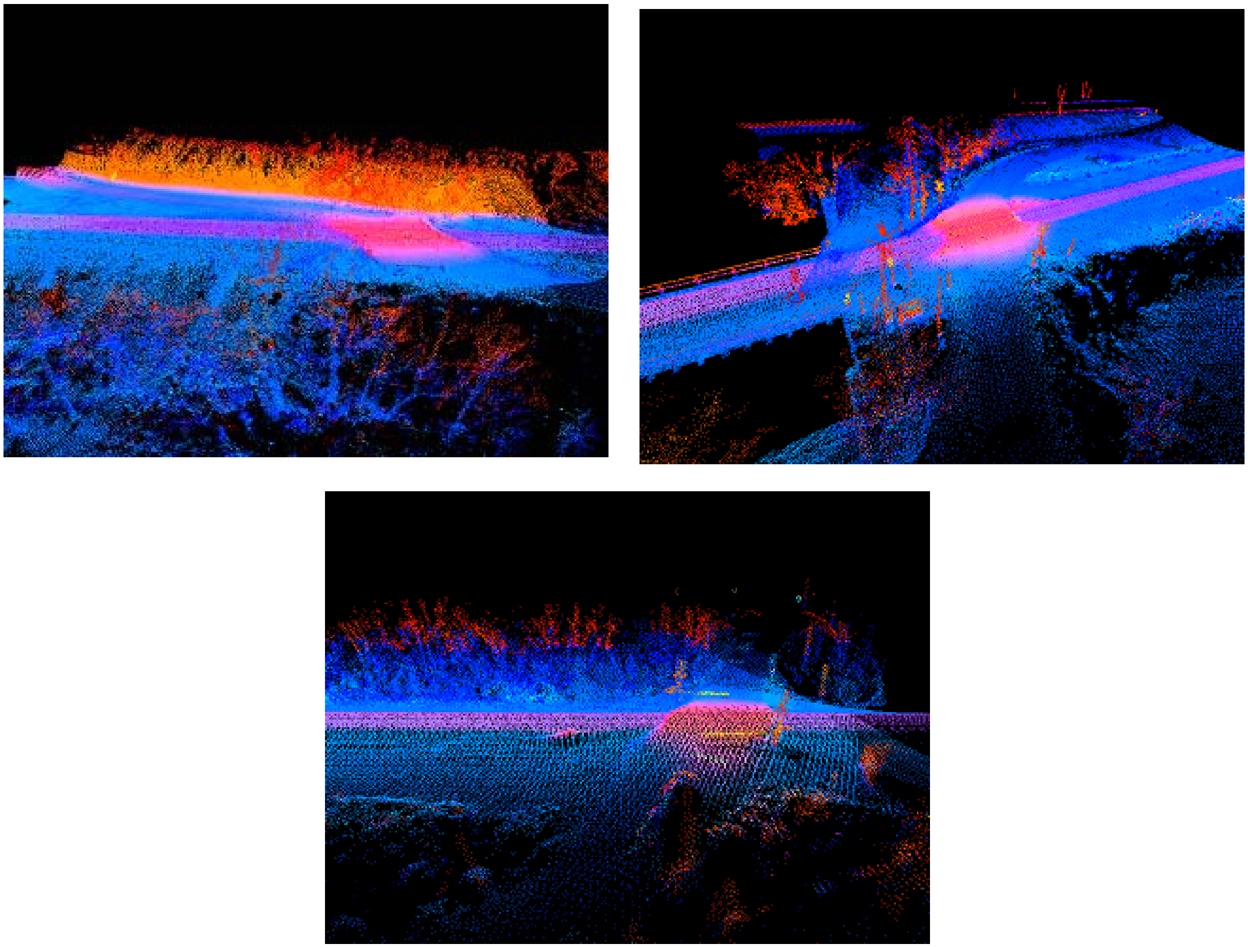

Figure 8. Examples of High-Profile Grade Crossings Surveyed with FRA's DOTX 218

NEXT STEPS

FRA is currently developing procedures to integrate the grade crossing survey data into existing information systems and utilities. Immediate efforts will focus on using the LiDAR-based data to update the FRA's National Grade Crossing Inventory. Currently, information regarding crossings is submitted to the FRA by states through a well-documented process *(6)*. It is anticipated that data produced by the survey system can be used to update incomplete inventory records as well as serve as a basis for auditing select information within the inventory. A process by which the original reporting agency is provided updates based on the LiDAR-based survey data is being formulated. As use of this approach continues, changes to the inventory to include parameters not currently captured, such as profile elevation or characterization of sight lines, may be considered. As at-risk crossings are identified, FRA can work with municipalities as well as navigation service providers to post warnings for motorists.

Data produced by the surveying system data can augment FRA's current GIS Safety Application *(7)* and the currently available Railroad Crossing Locator app to provide additional information on grade crossings. Safety-related information such as crossing elevations and, eventually, sight line characteristics could be accessed by the public to allow drivers to make informed decisions during route planning. Easy access to this information will also allow municipalities and railroads to prioritize crossing changes to improve safety.

ACKNOWLEDGMENTS

This paper represents the efforts of many people and organizations serving an ongoing initiative to promote grade crossing safety. In particular, the authors of this paper wish to thank Mr. Sam Alibrahim and Mr. Gary Carr of FRA's ORDT for their support of this initiative as well as Office of Safety personnel involved in these important efforts.

REFERENCES

1. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets, 2004 Edition*. Washington, DC. 2004.

2. U.S. Department of Transportation. Federal Highway Administration. *Railroad-Highway Grade Crossing Handbook - Revised Second Edition August 2007.* Washington, DC. 2007.

3. Van Arman, Pindar, and Al-Nazer, Leith. "Automated Technology for Rail-Bases Highway-Rail Grade Crossing Surveying." JRC2008-63033. Proceedings of the 2008 IEEE/ASME Joint Rail Conference, April 22-23, 2008.

4. Ranganathan, Pradeep, and Olson, Edwin. "Automated Safety Inspection of Grade Crossings." Proceedings of the 2010 IEEE/RSJ International Conference on Intelligent Robots and Systems, October 2010.

5. Huang, Albert, Olson, Edwin, and Moore, David. "LCM: Lightweight Communications and Marshalling." Proceedings of the 2010 IEEE/RSJ International Conference on Intelligent Robots and Systems, October 2010.

6. U.S. Department of Transportation. Federal Railroad Administration. *FRA Instructions for Electronic Submission of U.S. DOT Crossing Inventory Data; Grade Crossing Inventory System (GCIS) v2.0.* DOT/FRA/RRS-23. Washington DC. 2015.

7. U.S. Department of Transportation. Federal Railroad Administration. "FRA GIS Application." Web. June 2009. < http://fragis.fra.dot.gov/gisfrasafety >.

LIST OF FIGURES

Figure 7 – Cross-Section through DOTX 218 and Ground Survey Data Overlay

Figure 8 – Examples of High-Profile Grade Crossings Surveyed with FRA’s DOTX 218