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Application of the LIDAR System for Track Geometry Inspection

Mehdi Ahmadian, Masood Taheri Andani, Josh Muñoz, and Carvel Holton,
TTCI's Affiliated Laboratory Program, Virginia Tech, and David Davis, TTCI

Summary

As part of Transportation Technology Center, Inc.'s (TTCI) Affiliated Laboratory Program, Virginia Tech has investigated the applicability of light detection and ranging (LIDAR) technology for track geometry inspection.

A laboratory-grade LIDAR system with four Doppler channels, developed at Railway Technologies Laboratory, was tested on board a track geometry car. The data collected during the tests was processed using various signal processing techniques to obtain the measurements of interest; in this case, track elevation, profile, alignment, and gage variations. Comparing the LIDAR measurements with the data collected on board the track geometry car using standard instrumentation shows a close match both in magnitude and trends. The results indicate that the LIDAR system can serve as a reliable, noncontact track monitoring instrument for use over substantial track distances in inclement weather and harsh conditions with minimal operator supervision.

The ability of LIDAR to measure the speed of a moving rail vehicle in a noncontacting manner is extended to capture the lateral and vertical irregularities of the track itself. Using two pairs of lenses to capture speed signals from both rails individually, the track speed, curvature, lateral and vertical geometry variations on each side are determined. LIDAR lenses are installed with a slight forward angle to generate velocity signals that contain two components: (1) the left and right track speeds, and (2) any lateral and/or vertical speed caused by track motion and/or spatial irregularities. The LIDAR system collects and outputs the track information in the time domain. Separating each speed component (forward, vertical, and lateral) is possible because of the inherent separation of each phenomenon with respect to its spatial or temporal frequencies and related bandwidths. For the measurements to reach their full benefit in practice, the LIDAR data must be spatially located along the track. A data-mapping algorithm to spatially match the LIDAR track geometry measurements with reference spatial data, such as that available for Positive Train Control, would accurately locate the measurements along the track.

Additional efforts are needed to further investigate the integration of the prototype LIDAR system that was used for this study into an industrially viable platform for the rail geometry cars and/or hi-rail class vehicles operated by U.S. railroads. Recommendations as a result of this investigation are for (1) the prototype architecture to be used to develop a compact and ruggedized system readily accessible to the railroad industry, and (2) the feasibility and applicability of using the system to be assessed on board hi-rail trucks or portable units that can be operated remotely down to below walking speeds.



INTRODUCTION

With funding from the Association of American Railroads and working with various specific railroads, Railway Technologies Laboratory has developed and evaluated a noncontact inspection method for detecting track irregularity variations as extracted from measurements of track speed. Four slightly tilted LIDAR optics are used to measure the vehicle speed and vertical and lateral profiles of the left and right rails at the same time. Virginia Tech’s LIDAR system previously shown to be an effective replacement for wheel-mounted encoders,^{1,2} is now shown to be a reliable instrument to monitor track geometry parameters.

LIDAR as used for speed sensing is an accurate, noncontact speed measurement technique that uses the Doppler frequency shift imposed on laser radiation reflected from a moving object. Based on the Doppler frequency shift, the speed of a moving object is determined from a simple equation ($\cos \alpha \times 579 \text{ MHz/mph @ } \lambda = 1.5\mu\text{m}$).

Tilted Configuration of LIDAR Lenses for Track Geometry Measurement

A Doppler sensor measures the velocity vector aligned with the axis of the laser beam. The sensor is typically mounted in a way that the laser strikes perpendicular to the moving object. In this case, the object velocity is identical to the velocity measured by the laser. In the proposed embodiment, however, LIDAR sensor is not positioned exactly perpendicular to the gage surface, but the laser strikes the rail at a forward angle of θ . In addition, the lens is not installed at the same height as the gage surface because of the mounting limitations; thus, the laser direction also has an inclination angle of ϕ relative to the surface of the object (see Figure 1).

With this configuration, the sensor’s reading has a vector component of forward track speed as well as a vector component that represents lateral or vertical track variations that depend on the lens positioning and angles. As an illustration, the lens configuration used for track speed and lateral irregularities of the right rail is shown in Figure 1. In this case, the velocity measured by the right sensor, V_{mR} is related to the right rail forward speed V_R and right lateral variations rate V_L as:

$$V_{mR} = \frac{V_R}{\cos\phi} + V_L \sin\theta$$

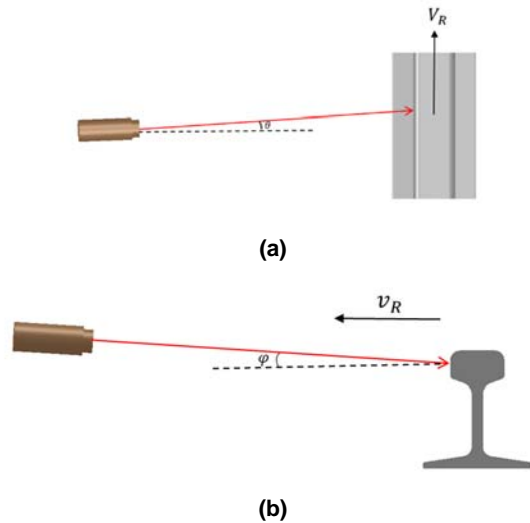


Figure 1. Velocity Measurement of the right LIDAR Sensor used for Lateral Irregularities (a) Top View of the Embodiment and right Rail, (b) Front View of the Embodiment and right Rail

