ABSTRACT

Track geometry in rail hump yards requires a unique level of precision and maintenance to manage proper railcar velocity through the classification tracks. Traditional methods of monitoring yard geometry included periodic traditional surveys involving crews on the ground capturing individual static location measurements every 50 feet along each of the classification tracks. The method meets accuracy requirements but is disruptive to yard operations for weeks at a time and creates safety concerns.

Surveying And Mapping, LLC (SAM, LLC) worked with Union Pacific Railroad to explore alternatives to the traditional survey method. The paper will compare a method of surveying using LiDAR data obtained from an aircraft to the traditional methods of ground survey. The aerial approach offers the benefits of low...
impact on yard operations and no fouling of tracks during acquisition, greatly easing safety considerations.

This paper will present the challenges that exist in aeronautically gathering survey points on the rail between cars in an active yard and outline the control and data collection methods employed for the application. The results of the LiDAR generated survey will be compared to a traditional survey of one of the classification tracks. Conclusions will be presented on whether the aerial survey method meets the accuracy requirements for yard track geometry maintenance and areas identified for future study will be listed. Finally, a summary of the costs of each approach, in terms of direct cost and impact on yard operational efficiencies, will be presented.

INTRODUCTION

Railroads have need for periodic surveys of hump yards to accomplish various maintenance and engineering goals. Horizontal and vertical geometry of tracks and switches must be carefully maintained, in some respects with tighter tolerances than mainline track. Additionally, hump yards consist of hundreds of assets that must be maintained and periodically inventoried.

Traditional survey methods require a crew of two or three survey technicians to set up control stations on site for Real Time Kinematic GPS and several weeks occupying track collecting horizontal and vertical points along the rail head. Points are assembled into a 3D CAD file to be analyzed by railroad engineers to determine compliance with specifications and areas where maintenance is required to correct geometry defects. The GPS survey produces highly accurate survey points. Each point is positioned globally <=0.1'. This accuracy is an absolute accuracy meaning it can be referenced by any properly controlled survey anywhere on the globe within 0.1'.

Traditional survey methods are accurate but are disruptive to yard operations and present safety concerns with survey technicians needing to occupy track for weeks at a time.

Union Pacific teamed with Surveying and Mapping, LLC (SAM, LLC) of Austin, TX to explore alternative ways of surveying Strang Rail Yard located in La Porte, TX.

Surveying and Mapping, LLC

Founded in 1994, SAM is one of the largest surveying and mapping firms in the United States. The company has offices in Texas, Colorado, Ohio and Missouri, more than 750 employees and 150+ field survey crews. The focus of the company from the beginning has been early adoption of technology to build services most survey firms do not provide. We service primarily long corridor mapping across industries: rail, highway, oil and gas pipeline, and electric transmission. The company offers traditional survey in addition to LiDAR, aerial photography, subsurface utility engineering, and utility coordination for construction projects.

Aerial LiDAR and Photogrametry Basic Concept

LiDAR stands for Light Detection and Ranging. Similar to sonar and radar, LiDAR is a time of flight technology that bounces signals off of physical objects and measures the time needed for the round trip. In the case of LiDAR, the signal used is a single beam of laser light. Various types of LiDAR sensors exist but they all use either a sweeping or rotating laser head and can be used either in stationary or mobile applications. SAM uses three primary configurations of sensors including HDS (stationary), on a hi-rail vehicle, and mounted on aircraft, most typically a helicopter.
SAM utilizes a Trimble 68i LiDAR sensor for aerial applications. The sensor collects points at up to 400 kHz and a scan speed up to 200 Hz. The sensor sweeps back and forth, creating a sin wave pattern of points on the ground. By selecting and controlling the altitude and ground speed of the aircraft, the point density on the ground can be optimized for the application, making aerial LiDAR well suited for long and narrow project areas. Wide project areas can be accommodated as well by running several parallel flight paths to build width. The multiple point clouds acquired from the multiple flight paths are tied together using ground control points.

**Project Goals**

The primary goal of the project was to determine the viability of the process for collecting existing track alignment information in enough detail and with sufficient accuracy to fully support the track design tasks associated with a hump yard renovation without impacting the flow of traffic through the yard. The secondary goal is to determine the level of design support that the mapping product derived from this process will provide.

