Plenary Presentation

Application of Non-contacting LIDAR Sensors for Track Condition Monitoring and Asset Management

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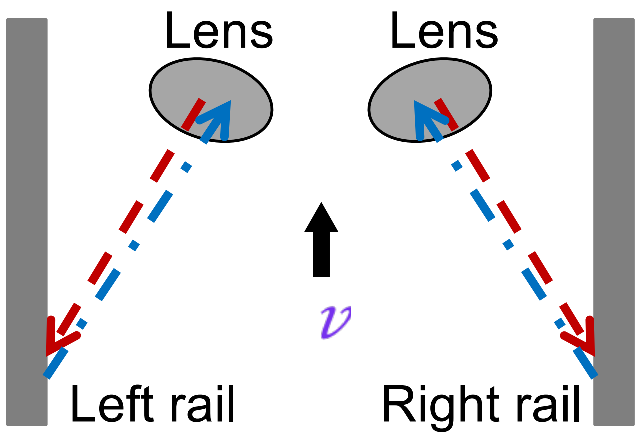
The primary focus of this presentation is on application of LIDAR sensors for assessing railroad track condition

- Brief introduction on LIDAR
- Track geometry applications
- Rail lubricity applications

LIDAR: Light Detection and Ranging

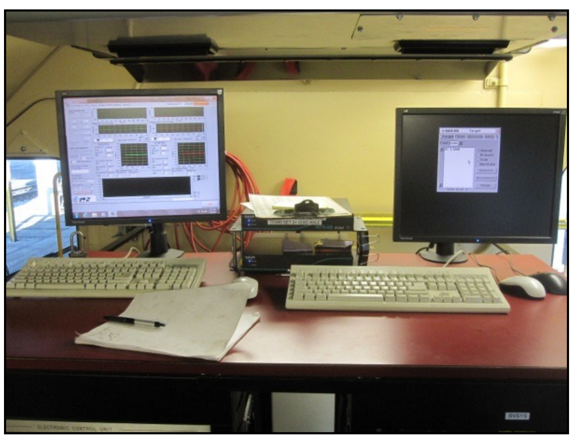
- **Definition:** A non-contacting method for determining the presence, location or properties of objects of interest using reflected or emitted light
- **LIDAR Classifications**
  - Passive, Remote Sensing: Analyzes light emitted by an object or ambient light reflected from an object to determine object parameters (e.g., Earth Sensing)
  - Active Sensing: Uses a light source to illuminate an object and determine object properties by analyzing changes in the reflected Light.
    - Incoherent Light Sources (e.g., structured lamps and cameras)
    - Coherent Light Sources – Lasers
      - Continuous Wave (CW), Pulsed, Modulated
    - Detection: Incoherent (e.g., Intensity) & coherent (e.g., doppler velocimetry)

Virginia Tech uses Doppler LIDAR technology to perform non-contact measurements from railway vehicles

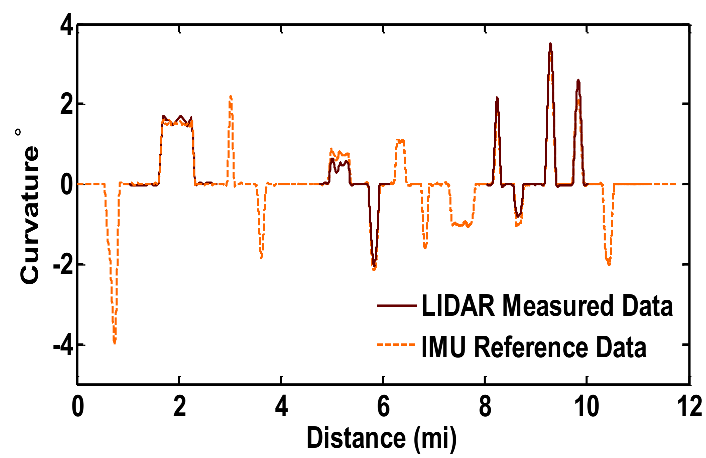


1. Doppler shift reading

2. On-board processing

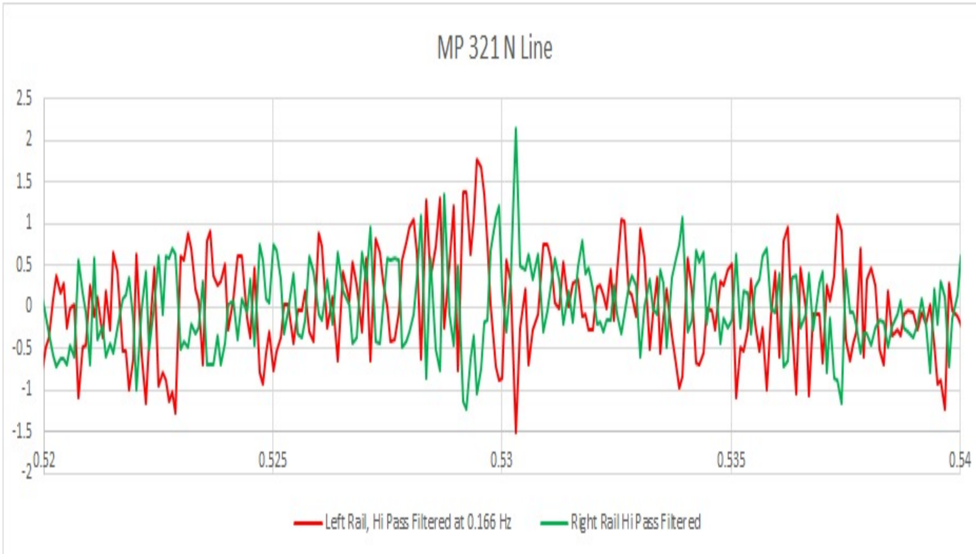


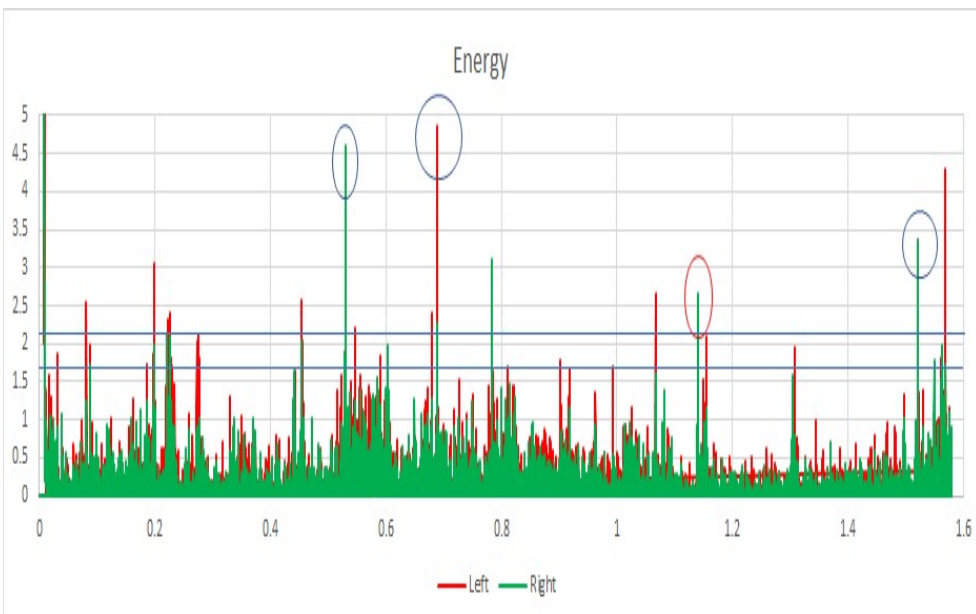
3. On-board speed readout



4. Post-processing

Researching Rail Stability Dynamics on "Hy-Rail" Vehicles using VT's Fiber Optic Research Lidars

