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LRAIL Deep Neural Network Railway Inspection and Change Detection

U.S. Department of Transportation
Federal Railroad Administration

Vision Systems for the Automated Inspection of Transportation Infrastructure

Project Overview

- **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 Partners:

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Industry Partners:

BNSF RAILWAY

CN

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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

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Convolution Neural Network

- 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

What We See

08	02	22	97	38	15	00	40	00	75	04	05	07	78	52	12	50	77	91	08
49	49	99	40	17	81	18	57	60	87	17	40	98	43	69	48	04	56	62	00
81	49	31	73	55	79	14	29	93	71	40	67	53	88	30	03	49	13	36	65
52	70	95	23	04	60	11	42	69	24	68	56	01	32	56	71	37	02	36	91
22	31	16	71	51	67	63	89	41	92	36	54	22	40	40	28	66	33	13	80
24	47	32	60	99	03	45	02	44	75	33	53	78	36	84	20	35	17	12	50
32	98	81	28	64	23	67	10	26	38	40	67	59	54	70	66	18	38	64	70
67	26	20	68	02	62	12	20	95	63	94	39	63	08	40	91	66	49	94	21
24	55	58	05	66	73	99	26	97	17	78	78	96	83	14	88	34	89	63	72
21	36	23	09	75	00	76	44	20	45	35	14	00	61	33	97	34	31	33	95
78	17	53	28	22	75	31	67	15	94	03	80	04	62	16	14	09	53	56	92
16	39	05	42	96	35	31	47	55	58	88	24	00	17	54	24	36	29	85	57
86	56	00	48	35	71	89	07	05	44	44	37	44	60	21	58	51	54	17	58
19	80	81	68	05	94	47	69	28	73	92	13	86	52	17	77	04	89	55	40
04	52	08	83	97	35	99	16	07	97	57	32	16	26	26	79	33	27	98	66
88	36	68	87	57	62	20	72	03	46	33	67	46	55	12	32	63	93	53	69
04	42	16	73	38	25	39	11	24	94	72	18	08	46	29	32	40	62	76	36
20	69	36	41	72	30	23	88	34	62	99	69	82	67	59	85	74	04	36	16
20	73	35	29	78	31	90	01	74	31	49	71	48	86	81	16	23	57	05	54
01	70	54	71	83	51	54	69	16	92	33	48	61	43	52	01	89	19	67	48

What Computers See

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

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Field Work

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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

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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

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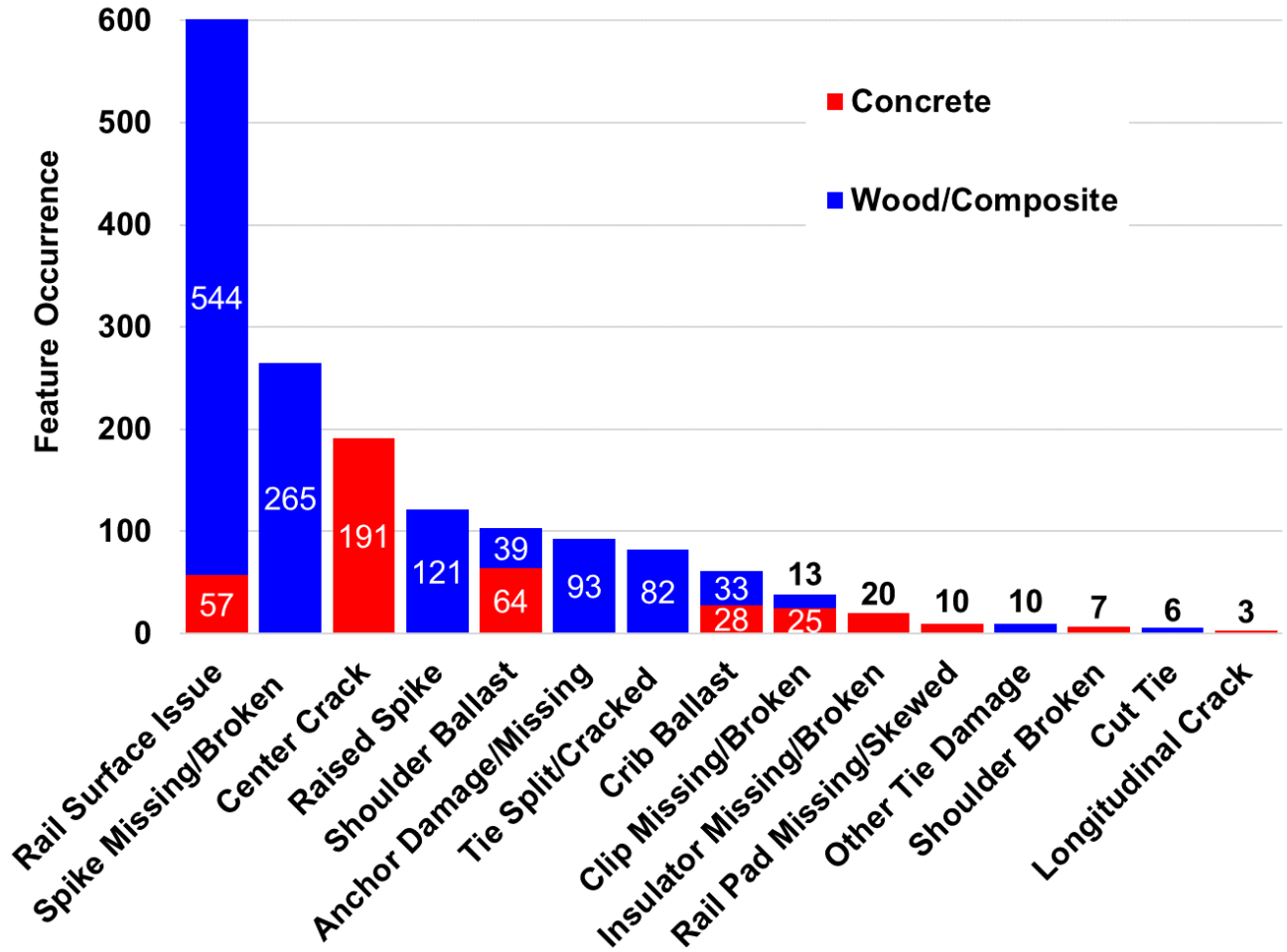
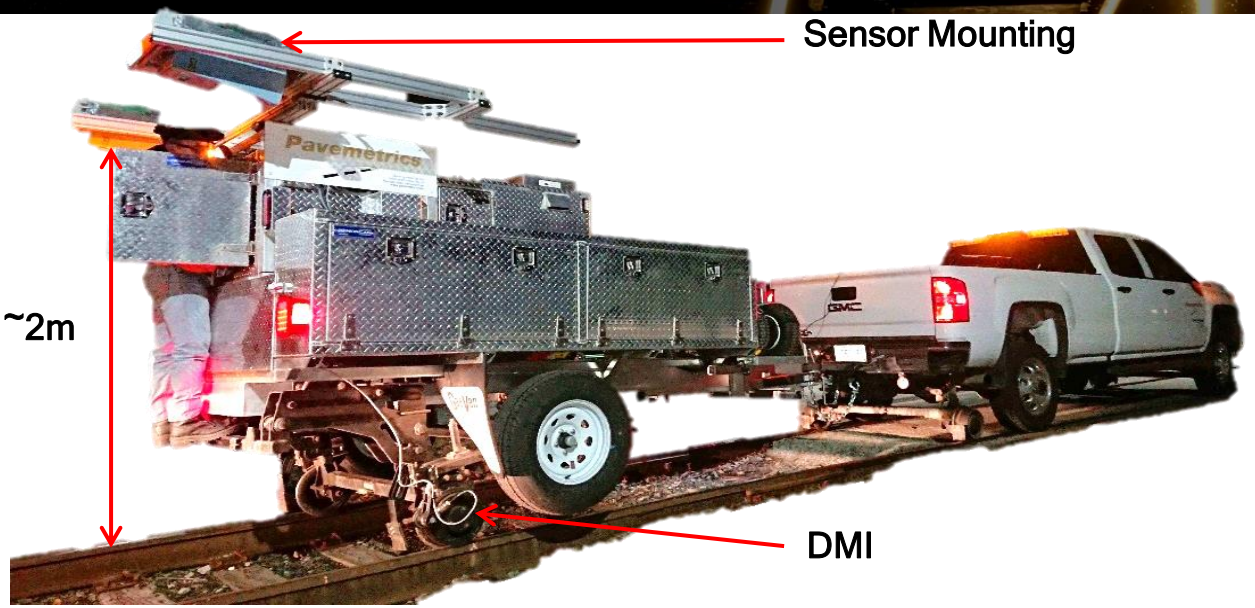
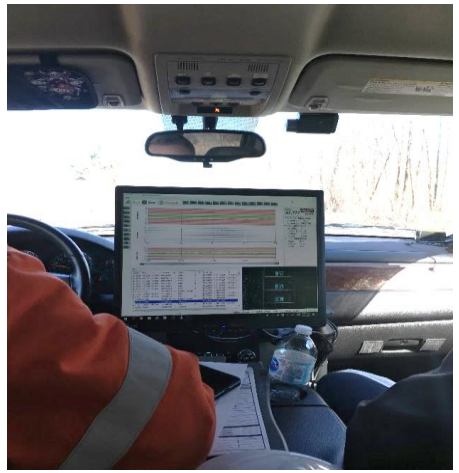
Ground Truth Summary