SAM, LLC developed an approach utilizing the latest aerial LiDAR sensor technology and a large number of flight lines at various orientations. According to the flight plan and calculations of track visibility angles, it was determined top-of-rail could be detected between the cars in the yard, thereby eliminating the need to clear track in order to perform the survey. From the points collected between the cars and throughout the rest of the yard, a complete CAD representation of rail alignment and rail profile throughout the entire yard was compiled.

While the known variables were carefully studied and a conservative acquisition plan with a high probability of success was created, SAM had not previously performed a mapping project utilizing LiDAR data from between stationary rail cars. We anticipated potential unforeseen variables that were not considered or unanticipated parameter values that would potentially negatively impact our ability to accurately map the rail and rail features.

Finally, Union Pacific planned on performing their own survey of a single track through the yard for comparison purposes.

**DETAILS OF STRANG YARD**

Union Pacific Strang Yard is located in La Porte in Harris County, Texas and features more than 20 miles of track and 60 switches. The yard was selected as the site for a pilot project to evaluate the accuracy of alternative survey methodology.
SCOPE OF PROJECT

Technical Requirements

The basic requirements for the mapping project were:

- Provide horizontal and vertical track alignments (centerline of rail) of all tracks located in the Strang Yard
- Provide track centerline positions at approximate 50 foot intervals on unoccupied track and between railcars on occupied track
- Provide locations of all switch points and frogs
- Provide locations of all retarders
- Set semi-permanent survey monuments within the yard
- All work shall conform to the American Society of Photogrammetry and Remote Sensing (ASPRS) for 1 = 20’ scale, 6-inch contour interval, mapping
- Mapping limits for Strang Yard represent approximately 200 acres
- LiDAR acquisition for entire project will be completed in a single mobilization, as all individual segments are to be collected in a single continuous effort
- The project horizontal datum will be relative to the Texas State Plane Coordinate System, Texas South Central, North American Datum 1983 (NAD83)
- The project vertical datum will be relative to the North American Vertical Datum of 1988 (NAVD88) using the National Geodetic Survey (NGS) Geoid 09

Ground Survey

Prior to the flight, SAM provided site preparation and aerial targeting required to control the areas for mapping and ground truthing. The following ground survey support was provided:

Prior to the flight, SAM set approximately nine at locations specified around the perimeter and within the project area. The locations of these panels did not require survey crews to foul track at any time.

Four of the nine control points set were placed in areas likely to remain undisturbed by rail yard activities. Horizontal and vertical control were established using Static and Rapid Static GPS methods with an error tolerance of +/- 0.03 feet horizontal, +/- 0.03 feet vertical. Levels were run between the nine ground control points.

SAM obtained multiple checks within the project area to validate the XYZ accuracy of the LiDAR survey. Simultaneous with LiDAR acquisition, survey field personnel positioned and operated a GPS base station on site.

LiDAR Acquisition

SAM sought to acquire LiDAR data with sufficient density to locate each top of rail between railcars with 32-inch gap and AAR Plate F and Plate H height and width dimensions.

Aerial LiDAR surveys are governed by The American Society for Photogrammetry and Remote Sensing (ASPRS).

Base Stations

Aerial acquisition was controlled with GPS base stations during the acquisition. Base station data was logged at 2 Hz and merged with GPS and IMU data recorded on-board the helicopter (GPS - 10 Hz and multiple receivers) using post-processed kinematic techniques to produce a highly accurate position for
the laser aperture.

Figure 2 – Side view of occupied track in point cloud

Figure 3 – Points Classified, Ground or Top or Rail
Quality Assurance/Control Process

Captured LiDAR data was recorded on removable data storage units onboard the aircraft. After acquisition, the data was copied to SATA drives and returned to our offices and copied to network drives. The data was post-processed and reviewed to confirm complete data acquisition coverage. Any seams, holes, or other unwanted artifacts were identified to assess the need for any data acquisition re-capture. Once approved, the data was archived and prepared for production.

Daily acquisition QC procedures were utilized to ensure data integrity from the mapping systems. The procedures included using a current satellite ephemeris for tracking the satellite constellation to plan scanning operations around the time of GPS Position Dilution of Precision (PDOP) spikes, adequate GPS static collection for receiver initialization and dynamic flying to initialize the Inertial measurement unit (IMU). During data acquisition, technicians constantly monitored the scanning system, checking the data logging rate, data storage capacity, GPS PDOP and imagery being collected.