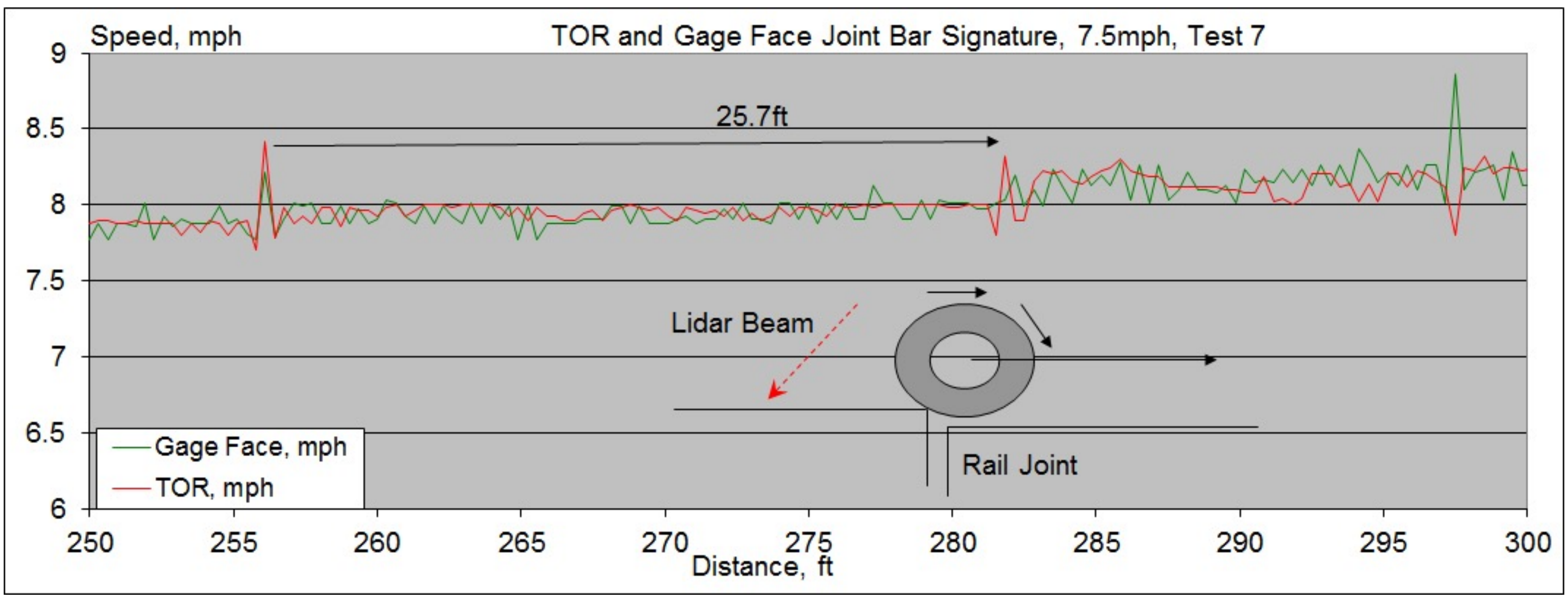




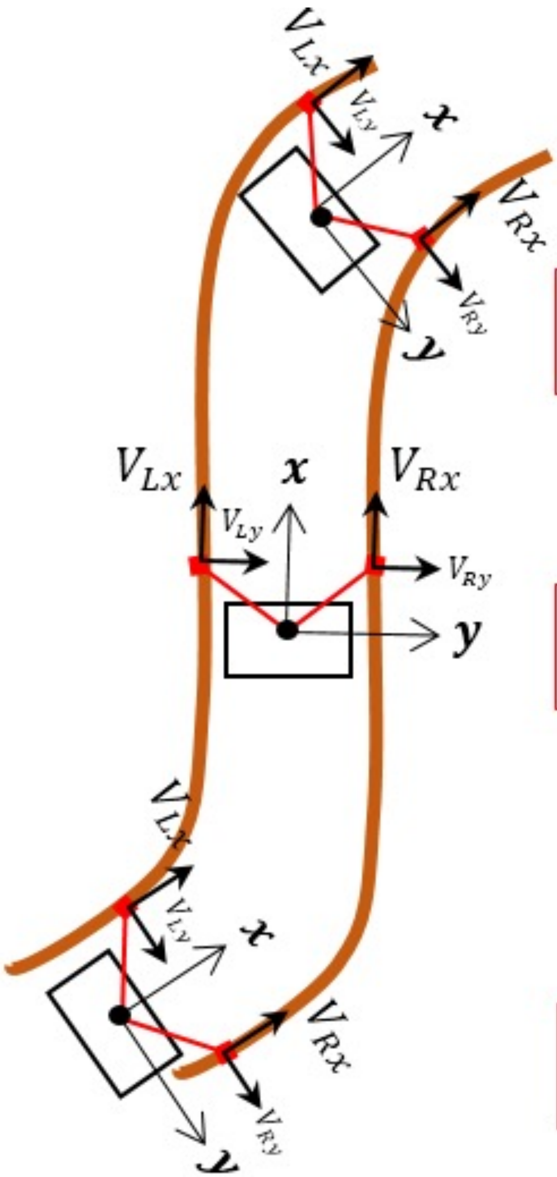
Lidar sensors can be used to potentially detect "soft" joints, by measuring track movement

- **Total Lidar Signature depends on the combined "Health" of the Ballast, Tie, hold-downs and Joint Bar Structure Itself.**

Characteristic Doppler Lidar Velocity Signature of a Track Joint bar



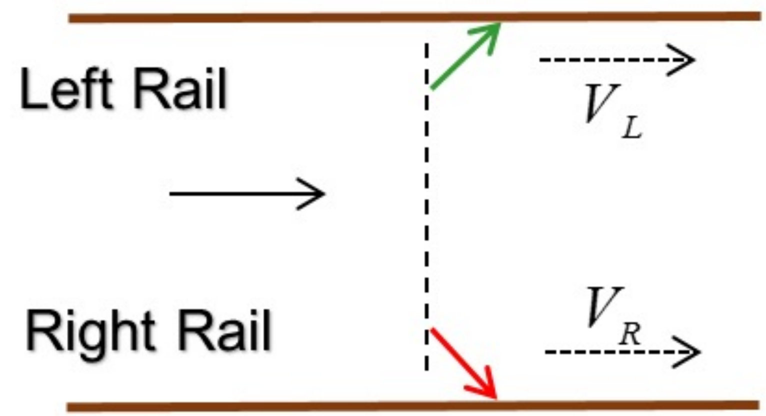
Track instantaneous curvature is accurately measured by detecting the left and right forward speeds