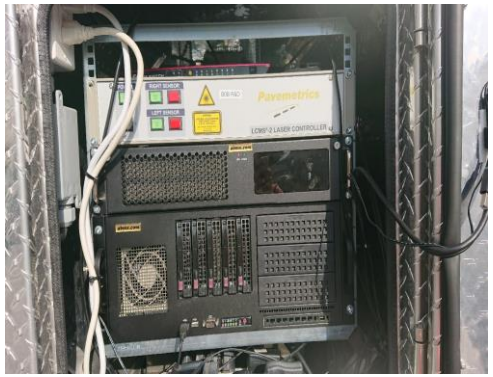


Intensity and Range Image Data Collection (LRA/L)



Operator's Station





- Sensor Controller
- Data Storage PC
- Data Processing PC
- Power Invertor
- 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

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Fully Self-contained LRAIL Test Trailer

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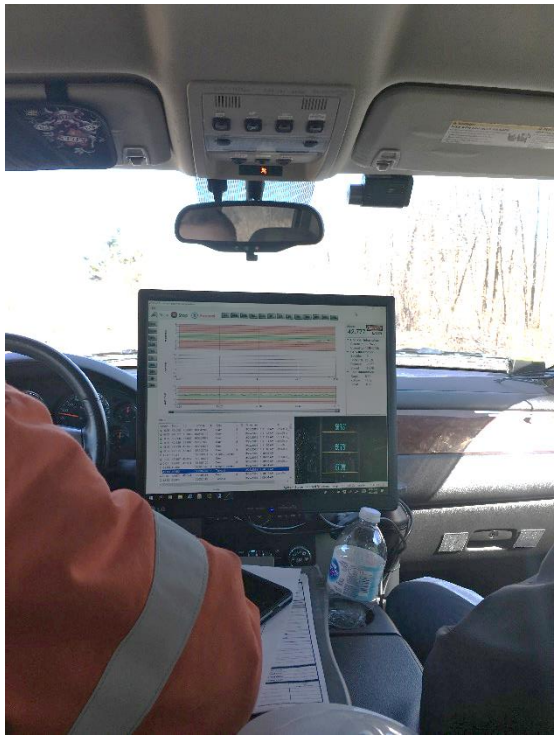
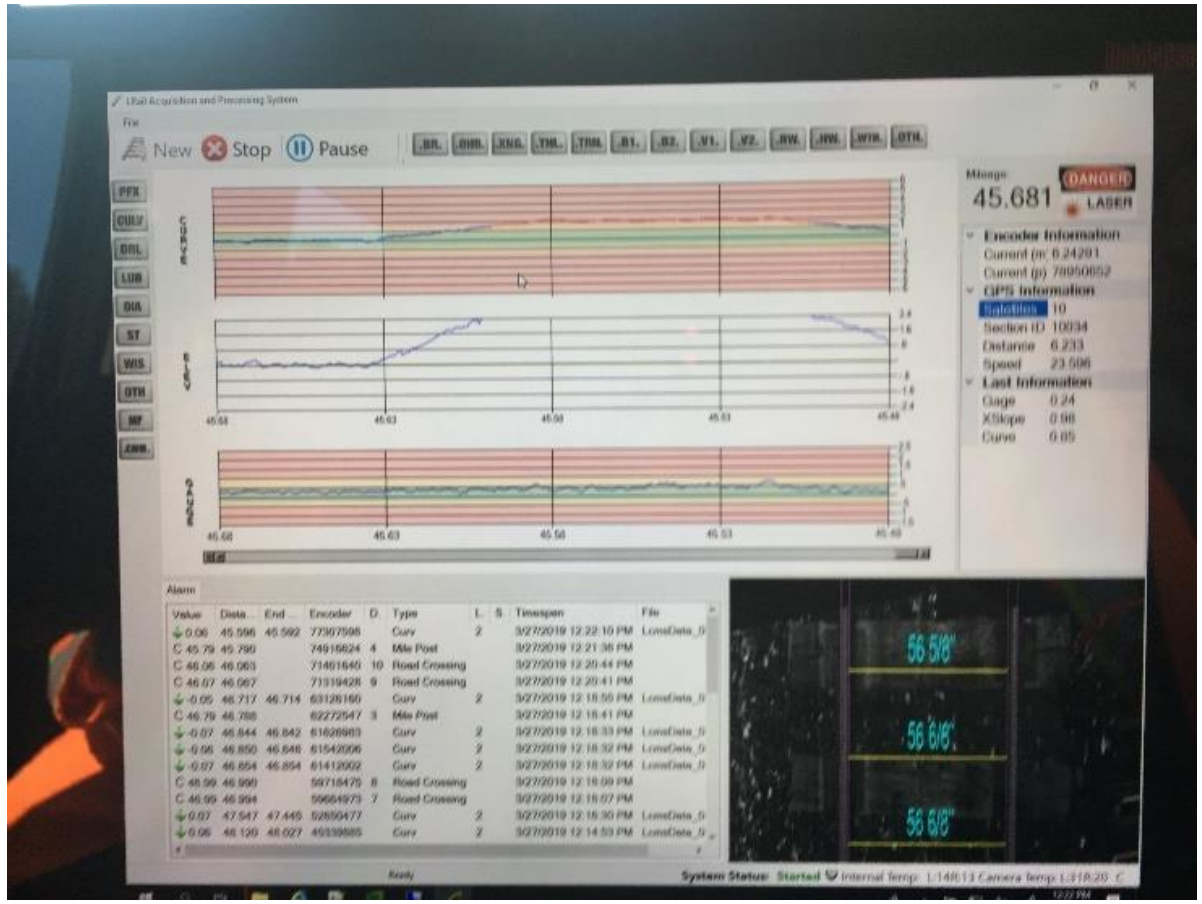
Real-time Data Collection Interface





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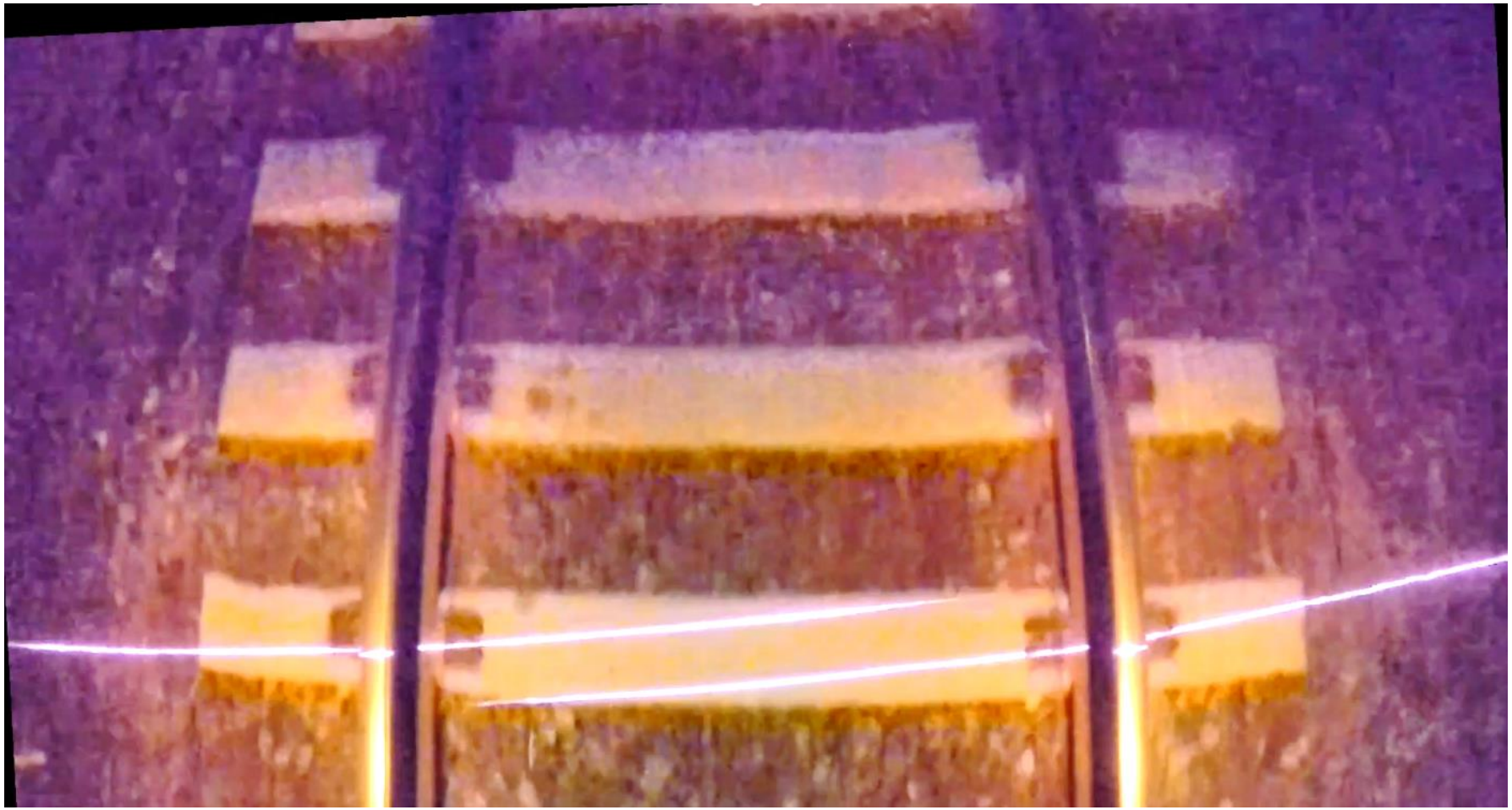
Railway Scanning