GEOMETRIC CHALLENGES OF THE APPLICATION

Several challenges are present in the aerial scanning of rail geometry in an occupied rail yard. The project goal was essentially zero impact to yard operations. We expected significant traffic in the yard on the day of scanning, as on any normal operating day. We also expected some tracks to be occupied with no movement of railcars. This was the most challenging case.

The project began by examining the worst case geometry, a tall car with the narrowest gap allowed by AAR rules. The challenges including capturing data between stationary Plate H cars with a 32-inch gap, a coupler and hoses in the way while landing the laser on top of a 3-inch wide target. The solution was a combination of carefully selected geometry and volume of points.

Based on the angle of sweep and a 3D CAD model of the “worst case” geometry, we selected an angle best suited for the conditions. The angle was flown both directions and along with a third flight line in line with the rail, which was optimum for better than the worst case. Then we ran multiple parallel lines to the base lines to effectively carpet bomb the yard with laser points.

GENERAL FLIGHT PLAN

The flight plan and data acquisition resulted in a point cloud file with approximately 460 million points covering 200 acres: over 50 points per foot². The point cloud was collected over an eight hour period. As expected, traffic on each track was variable. A considerable number of tracks were vacant for a significant amount of time during data collection that the top of rail is clearly visible along entire length of track.

Other sections of track were occupied for the entirety of the data collection. On these sections of track, we were successful collecting enough points in the gap. The goal was for a minimum of six points on every top of rail between every gap.

LIDAR DATA PROCESSING

Initial Processing

GPS/IMU Geo-referencing and Data Calibration - Once the collected data arrived, it was immediately processed and verified. IMU data was processed and checked for gyro bias, systematic errors, and positional error.
Laser Point Processing

The calibration parameters were systematically checked and refined by estimating the residual boresight angles (roll, pitch, heading) and scanner scale corrections from overlapping strip areas, minimizing the inter-strip differences using a least squares approach.

LAS data was then projected into the required coordinate system. Simultaneously, the elevations were transformed from ellipsoidal to orthometric heights by applying the latest GEOID models and all data was geo-referenced to appropriate State Plane Coordinate System NAD83.

Accuracy Testing

Once the LAS files were created for a line, the data was tested to ensure it met accuracy standards for the project. The ground survey information collected was used as an independent check of the LiDAR accuracy (minimum six points required). SAM, LLC recommended not less than six well distributed check points throughout the project. The survey test points were located on hard surfaces with well-defined features. Using the conventional survey data, a statistical comparison test was run to verify the geodetic positioning of the LiDAR data met the accuracy standards required for the project. The minimum absolute vertical accuracy specification of the project was +/- .1 ft. vertically, and 90 percent of the points tested shall be within this accuracy.

LIDAR DATA CLASSIFICATION AND FEATURE EXTRACTION

Data Filtering

Once the initial post processing of the laser and imagery data was completed, data was ready for project set up and initial automated filtering and classification.

Automated Filtering

Once the GPS/IMU data was processed and LiDAR data had gone through the boresite (correct for all roll, pitch, and yaw) the LiDAR data as sent to SAM, LLC’s LiDAR processing technicians for automated filtering and classification. Automated filtering of the data is the first process necessary to complete the bare earth ground processing and prepare the topographic mapping.

Manual Editing

Effective auto filter routines can produce very clean LiDAR classifications. It is, however, always necessary to complete a manual review and edit of the data. The manual edit process eliminated any remaining anomalies and misclassifications within the data set.

Feature Extraction and Planimetric Mapping

While automated filtering is a necessary component of each project and produces useful point cloud products, additional processing was required to produce all deliverables requested for the project. The process included collection of visible planimetric features in the specified collection area in accordance with the features required by Union Pacific. Vector mapping was produced for each of the planimetric features and delivered as a DGN drawing file for each line.
QUALITY ASSURANCE/CONTROL PROCESS

Feature Extraction Quality Control

At the time of classification and feature extraction, LiDAR technicians used LiDAR data processing and feature extraction software to accurately identify, classify and locate specific features. Multiple Quality Control (QC) steps are built into our feature collection process. The methodology used for the project was
designed to ensure QC steps for feature extraction and attribution meet or exceed the requirements set forth in the RFP. The major QC components of feature extraction process are summarized below.