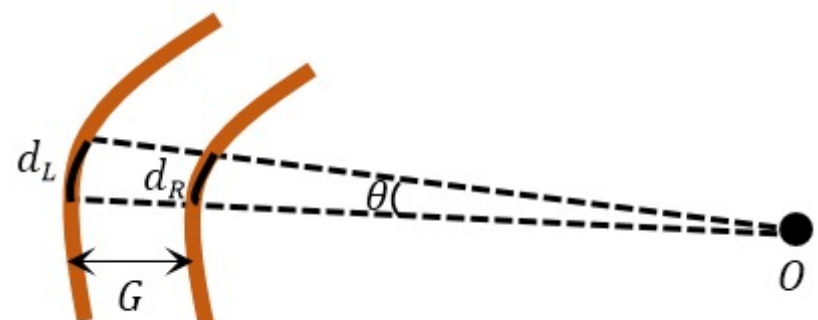


$V_{Lx} > V_{Rx}$

$V_{Lx} = V_{Rx}$

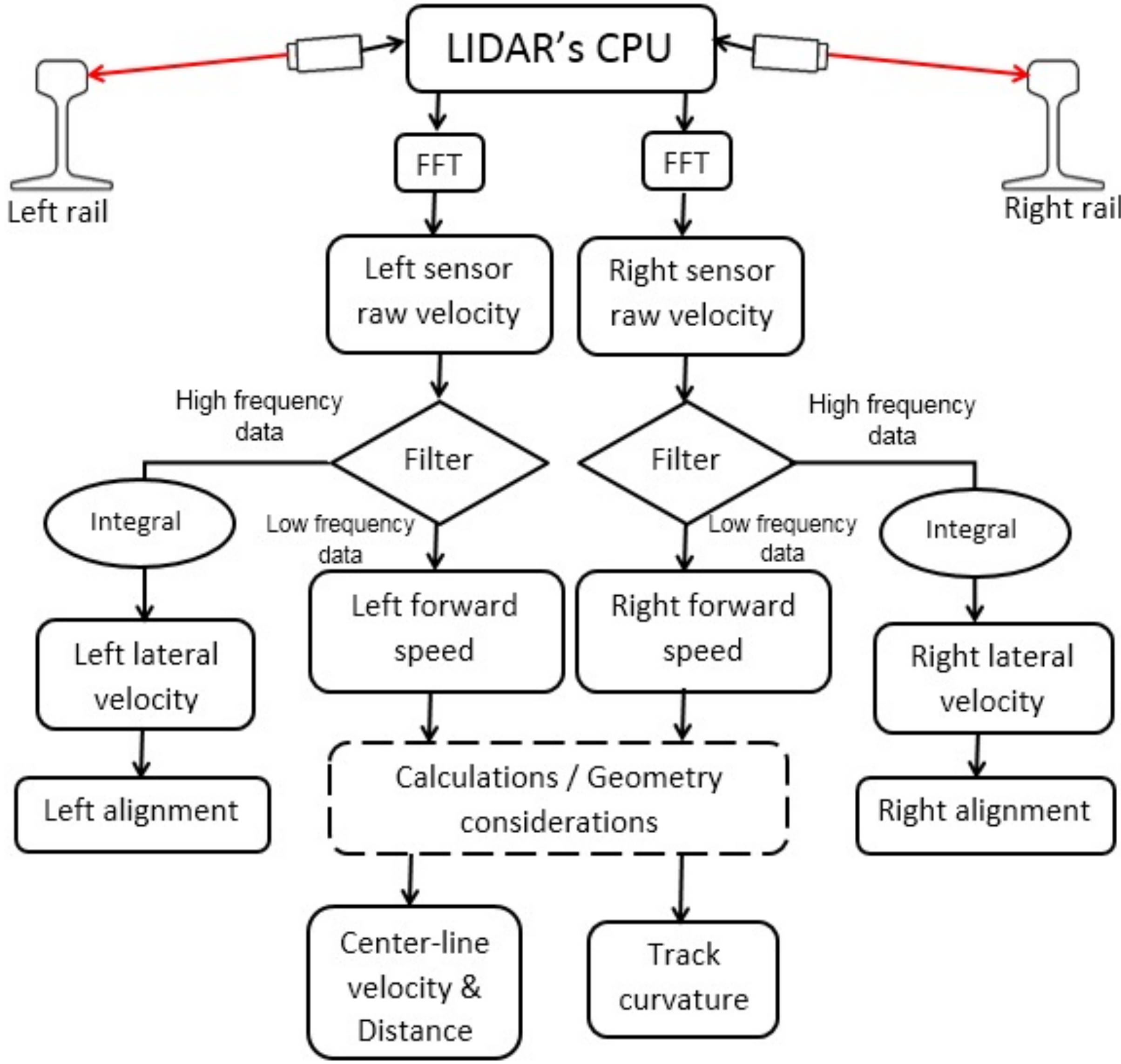
$V_{Lx} < V_{Rx}$



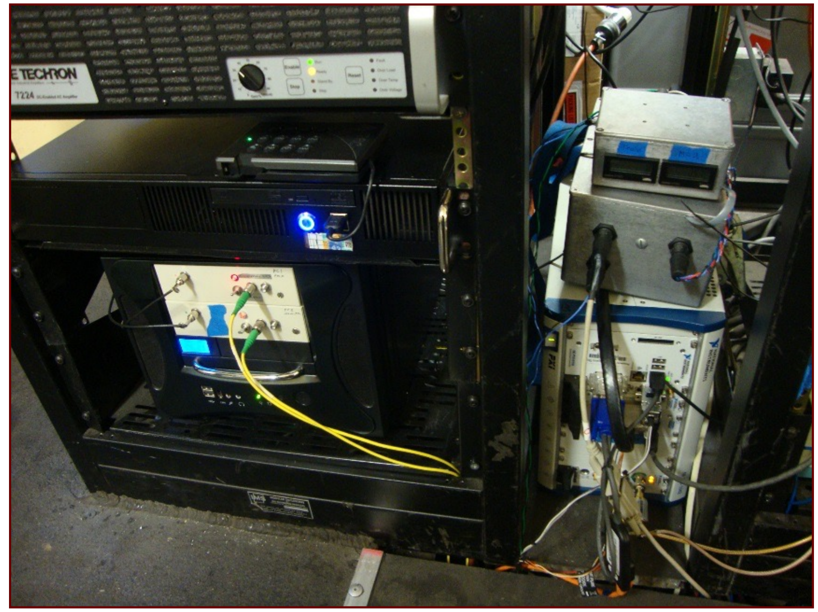


$$\theta \approx \frac{d_L - d_R}{G} = \frac{(V_{Lx} - V_{Rx})dt}{G}$$

Track Gage variation and Alignment are established through the separation of lateral and forward speed components



VT's LIDAR system is tested onboard a geometry car for 7000 miles on revenue service tracks