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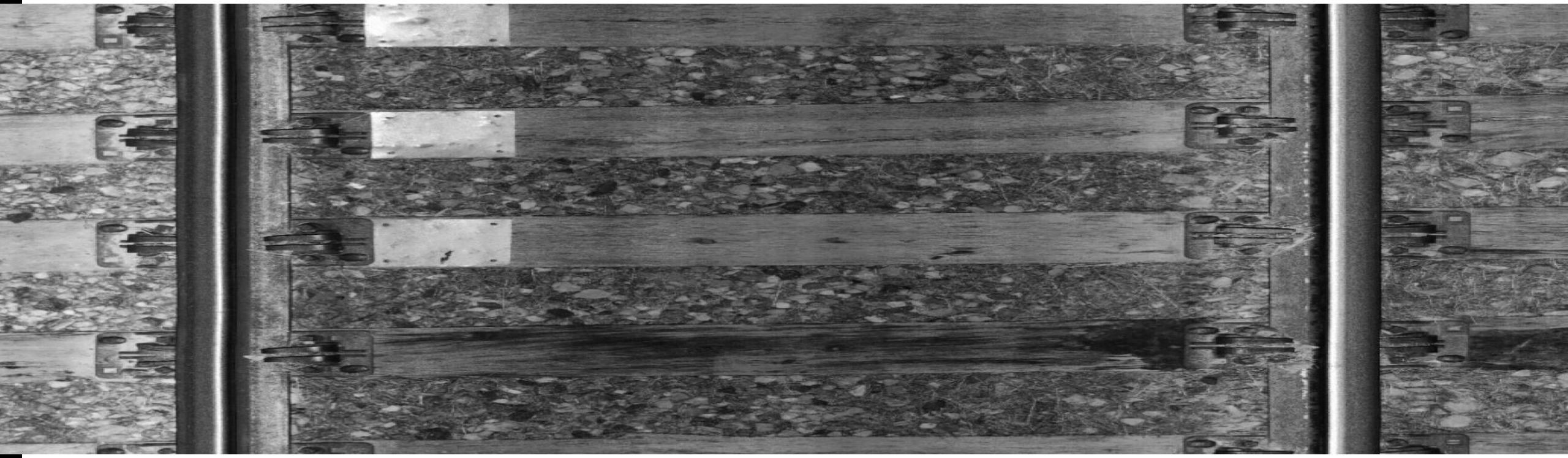
2D Intensity Image



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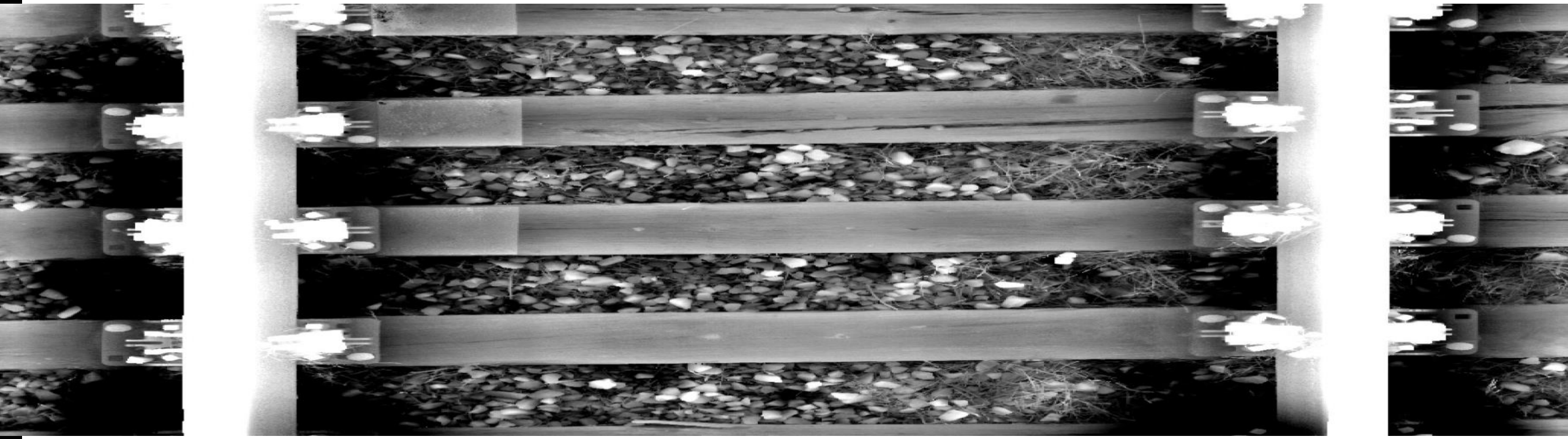
3D Range Image



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Combined Result

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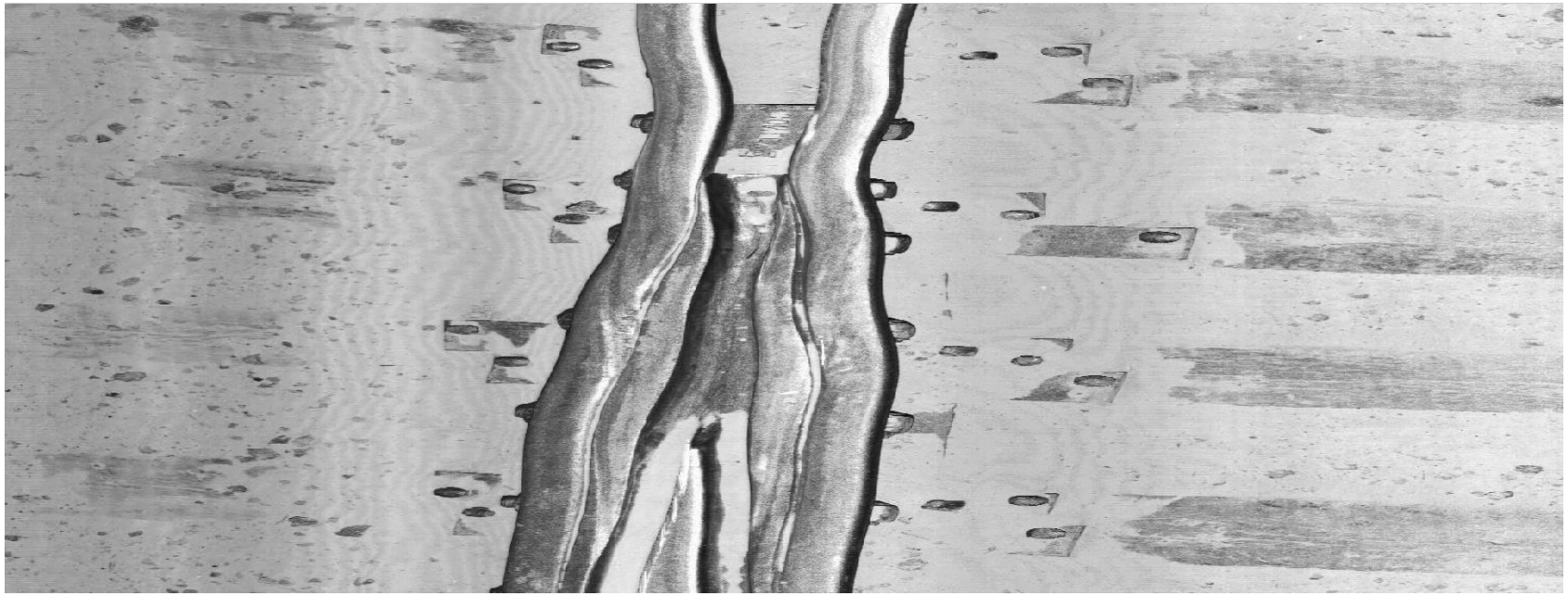
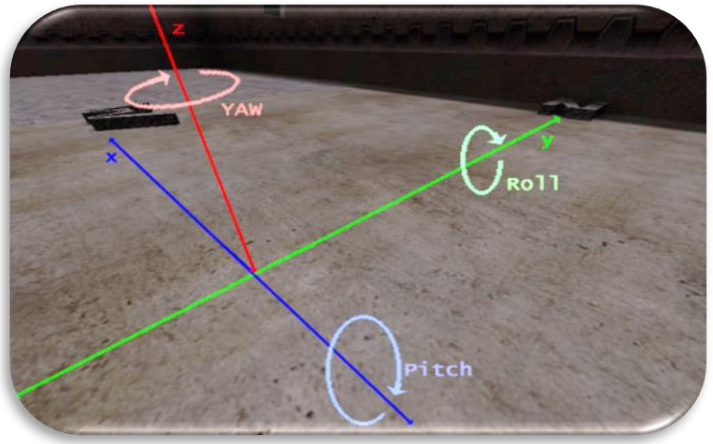
Algorithm to Correct for Vehicle Motion (uncorrected example)