Use of Workflow Checklists

Our software suite is designed specifically to ensure QC is part of each step in the process. One key feature is the use of well documented and managed workflows or cues which define and control each step of a given task. The work flow checklists serve several purposes in the QC process including:

Process Repeatability and Consistency

The software guides each technician through the required processing steps. Each technician uses the exact same process. Cues encode flow logic requiring steps to be executed in a specific order. This ensures each part of the collection process is repeatable and consistent regardless of the number of technicians working on the project.

Process Tracking

The software automatically records a time-stamped history of who executed each step on each workstation creating a time and date trail for any change recorded to the database during the project. The records are reviewed to ensure each step in the collection process is completed.

Access Control

Cues also control access such that only a person who is a member of a specific processing group can execute a specific step (for example, if technician X is not a member of the QC group, he or she cannot execute the QC step). This also limits use of any data block to one person for any given task. It is not possible for two technicians to complete tasks at the same time on a given section of data and overwrite each other’s updates.

PROJECT DELIVERABLES

Deliverables included:

- Digital Orthophotography Image files
- CAD file of planimetric features including track alignments
- Bare-Earth, DTM (Digital Terrain Model)
- Classified LAS files
- AT Report

ADDITIONAL USES OF ACQUIRED LIDAR DATA

Because the sensor picks up points at all locations within its field of view, the value of the point cloud is not limited by the relatively narrow scope of the project. Once LiDAR data is acquired and controlled, it is archived for future use at any time. If the client needs additional survey features extracted, it can be done in the office at any time requiring no further field presence. Features that can be extracted from the Strang Yard data set that may be of value to a railroad include:

- Relative elevations of bridges to top of rail
- Location of power poles
- Sag of transmission and distribution electric lines
- 3D linework of existing buildings and other structures
- Topographic survey
CONCLUSIONS

Union Pacific compared a ground survey of a single track to the 3D survey drawing produced by SAM, LLC from the aerial LiDAR data. The two surveys matched with enough precision determining aerial LiDAR acquisition as a viable alternative to traditional surveying methods in busy yards where impact to operations is disruptive.

Every yard and application is different, however, when comparing costs of traditional survey versus aerial LiDAR, significant cost savings related to yard operation efficiencies and intangible savings of enhanced safety, as well as the ability to revisit the data to extract additional information as needed provides significant value to rail operators and maintenance.

ACKNOWLEDGEMENTS

The author is grateful to the senior management of SAM, LLC for the support and encouragement to participate and present at this conference and to Kevin Hicks, General Director Design at Union Pacific Railroad for his desire to explore alternatives to traditional survey and support of this presentation. Thank you to Matthew Thomas who collaborated with the author to develop and refine the unique data acquisition plan for this project. I also thank Jaime Higgins, Peggy Cobb, Bryan Philips, and Laura White for providing additional material and technical assistance during the preparation of this paper.
REFERENCES


Aerial LiDAR Survey of Track Geometry in Union Pacific’s Strang Yard

Christopher M. Villar, PE
Surveying and Mapping, LLC
**SAM Background**
- **FOUNDED IN 1994**
- **650+ EMPLOYEES**
- **RECOGNIZED IN GEOSPATIAL INDUSTRY**  
  - #1 Surveying and Mapping in TX & LA (ENR 2014)
  - #97 Top Design Firms (ENR 2014)
  - 2014 ACEC Gold Engineering Excellence Award (National & TX)
  - 2015 ACEC Gold Engineering Excellence Award (TX)

**Corridor Focused**
- Transportation
- Utilities
- Rail
- Electric
- Oil & Gas

**What is LiDAR?**
- Light
- Detecting
- And
- Ranging

**LiDAR Acquisition Methods**
- FIXED WING
- ROTARY WING
- MOBILE
- STATIC TERRESTRIAL

**LiDAR System Components**

**Point Cloud Density Comparisons**
- 1 to 40 PPM
- 10 to 80 PPM
- 100 to 3000 PPM
- > 1000 PPM
PROJECT DELIVERABLES

- DIGITAL ORTHO IMAGE FILES
- CAD FILE OF PLANIMETRIC FEATURES
- CLASSIFIED LAS FILES
- AT REPORT