LIDAR frame

Encoder on the left rail of the lead truck middle axle

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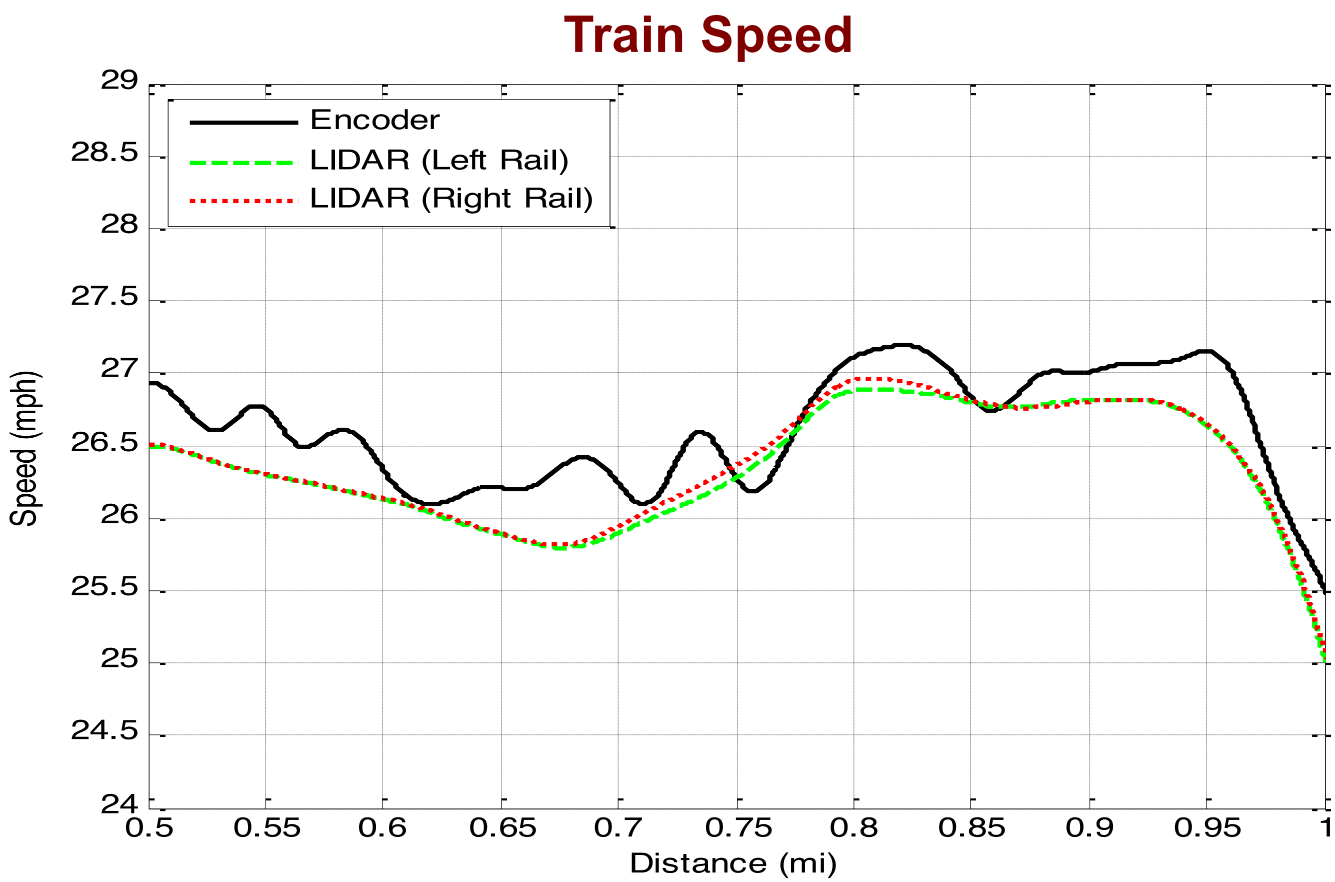
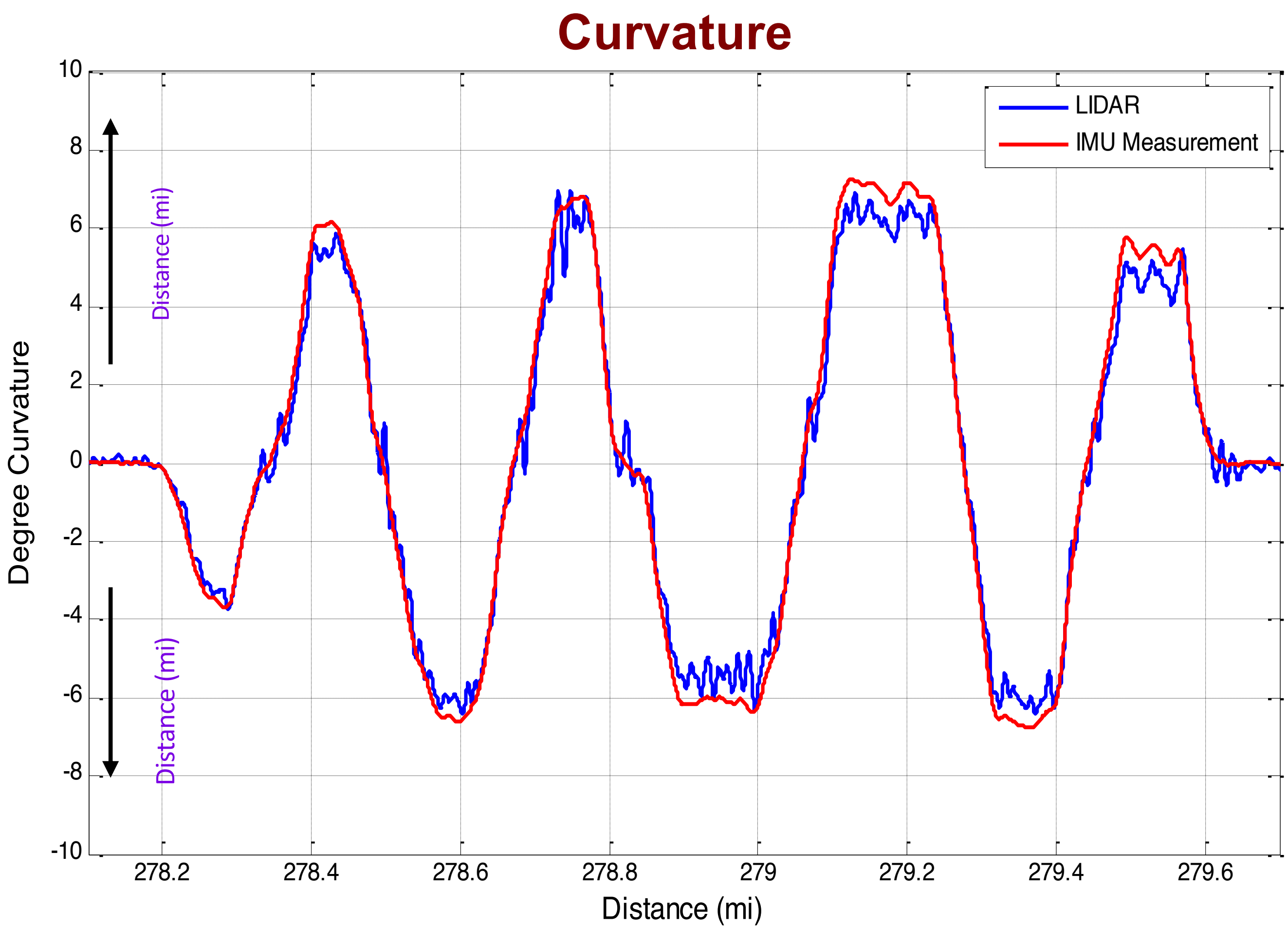
VT LIDAR records velocity with higher accuracy and less fluctuations than wheel-mounted encoders



- Accurate velocity measurements at speeds as low as 0.1 mph
- Smoother velocity data generates more accurate curvature measurements

VT LIDAR provides accurate curvature measurements



LIDAR's track curvature measurements can be made at speeds far lower than IMU's

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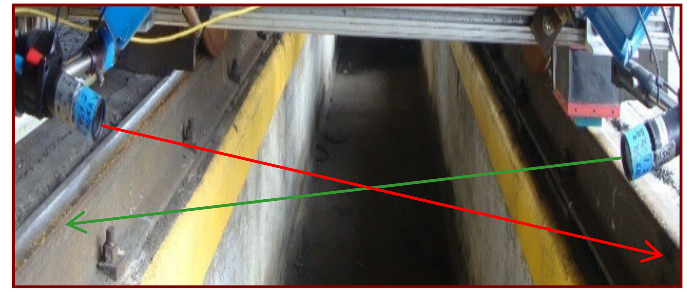
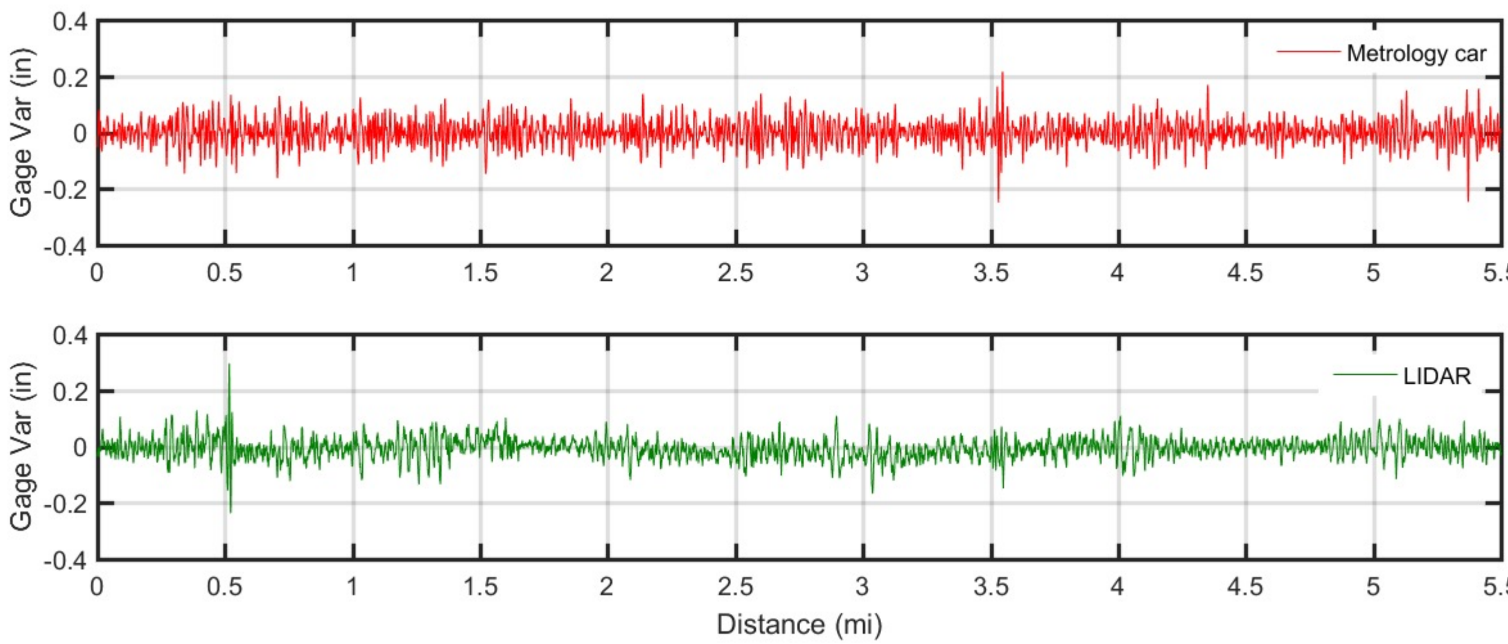
Track gage variation is measured by the gage LIDAR lenses