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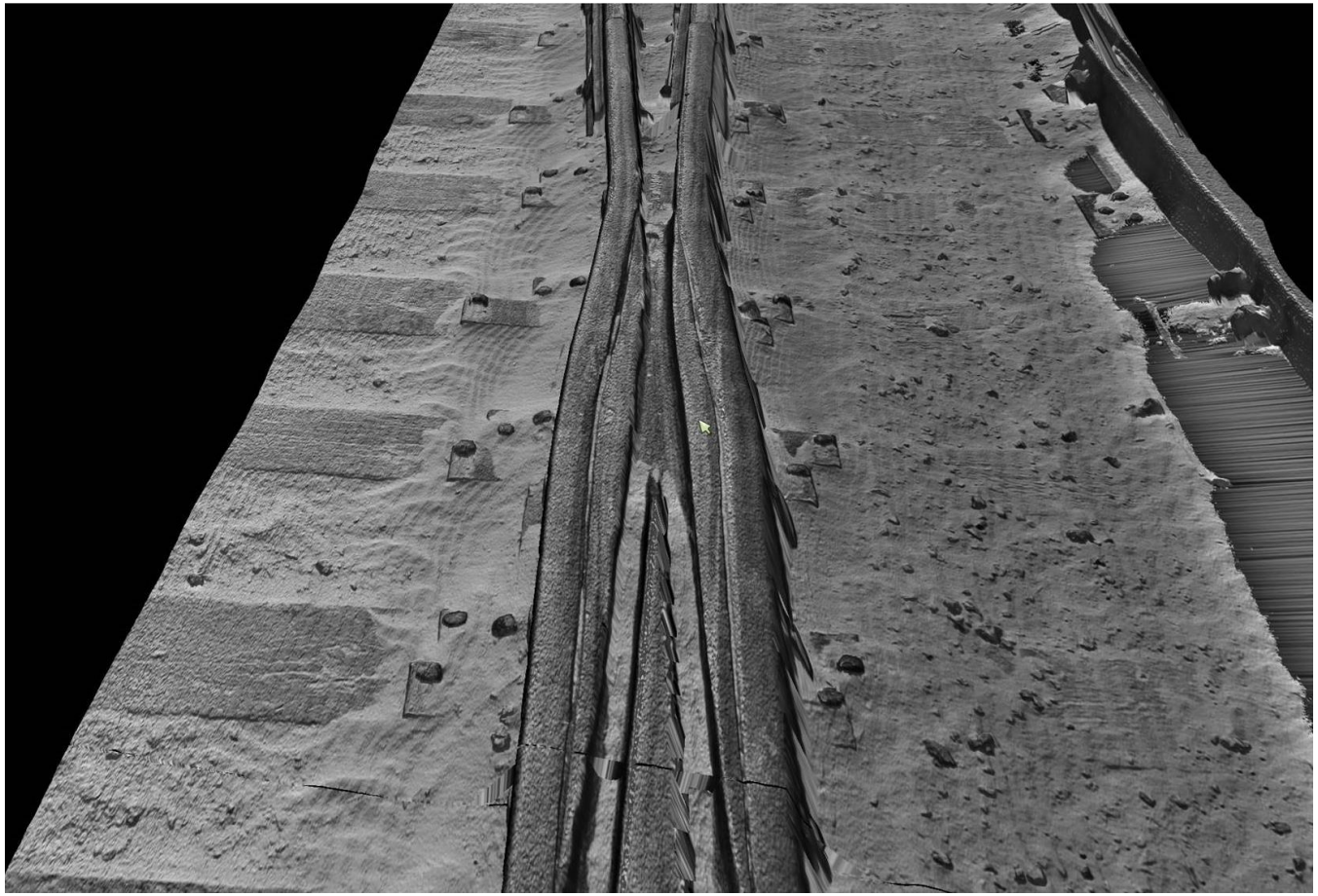
Algorithm to Correct for Vehicle Motion (corrected example)



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A Word on LRAIL 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

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DNN Training

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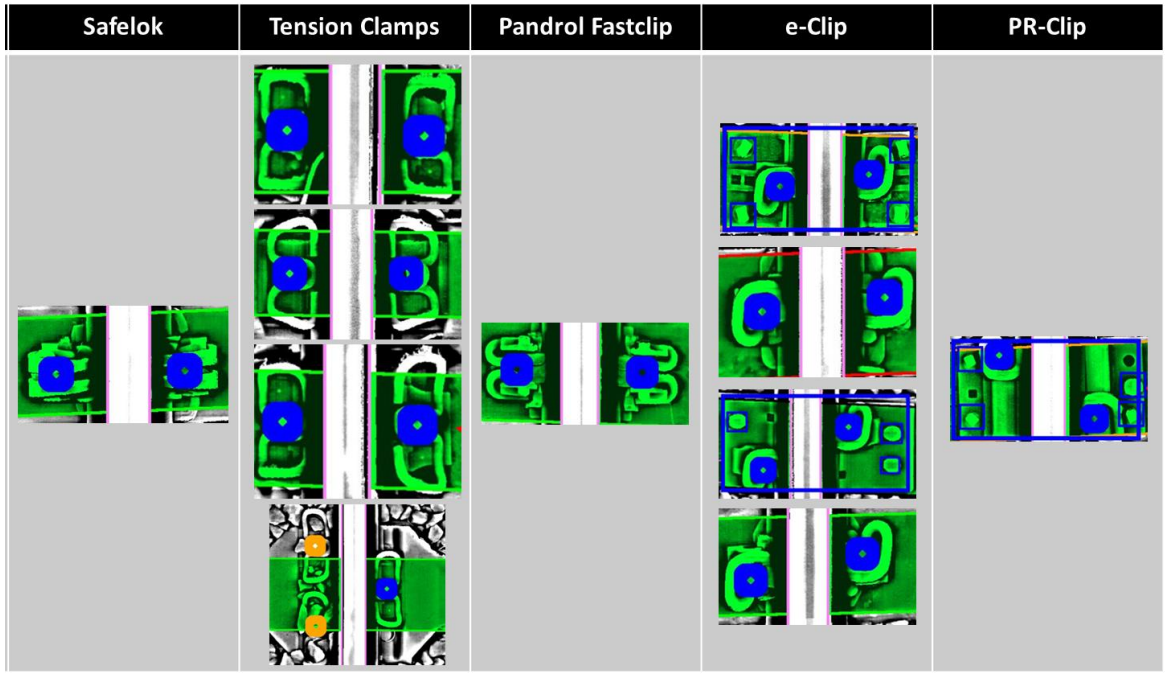
A Few Notes about the HTL Environment (Related to Training)

