LRAIL Deep Neural Network Railway Inspection and Change Detection
• **Mission** - Evaluate the potential for 3D Laser Triangulation and Deep Neural Network (DNN) technologies to provide value-added inspection data to existing geometry car inspection systems

• **Timeline**: May 2019 → October 2020 (live)

• **Objectives**:
  - Improve railway network safety through improved reliability and robustness of track inspections
  - Provide value-added inspection data to existing geometry car inspection systems in two different scenarios:
    - A. No prior knowledge inspections
    - B. Repeat inspections (change detection)

Project Overview
Project Approach

Field Work
- TTCI High Tonnage Loop
- 6 Weeks of FAST operations
- Walking ground-truth surveys
- LRAIL scanning

DNN Training Data Preparation
- RailTEC manual image review to build a database
- Feature identification
- Condition of interest identification

DNN Training
- Input of training set
- DNN feature and condition identification
- Review and correction of DNN analysis
- Retraining of DNN

Testing and Evaluating the Trained DNN
- A set of “Novel” images are presented
- DNN processes the images detects features and conditions
- DNN performance analysis

Change Detection
- DNN processes two separate runs
- Run-to-run alignment
- Change detection algorithm detects differences between runs
We use a kind of DNN, a Convolution Neural Network (CNN or ConvNet)

- CNNs are a special kind of multi-layer neural network that is designed to recognize visual patterns directly from pixel images with minimal preprocessing
- Normally computers “see” images as just another array of numbers
- CNNs help computers to analyze images in a way that is similar to how a human would analyze them
- You train a CNN by presenting it numerous different images of the features that you want it to be able to recognize

https://adeshpande3.github.io/A-Beginner%27s-Guide-To-Understanding-Convolutional-Neural-Networks/
3D Scanning Dataset

- 7 weeks of repeat scans; Sept 10 to Oct 23
- 22 complete runs around HTL
- Full loops, forwards and backwards
- Diverging trips through turnouts
- Each pass through the HTL results in approximately 2,000 3D scan files
- Each 3D scan file covers a 2m x 3.4m surface area
- Each 3D scan file contains both an intensity dataset and a range dataset
Ground Truth Walking Inspections

- Spreadsheet list of features prepared prior to arrival
- Tablet used to record manual inspection data in the field
- 15 features of interest
- Subcategories for features: missing spike, center crack, broken clip, etc.
- 7,500 ties inspected; categorized by type, section, number, material
Ground Truth Summary

- Rail Surface Issue: 544
- Center Crack: 265
- Spike Missing/Broken: 191
- Raised Spike: 121
- Shoulder Damage/Missing: 39
- Tie Split/Cracked: 64
- Crib Ballast: 93
- Clip Missing/Broken: 82
- Insulator Missing/Skewed: 33
- Rail Pad Missing/Broken: 13
- Other Tie Damage: 20
- Shoulder Broken: 10
- Cut Tie: 7
- Longitudinal Crack: 6

Legend:
- Concrete
- Wood/Composite
Intensity and Range Image Data Collection (LRAIL)

- Sensor Mounting
- DMI
- ~2m
- Sensor Controller
- Data Storage PC
- Data Processing PC
- Power Inverter
- UPS

- 1 point every mm transversely and longitudinally
- 0.1mm vertical resolution
- 3.4m scan width (as tested)
- 2D Images + 3D scan
- IMUs for motion correction
Fully Self-contained LRA/L Test Trailer
Real-time Data Collection Interface
Railway Scanning
Algorithm to Correct for Vehicle Motion (uncorrected example)
Algorithm to Correct for Vehicle Motion (corrected example)
A Word on LRA/L Repeatability (based on prior project work with Amtrak)

- 9 mile test loop on Amtrak lines between south leg of Wye Landlith (DE) and the Hook Interlocking (PA)
- Repeat runs in same and opposite directions used to establish noise floor and repeatability of measurements related to:
  - Ballast height measurements
  - Ballast fouling measurements
  - Tie skew and condition measurements
  - Fastener inventory
  - Joint bar bolting
  - Joint gap measurement
  - Rail surface defect detection
- Average overall repeatability between runs for all measurements, collected in all directions was 99.28%
- Multiple measurements at 100% repeatability including fasteners, joint bar bolting and tie rating
DNN Training