- The results are compared with onboard gage sensor
- No exact spatial correlation can be established between LIDAR and gage sensor because the measurements are made asynchronously
- The range of LIDAR measurements are the same as gage sensor's

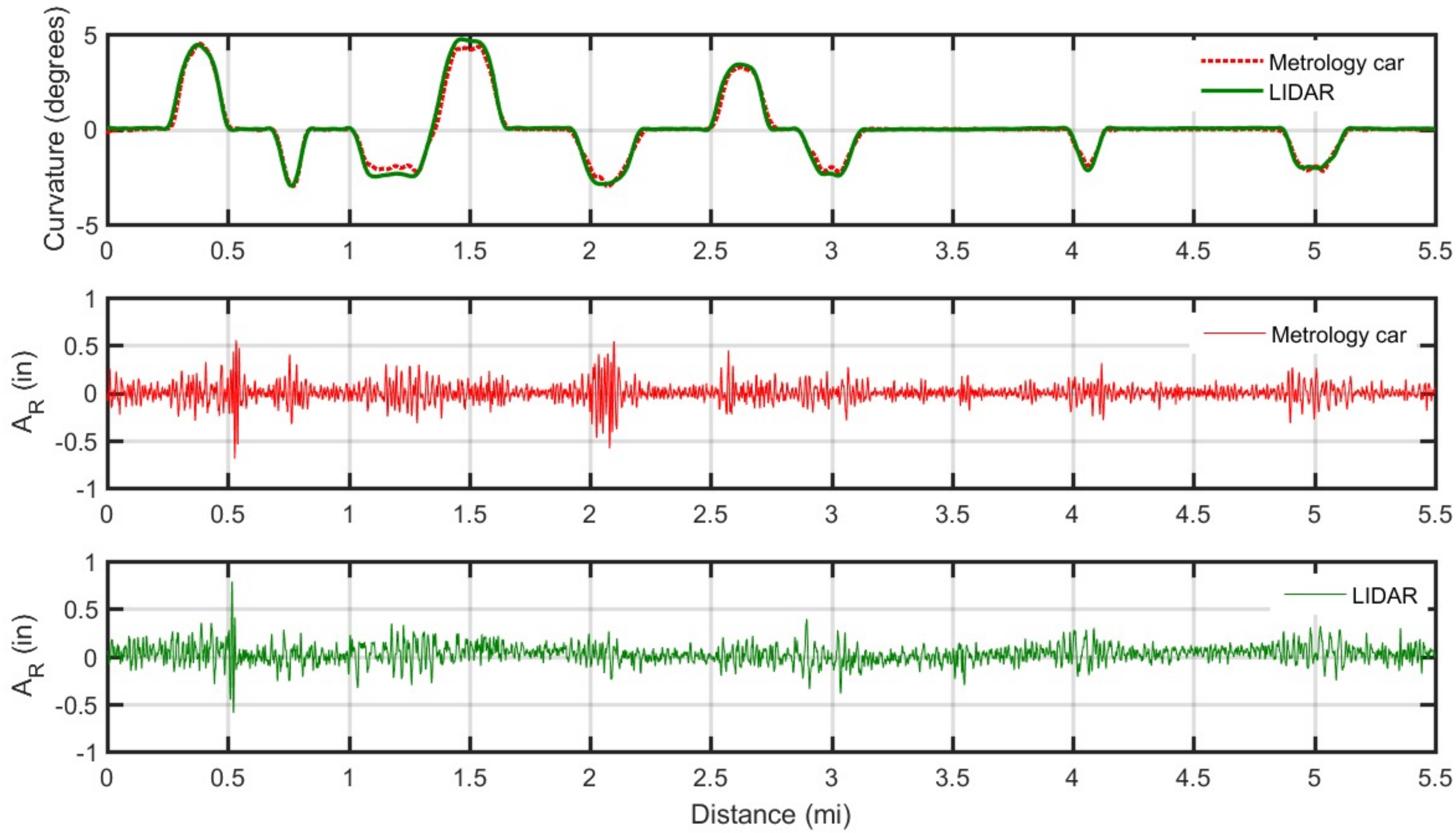
LIDAR Gage face Beams





Left and right alignments are successfully measured by the gage variation LIDAR lenses

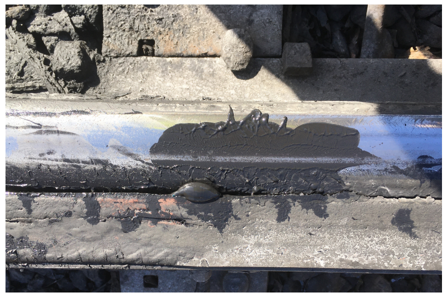
Right Rail Alignment



- Left and right alignments are evaluated for a long track with multiple left and right curves
- The LIDAR alignment measurements closely match the IMU data
  - range
  - variation trend

Rail Lubricity Applications

Top-of-Rail (TOR) friction modifiers and flange greases are widely used by railroads for friction management and wear reduction



TOR Friction Modifier is applied on top of rail

Flange grease is applied to the gauge face of the rail before entering curve

Benefits of TOR Friction Modifier:

- Preserves a stable traction condition
- Reduces wheel and rail wear
- Reduces fuel consumption

Benefits of Flange Grease:

- Reduces lateral force during curving
- Reduces wear caused by flange contact during curving
- Increases train efficiency and reduces maintenance cost

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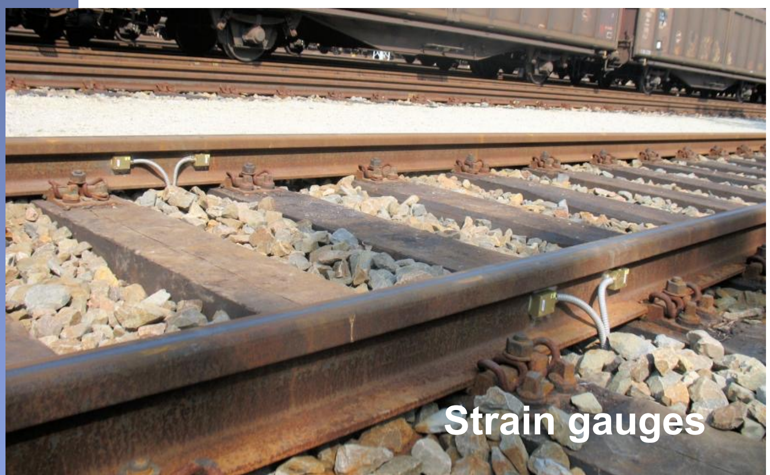
Existing methods for detecting rail lubricants have limitations