- 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



Large Variety of Clips and Installations

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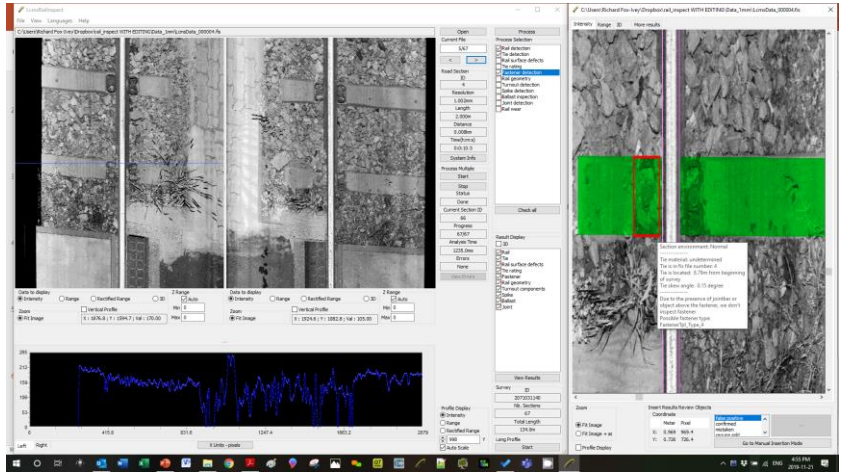
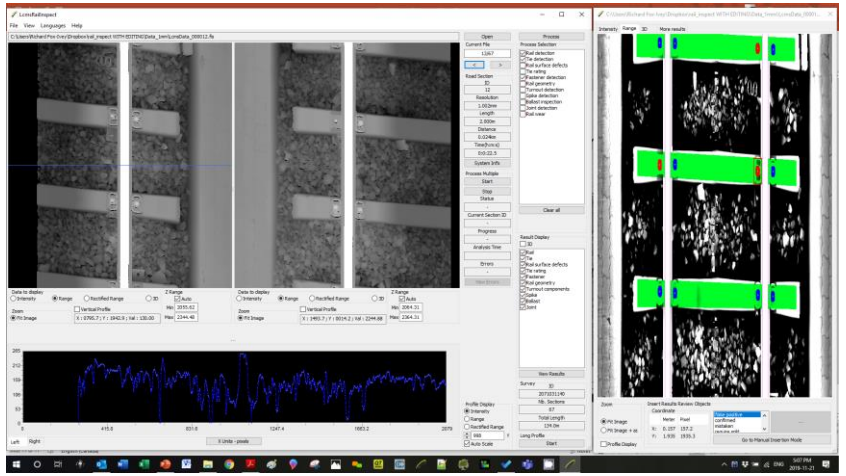
DNN Training

- 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





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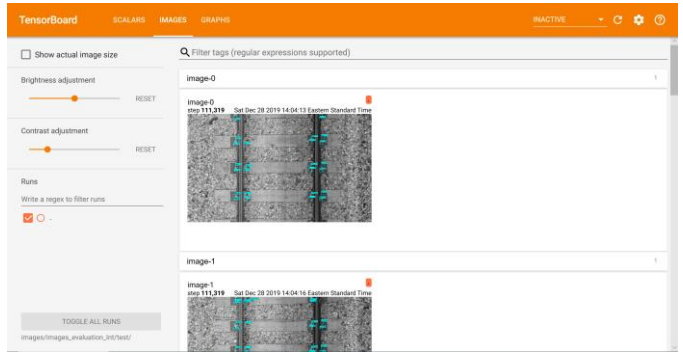
DNN Training

- 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.



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Preliminary Results From DNN

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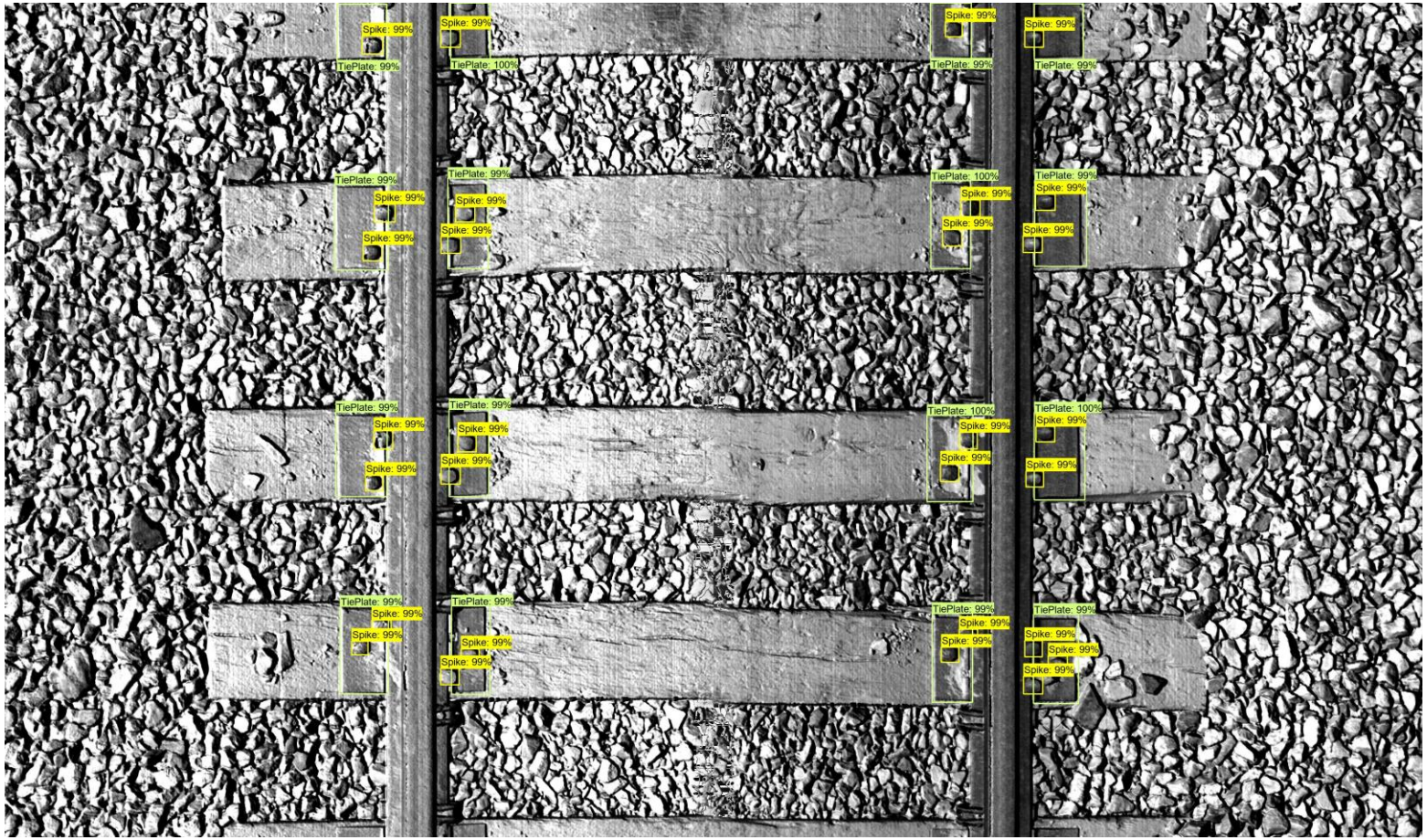
Preliminary Results – Plates and Spikes