Vision Systems for the Automated Inspection of Transportation Infrastructure
A Few Notes about the HTL Environment (Related to Training)

- Best and worst case scenario
- Plenty of change in a short period of time...just what we need
- However, from a DNN training perspective, it's challenging
- Training (humans and DNNs) relies on lots of similar examples of each thing/condition
  - Unfortunately, the HTL is pretty heterogenous and constantly changes along its length
  - Plus...numerous tie types
  - Plus...numerous clip types
  - Plus...numerous clip install plates
  - Plus...numerous spike patterns
  - Plus...strange hardware along the track that algorithms must ignore
- The upshot? The HTL is harder to train on than regular track
DNN Training

• 3D scans are first automatically analyzed, then the user performs a manual review to correct errors and to add additional data; this creates a DNN training feedback loop

• Manual review is “point an click” and is performed in Railmetrics inspection software

• User can select from a list of pre-programmed features and conditions in order to maximize data quality

• Manual marking of images creates XML records that are tied to each image containing feature location, dimensions, type, etc.

• XML used as an input to train DNN, algorithms are updated, training cycle repeats until no further improvements are possible
DNN Training

- Full cycle through the training data set is called an epoch; millions of epochs performed

- Training for feature identification
  - Multiple kinds of spikes
  - Multiple kinds of clips
  - Multiple kinds of tie plates
  - Etc.

- Training for condition state identification
  - Defective tie plate (missing spike, twisted)
  - Defective clip (loose, damaged)
  - Defective spike (raised, broken)
  - Change in spiking pattern
  - Etc.
Preliminary Results From DNN

Vision Systems for the Automated Inspection of Transportation Infrastructure
Preliminary Results – Plates and Spikes
Preliminary Results – Plates, Chair Screws and e-Clips
Preliminary Results – Plates, Chair Screws and e-Clips
Preliminary Results – e-Clips
Preliminary Results – Fastclip
Preliminary Results
Preliminary Results
1. Same length of track is inspected two times; can be collected in same or opposite directions
2. Each run is analysed by the DNN plus human-devised algorithms to create features of interest for change detection
3. 2 runs are then automatically aligned (or “collocated”)
4. Differences between the two runs (changes) are reported
- Inspection vehicle never starts nor stops at the exact same location
- Therefore, must determine which points in RUN A match which points in RUN B
- Matching is fully automatic
- GPS is used to “get close”
- Then exact match made through 3D analysis of features in each run
Example Change Results in Google MyMaps
Initial Change Detection Results from TTCI (Joint Bar Bolting)
Joint Bar Change
(Sept 10 vs. Oct 23, 2019)

Continuous Rail

Joint and Bar Added
Ballast Level Change
(Sept 10 vs. Oct 23, 2019)

<table>
<thead>
<tr>
<th></th>
<th>Left Rail Ballast Change</th>
<th>Gauge Ballast Change</th>
<th>Right Rail Ballast Change</th>
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<tbody>
<tr>
<td></td>
<td>-23.82</td>
<td>8.44</td>
<td>0.33</td>
</tr>
</tbody>
</table>
Fastener Change (Sept 10 vs. Oct 23, 2019)
Rail Surface Defect Change (Increase, Sept 10 vs. Oct 23, 2019)

1,708 square mm... (17 sq cm, 2.65 sq inches)... about the size of 3 quarters
Rail Surface Defect Change (Decrease, Sept 10 vs. Oct 23, 2019)

1,933 square mm... (19 sq cm, 3 sq inches)... about the size of 4 quarters
• Research Sponsor: U.S. Department of Transportation Federal Railroad Administration

• Subcontractor: Railmetrics

• Industry Partners: BNSF, CN

• Field Testing Support: TCI