Tribometer

<u>Working Principle</u>

❖ Lateral force reduction ⇨ Presence of lubricant

<u>Limitations</u>

❖ Results subjected to other uncontrollable factors
- Train tonnage
- Tran speed

❖ Expensive for installation and maintenance

<u>Working Principle</u>

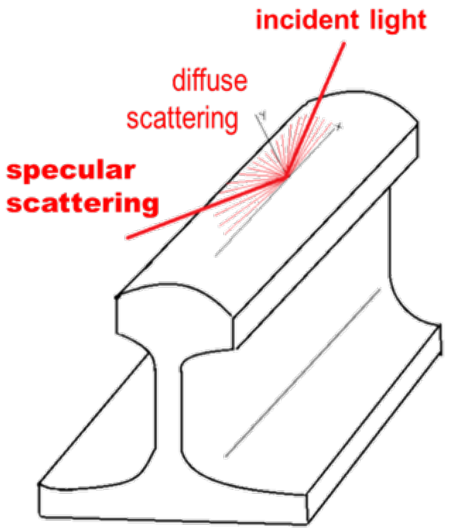
❖ Decrease of friction coefficient ⇨ Presence of lubricant

<u>Limitations</u>

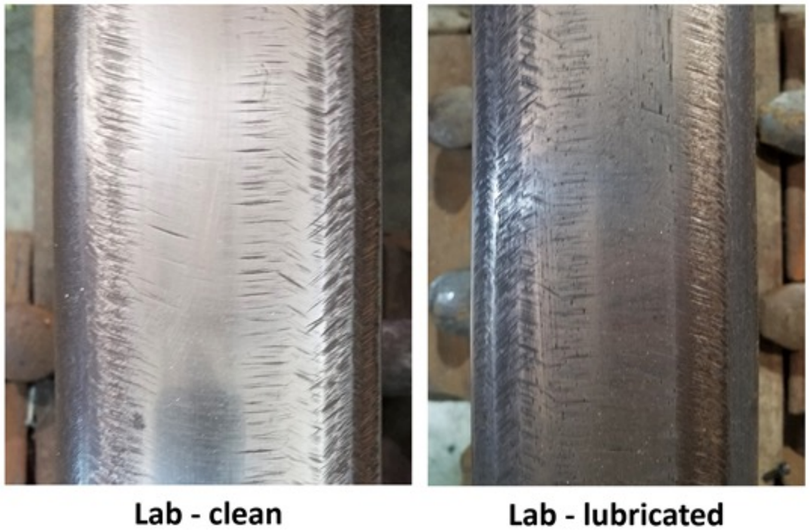
❖ Does not replicate the true wheel-rail contact condition

❖ Repeatability and accuracy issues

The difference in optical properties of unlubricated and lubricated rail promises to provide a new way of detecting lubricity conditions



Scattering behavior of rail



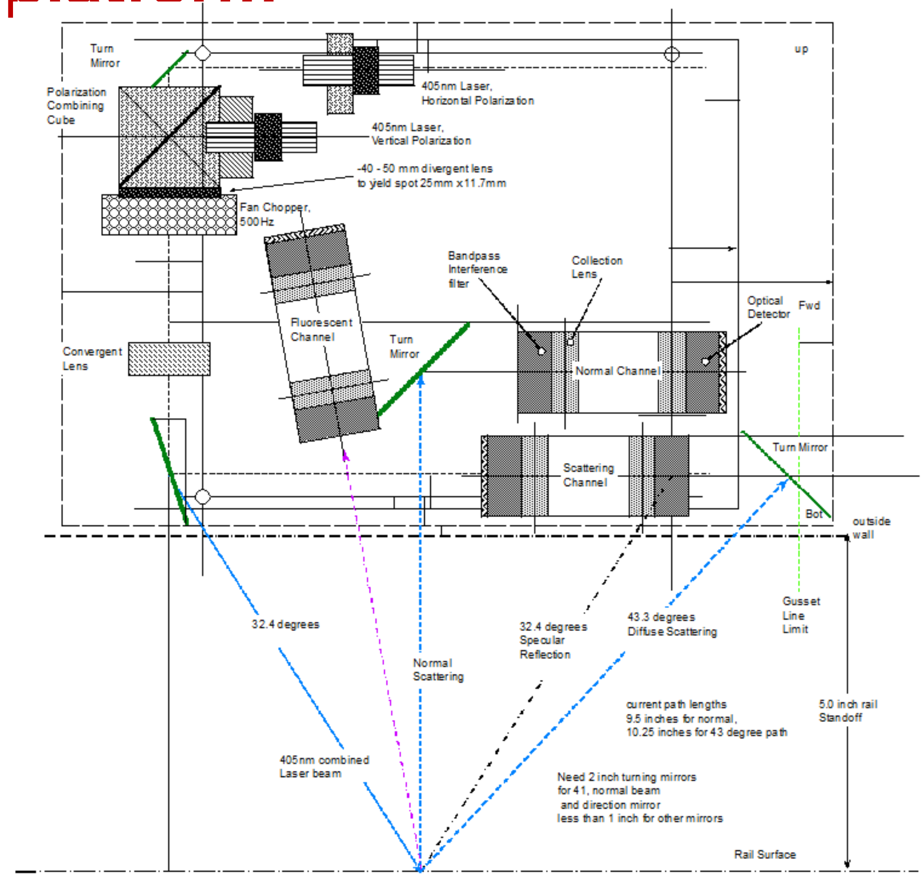
Gloss comparison between clean and lubricated rail

$$Gloss\ Ratio = \frac{Diffuse\ Scattering\ Intensity}{Normal\ Scattering\ Intensity}$$

- A clean and shiny surface has a higher gloss ratio
- a haze or foggy surface with lubricant and/or third body layers would have a lower gloss ratio

Blue laser is used to qualitatively assess the amount of top of rail lubrication or other additives onboard a moving platform

- 2x cross polarized blue (405 nm) laser diodes
  - 16x increase in scattering over red lasers
  - Enables detecting flange grease or other contaminants with a fluorescence signature
  - Cross polarized lasers remove speckle
  - Sensor signal is isolated from sunlight
- Normal, Diffuse (43.3° off-angle), and Fluorescence photodetectors
- Housed in aluminum optical enclosure
- Remote controlled rail cart



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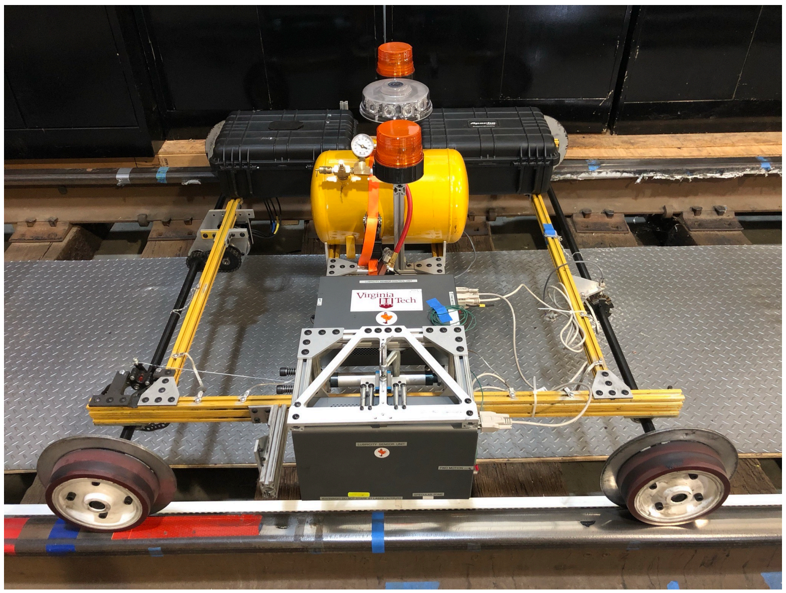
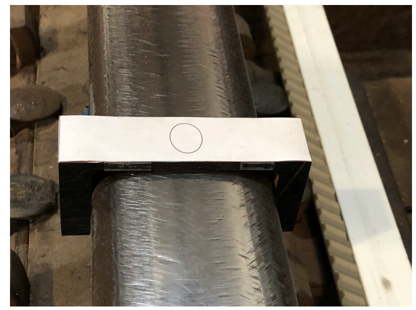
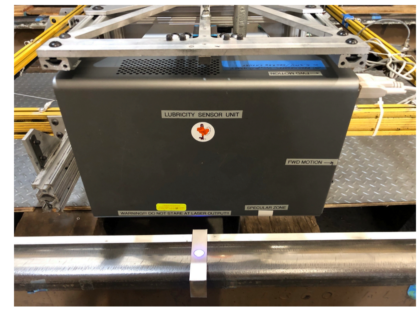
Static and dynamic experiments were performed using the developed optical sensing system on a 40-foot track panel in the laboratory