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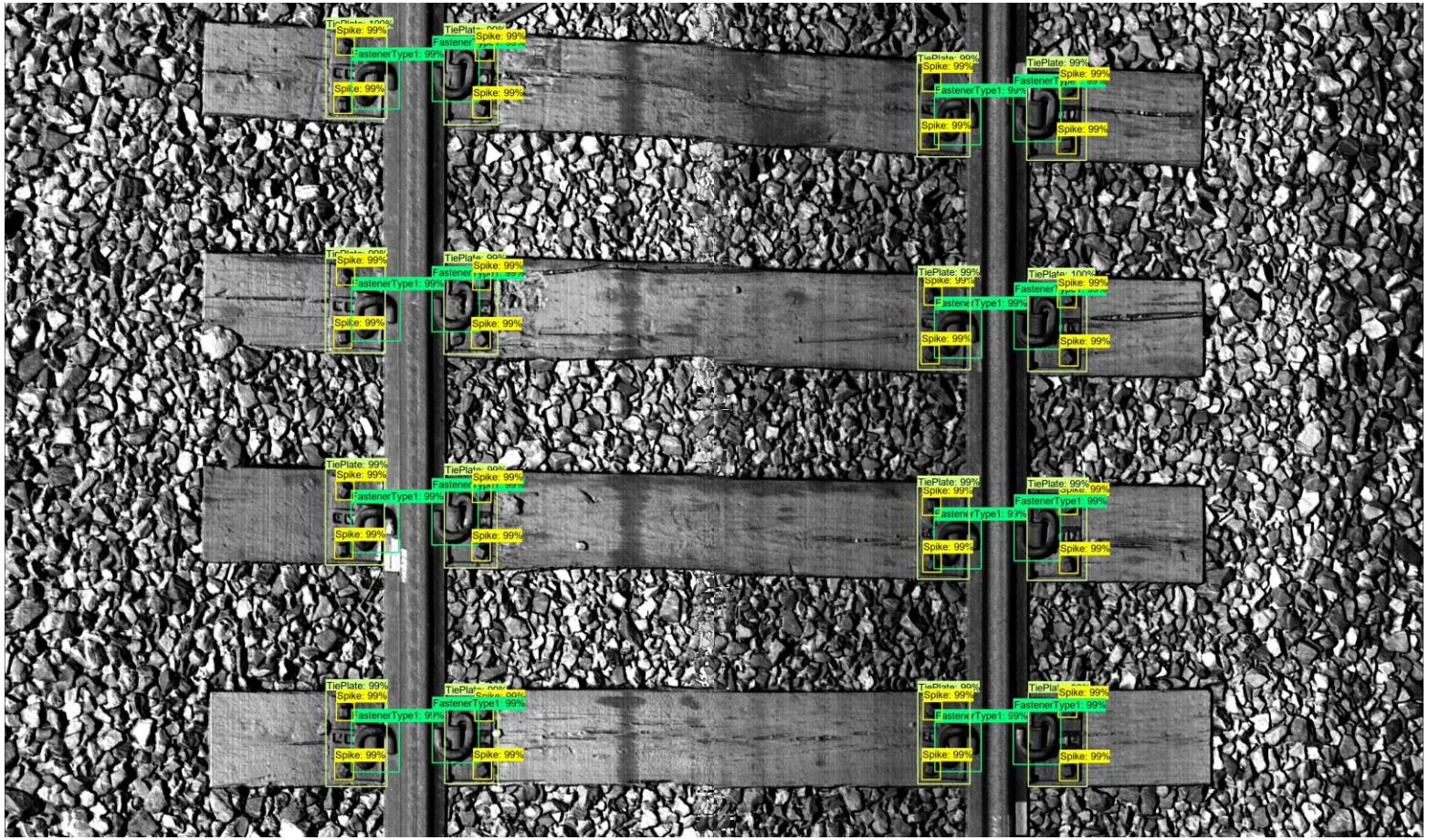
Preliminary Results – Plates, Chair Screws and e-Clips



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Preliminary Results – Plates, Chair Screws and e-Clips

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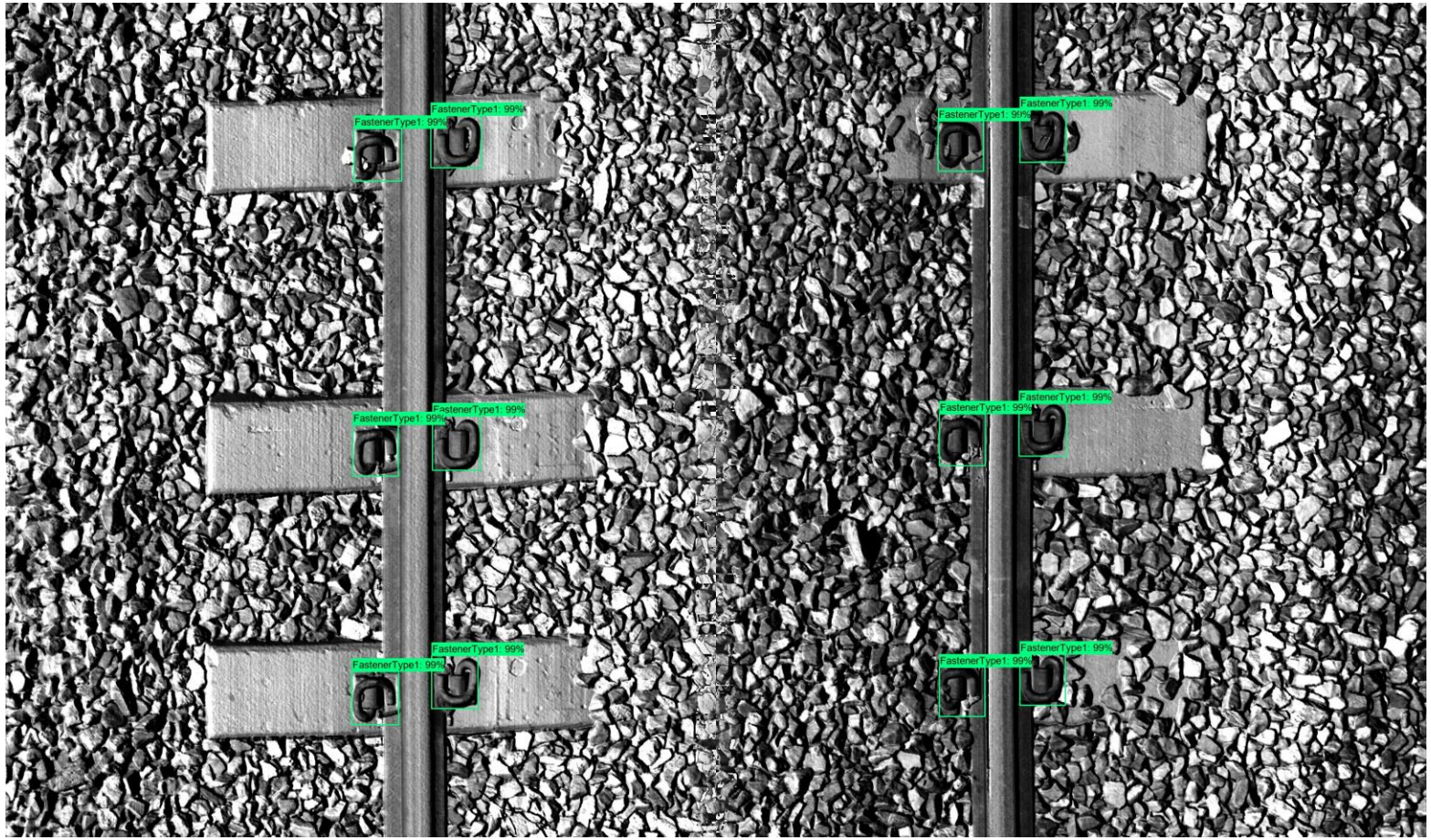
Preliminary Results – e-Clips



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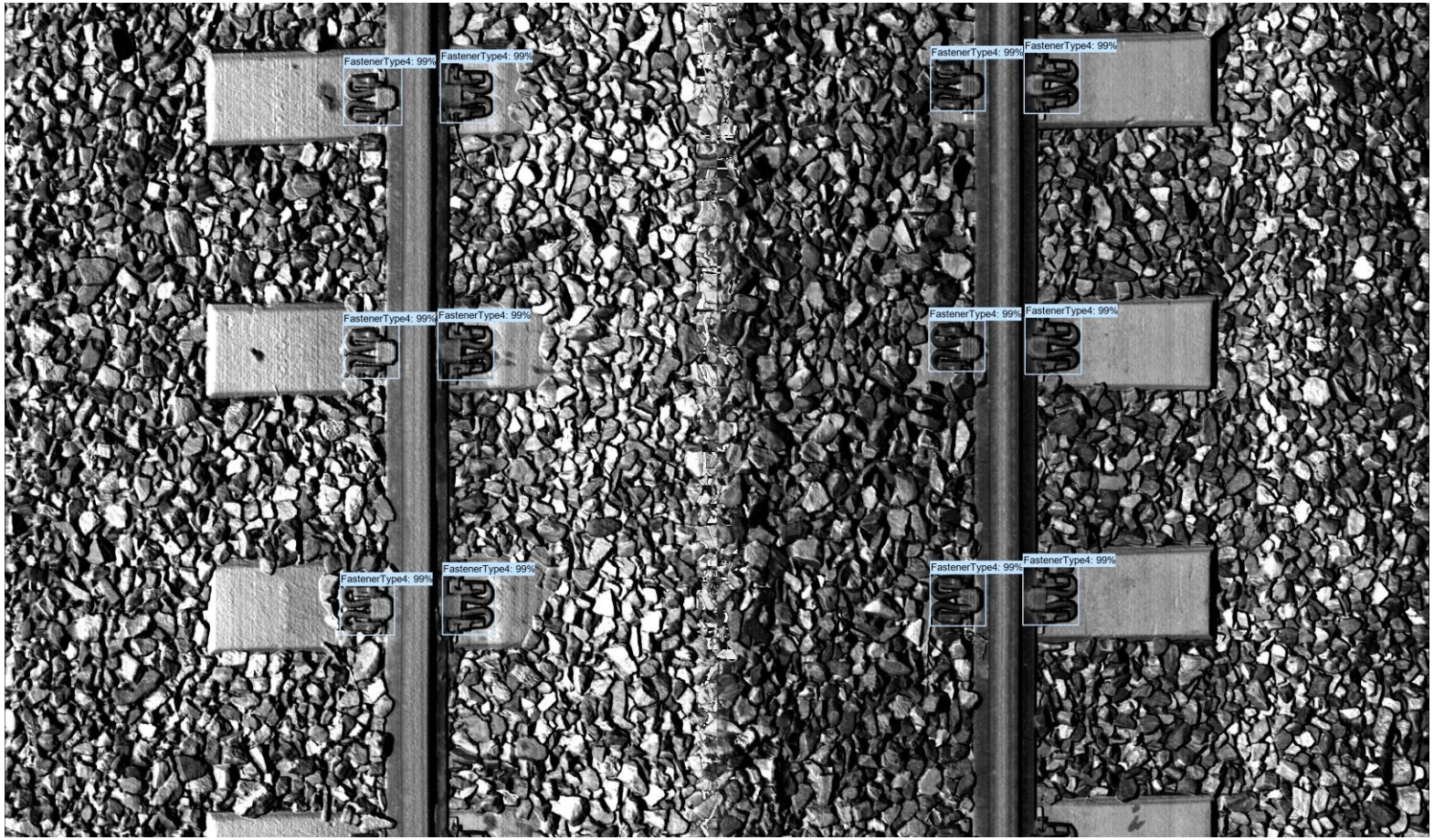
Preliminary Results – Fastclip