LIDAR Data Mapping

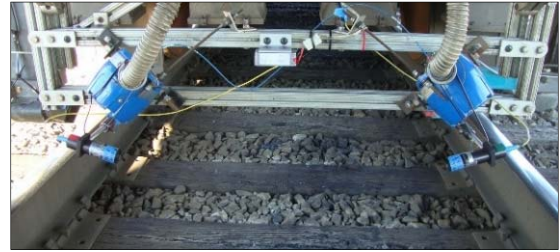
LIDAR measurements are made in the time domain. But for the data to be beneficial for track administrators, geometry data must be presented in the spatial domain. A data-mapping algorithm is developed to find the correct location of LIDAR measurements. This algorithm includes steps for (a) obtaining spatial track data for reference use, (b) constructing the LIDAR signature data in the spatial domain to be correlated, (c) dividing the LIDAR track data into spatial segments, (d) comparing the reference data to the measured track LIDAR data segments to identify the location of the segments, and (e) stretching or shrinking (re-scaling) the LIDAR data to account for local spatial deviations in calibration value(s).

System Installation

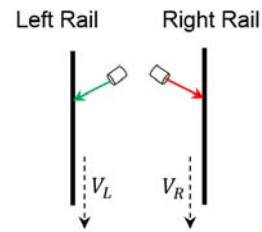
The LIDAR frame is body-mounted to the metrology car, as Figure 2 shows. This frame supports and orients the four LIDAR lenses. The two lenses primarily employed for measuring train speed are shown in this embodiment enclosed in blue housings. These lenses are oriented toward the gage corner and point opposite to the forward direction of travel. The two lenses that capture rail lateral variations are installed below the blue housings. As mentioned earlier, they are oriented at a shallow backward and vertical angles to allow for a simultaneous measurement of track speed as well as lateral deformation. Figure 3 illustrates the configuration of these two lenses as used for the lateral measurements. As shown, each lens measures the track speed in addition to left or right lateral deviations from the mean of the track gage. As the train moves down track, lateral deviations in space are seen as time varying displacements. The time variance gives rise to a lateral velocity component that is sensed by the LIDAR as a Doppler frequency shift. Figure 4 illustrates the orientation of the lenses used for measuring vertical deviations. The LIDAR processing systems are located in the cab of the metrology car and are connected to the lenses below the car via fiber optic cables.



Figure 2. Carbody Mounted Configuration of the LIDAR System (The frame supports four LIDAR optics for the purpose of lateral and vertical geometry measurements.)



(a)

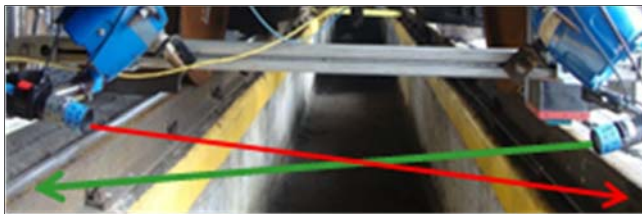


(b)

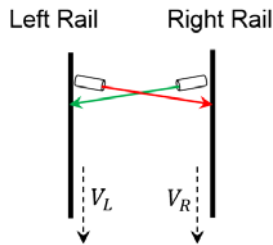


(c)

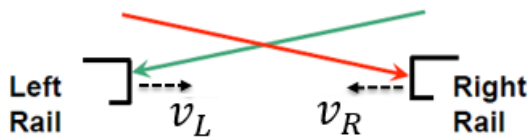
Figure 4. Vertical LIDAR Optics used for Vertical Geometry Measurements (a) Beams Target the Gage Corner of the Rails, (b) Left and Right Track Speeds are measured, (C) Rates of Left and Right Vertical Geometry are observed by the Vertical Lenses



(a)



(b)



(c)

Figure 3. Lateral LIDAR Optics used for Lateral Geometry Measurements (a) Beams Target the Gage Face of the Rails, (b) Left and Right Track Speeds are measured, (c) Rates of Left and Right Lateral Geometry are observed by the Lateral Lenses

RESULTS

LIDAR data for the current report was collected from a round-trip itinerary between Roanoke and Lynchburg, Virginia. Wheel-mounted encoder speed data, onboard inertial measurement unit (IMU) spatial data, and gage sensor data were also collected for evaluation of the spatial data derived from the LIDAR data. Data was accumulated over multiple sections of both tangent and curved tracks for analysis.