(a)



(b)



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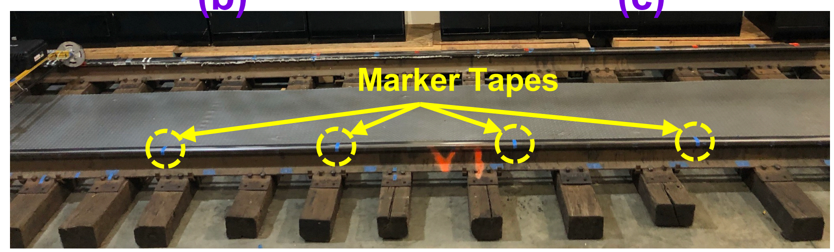


(d)

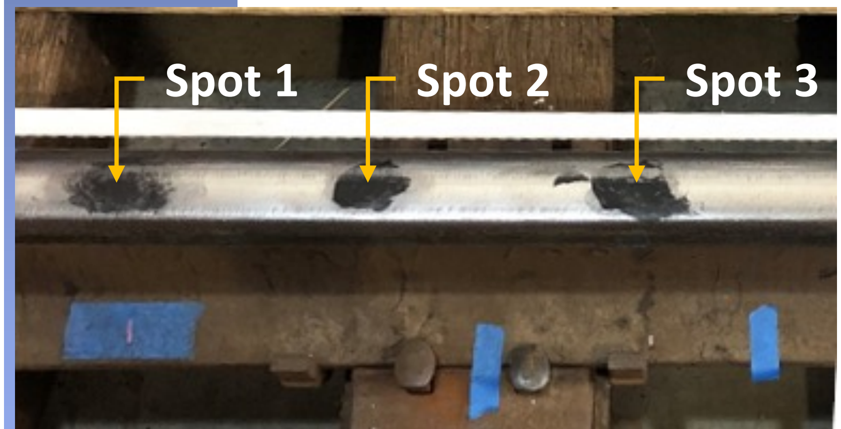
a) Proposed optical sensing system mounted on a remote-controlled moving cart

b) Optical sensor lateral position calibrator

c) Laser beam falls on the ellipse marker on the lateral position calibrator

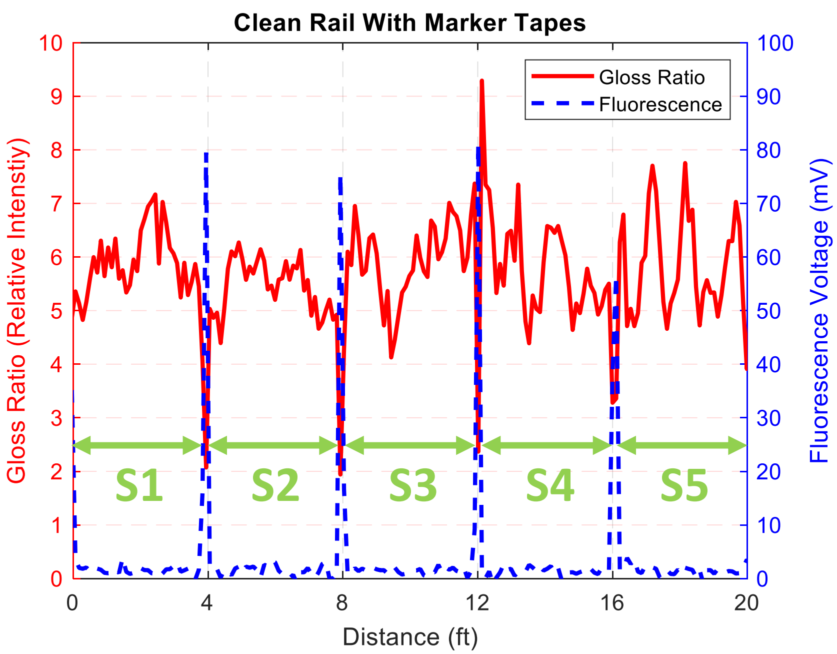
d) Four blue marker tapes divides the selected lab track panel into five sections

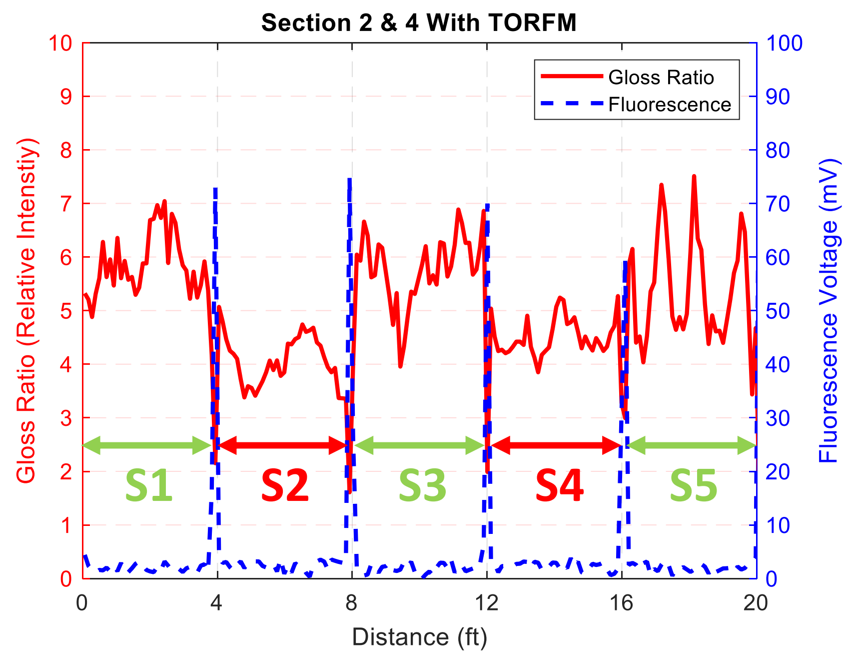
Controlled tests were performed on a track in the Laboratory to determine if gross changes in the amount of TOR can be detected in spots, statically



- The amount of TORFM applied to the track was substantially thicker than commonly applied in the field
- Thoroughly cleaned the rail before applying TORFM
- TORFM was applied in Three spots, with relative “light,” “medium,” and “heavy” thickness
- The process was repeated for flange grease