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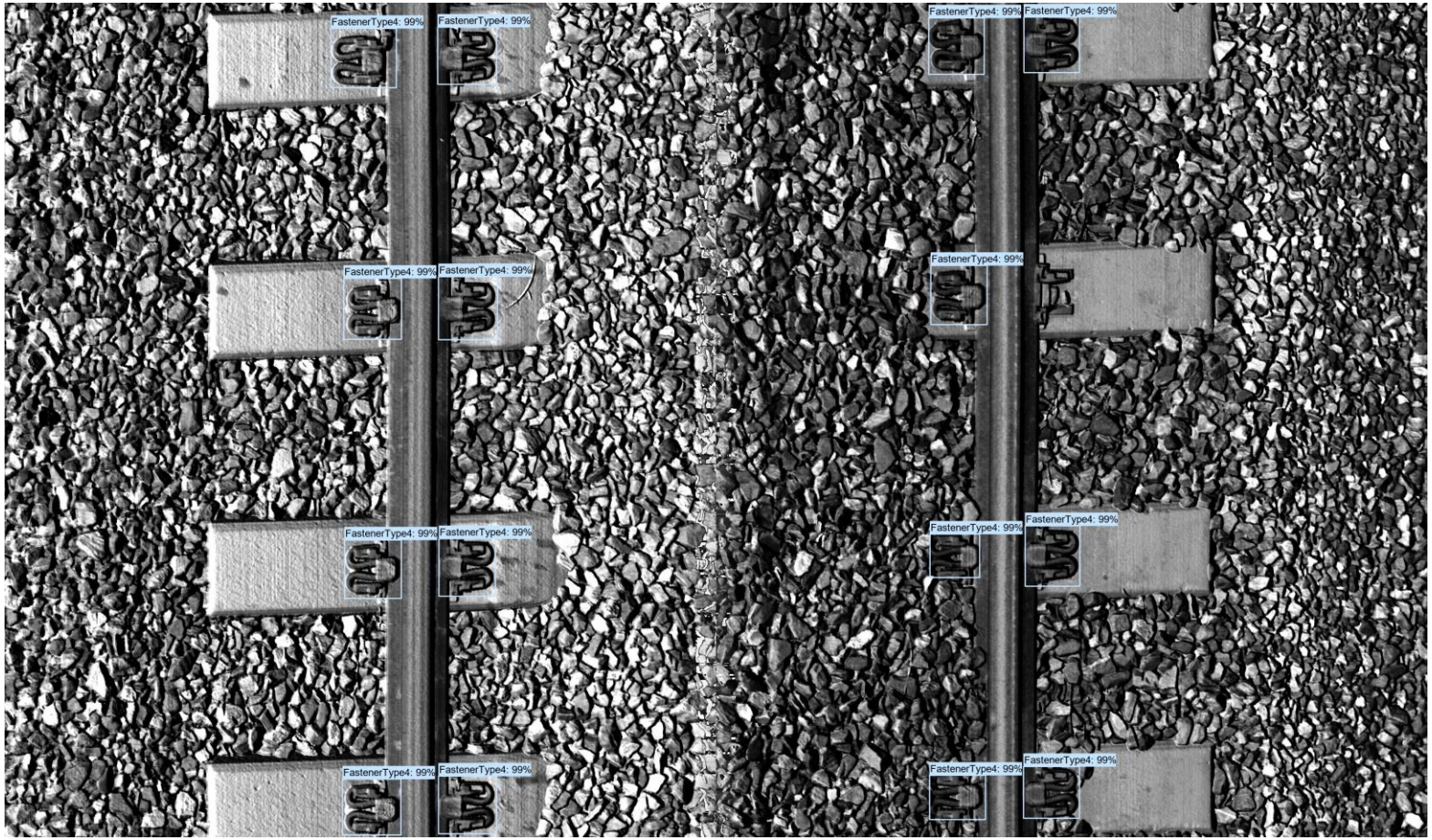
Preliminary Results – Fastclip



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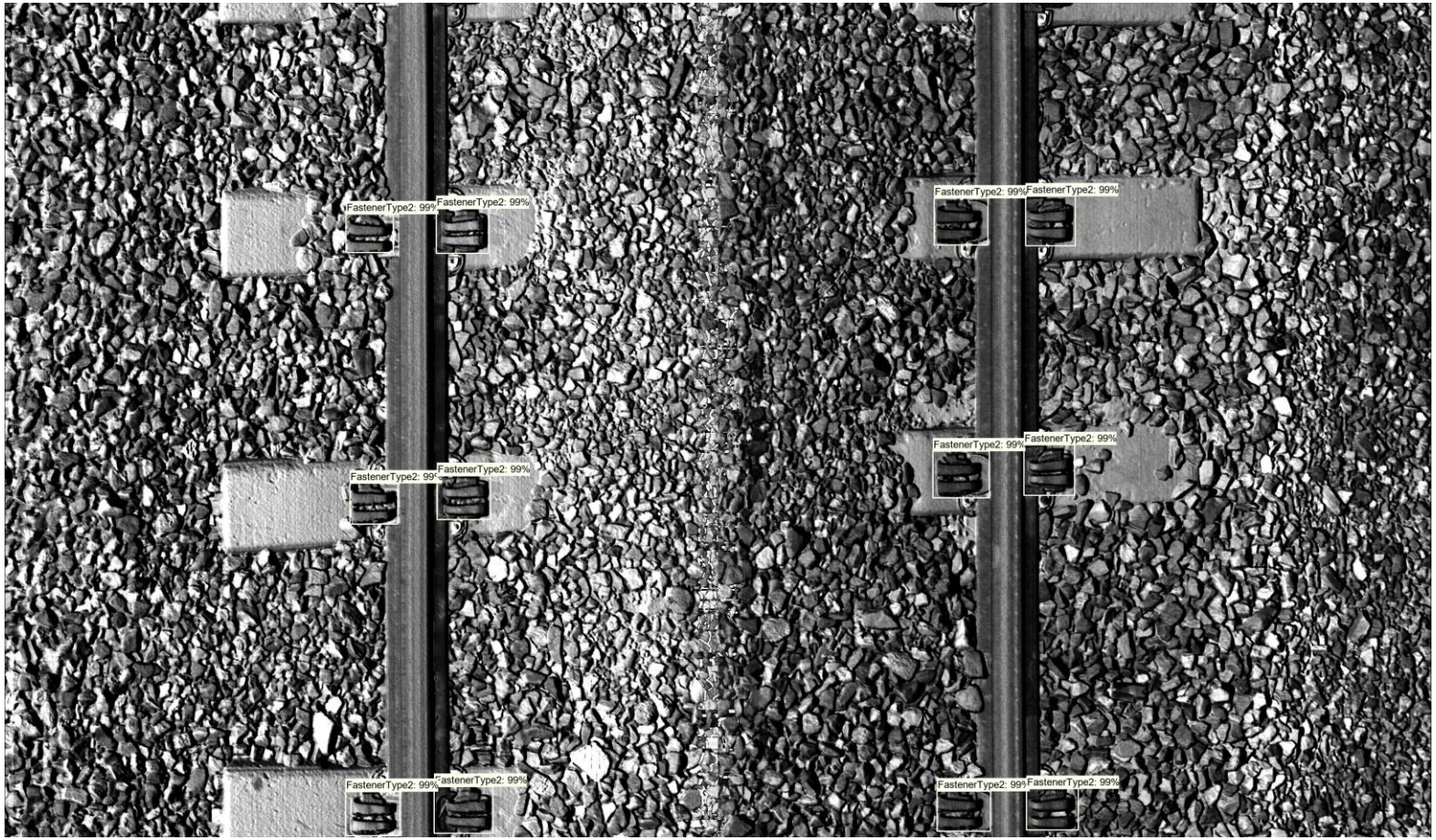
Preliminary Results