The local alignment variations measured by the lateral LIDAR optics (Figure 3) for the right rail is compared with IMU's alignment measurements in Figure 5 for a distance of a 0.7 mile. IMU curvature is also simultaneously plotted in Figure 6 to distinguish the curved rail from tangent rail. The LIDAR data corresponds reasonably with IMU data in measuring the alignment deviation and its trend. However, a perfect correlation is not achieved because the two measuring systems use different sensing, detection, and processing techniques. The gage variations are also computed for the same piece of track, and the results are compared with an onboard gage sensor in Figure 6. A closer match is observed between the two units in assessing the gage variations. In a manner similar to that used for the lateral geometry parameters, vertical parameter deviations, such as profile and superelevation variation, can be measured by using the vertical LIDAR optics (Figure 4).

Figure 7 shows the superelevation variations derived from the LIDAR measurements compared with those from IMU data over a short section of track. Although the two systems monitor the same trend of variations, some discrepancies are evident between the results. A more exact spatial match cannot be achieved using the current data because the measurements were made by asynchronous instruments.

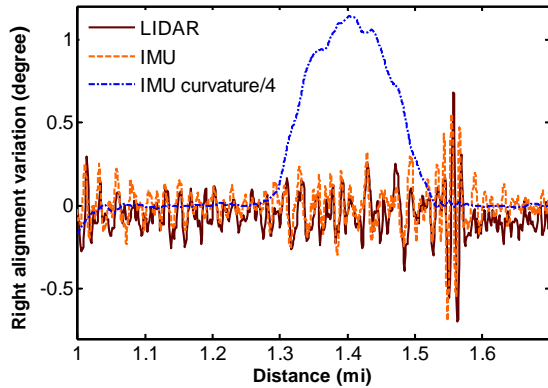


Figure 5. Right Rail Alignment Measurements made by Lateral LIDAR System and compared with IMU Data

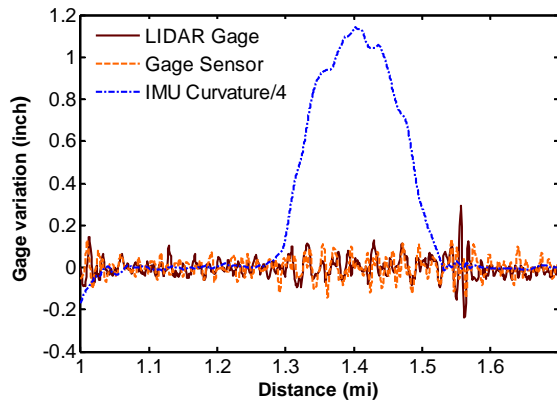


Figure 6. Gage Variations measured by the Lateral LIDAR Optics are compared with the Onboard Measurements made by the Gage Sensor

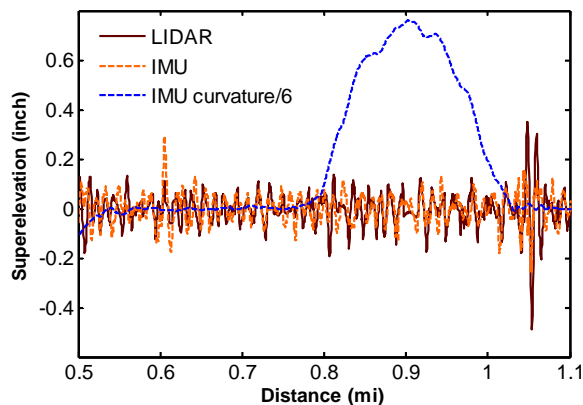


Figure 7. Superelevation Variations measured by Vertical Optics are compared with IMU Data

The developed data mapping approach was further evaluated over a longer stretch of 12 miles of track. IMU curvature is used as reference (or “signature”) data. Three LIDAR data segments of different lengths are then analyzed for the purpose of correlation with the asynchronously acquired IMU signature. The first segment contains a right curve in about 2 miles of the track. The second segment has two curves, including one right and one left curve over 1.5 miles. The third segment includes four curves of differing radii. The LIDAR data for these three segments are then overlaid on the IMU data in Figure 8. The plots show a comparable measurement accuracy between the two sensors.

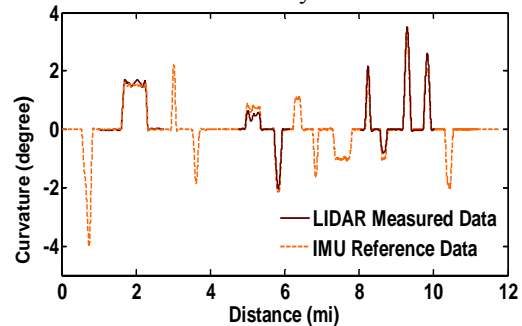


Figure 8. LIDAR Curvature Data is positioned with respect to a Set of IMU Reference Data using the Developed Mapping Algorithm

CONCLUDING REMARKS

A body-mounted LIDAR velocity measurement system was shown to be capable of measuring lateral and vertical spatial deviations of track rails. The method is an adaption of the LIDAR technology developed at Virginia Tech and already proven to be effective for noncontact measurements of track speed and distance. Data from field tests was used to demonstrate the capability of developed signal processing algorithms to identify and separate the different vector speed components to calculate the variations in track geometry. The results showed a good agreement between LIDAR measurements and other established measurement methods.

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