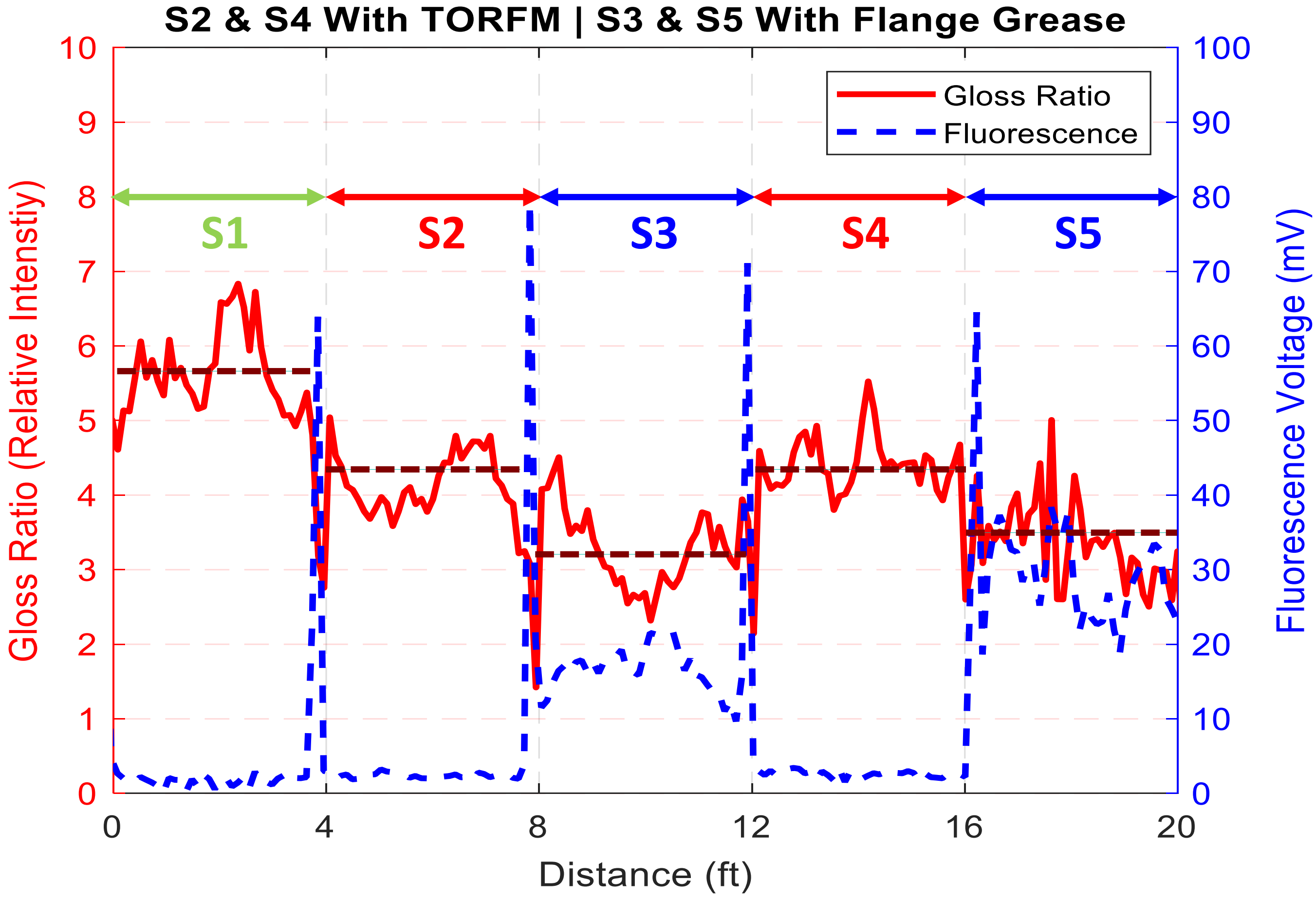
The rail with TOR has a lower gloss ratio than an unlubricated rail that can be detected in motion





- Gloss ratio valleys and fluorescent peaks represent the marker tapes on the lab track panel (painter's tape is highly fluorescent with a low gloss ratio)
- Adding TORFM drops the gloss ratio, but doesn't have influence on fluorescence
- Note: Gloss Ratio is a surface scattering property for TORFM, whereas Fluorescence is volume absorption property of Flange Grease

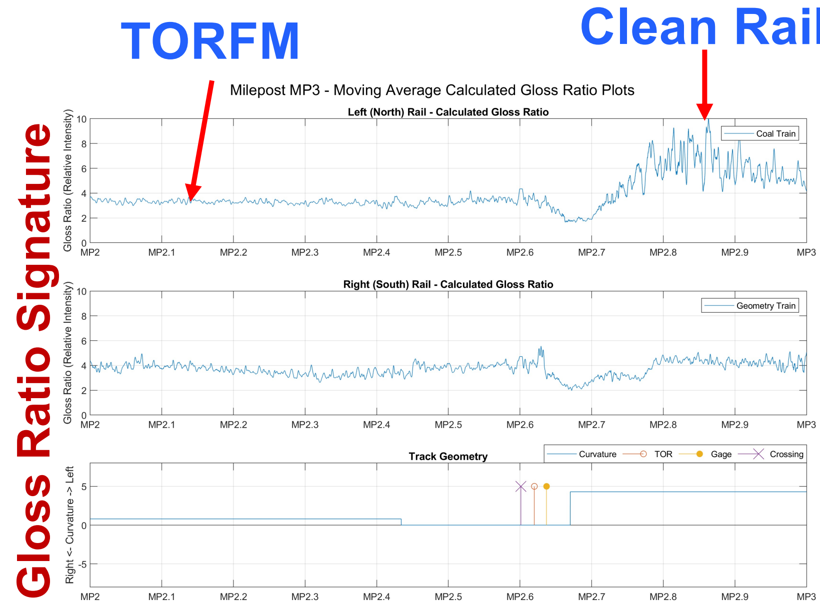
The rail with TORFM has a lower gloss ratio than an unlubricated rail, and flange grease contamination increases fluorescence levels

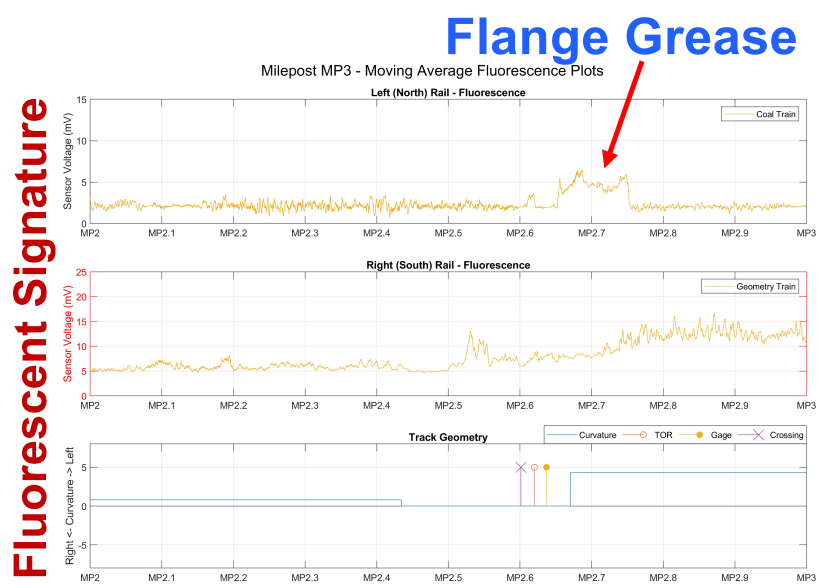


Adding flange grease significantly increases fluorescence signal

Significant lubricity and fluorescent signal responses from field tests at wayside applicator sites on revenue service track

- Significant and repeatable signal inflections can be seen at wayside applicator sites
  - Both TOR and Gage Face applicators
  - Calculated Gloss Ratio typically lowers from heavy dark, thick TORFM
  - Fluorescence rises from fluorescent carriers and particularly flange grease





The LIDAR sensing methods are well suited for less costly track condition monitoring and asset management in near real time

- They can be used for a wide variety of applications
  - Assessing the track and track components' structural condition
  - Determining the track geometry and any need for maintenance
  - Evaluating the lubrication condition of the rail
- Their accuracy is far higher than most available methods
- They are less costly!
- Do not require installation on track geometry car
  - Can be used onboard Hy-rail trucks or locomotives and railcars
- Can be used for in suite asset management

Acknowledgements

- Special thanks are due to:
  - Federal Railroad Administration (financial support)
  - Association of American Railroads (financial and technical support)
  - Norfolk Southern railroad’s Research and Tests Department (technical support)
  - U.S. Department of Transportation (financial support)
  - Different generation of graduate students at CVeSS who have worked on this project

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Thank You!