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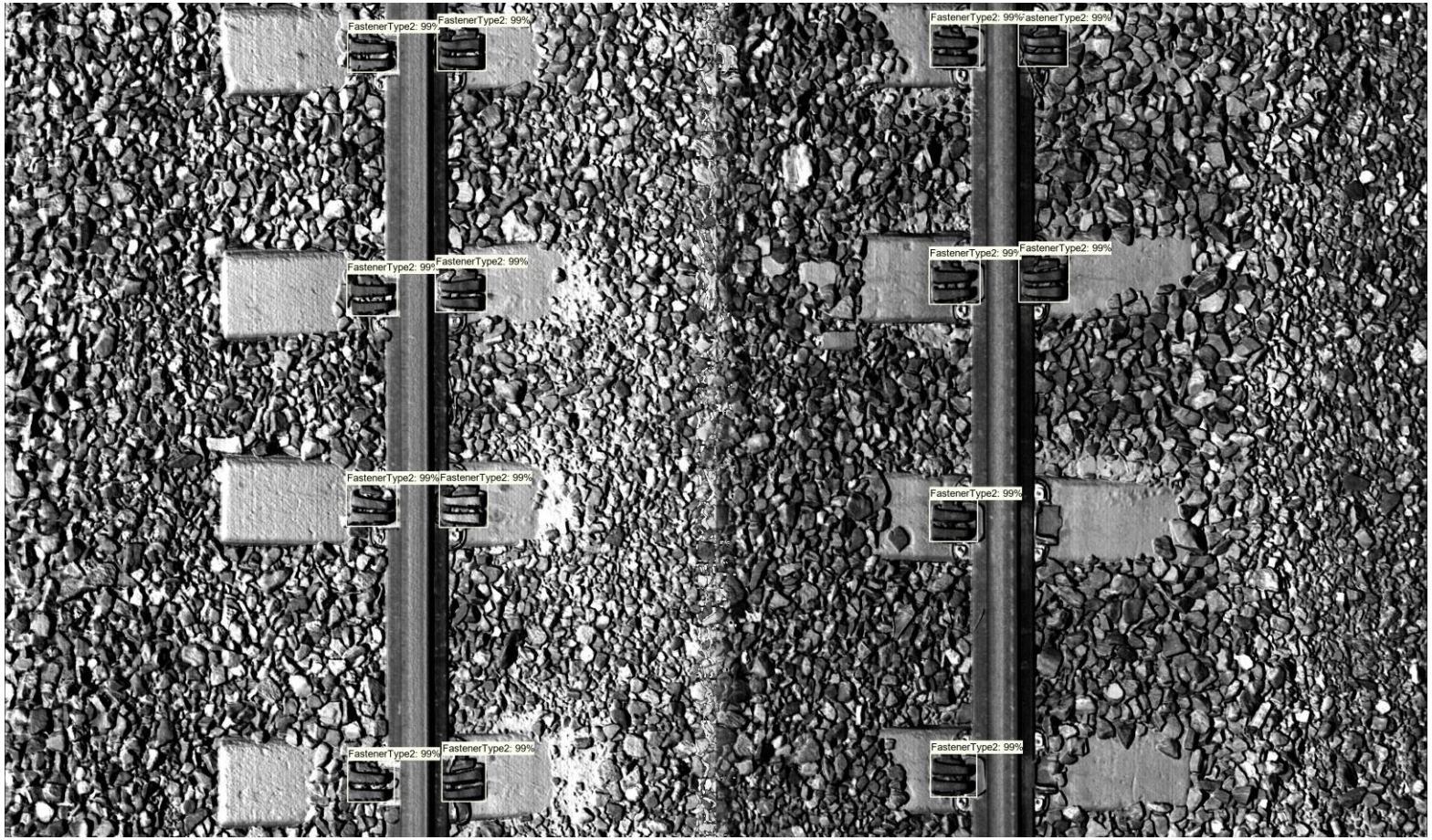
Preliminary Results



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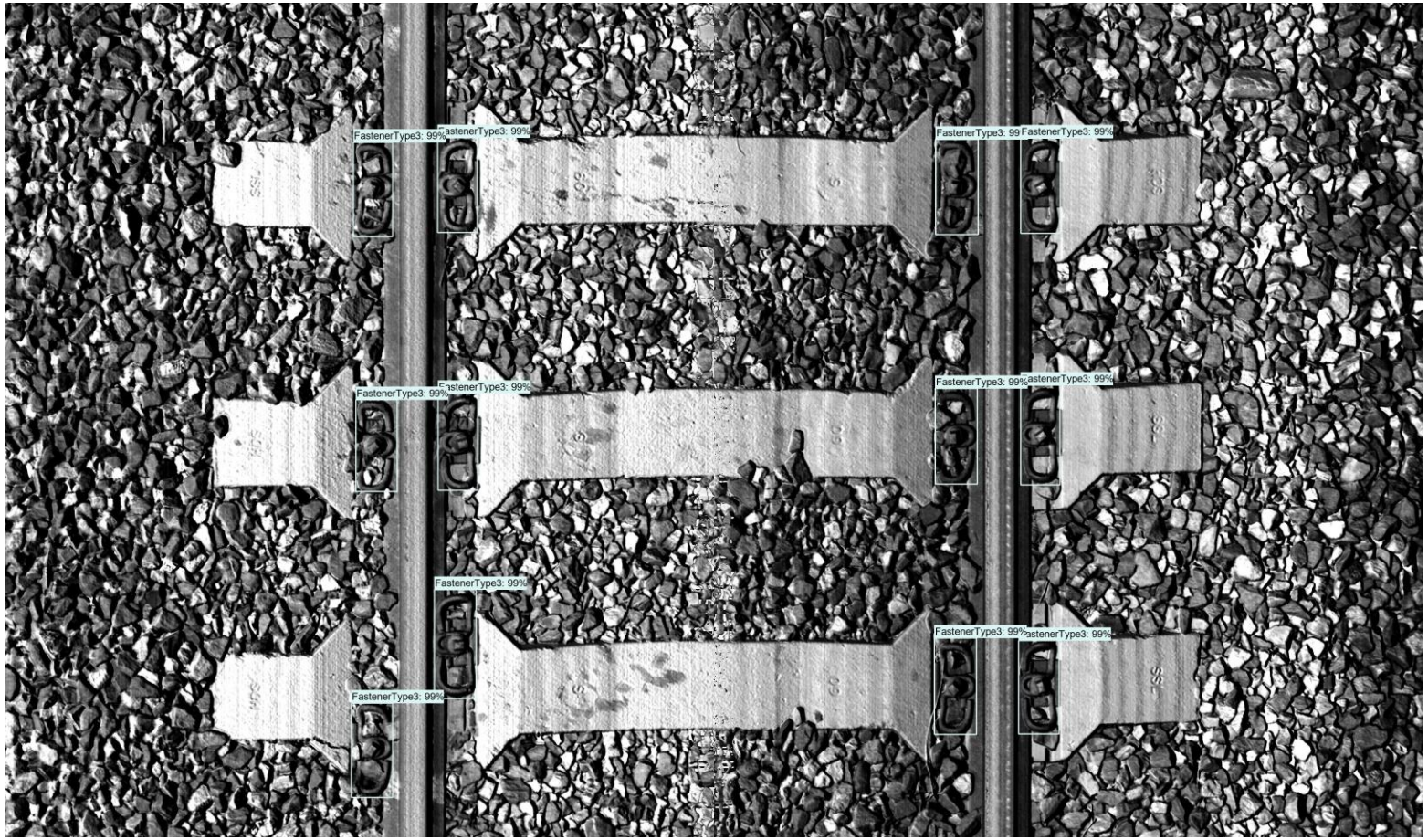

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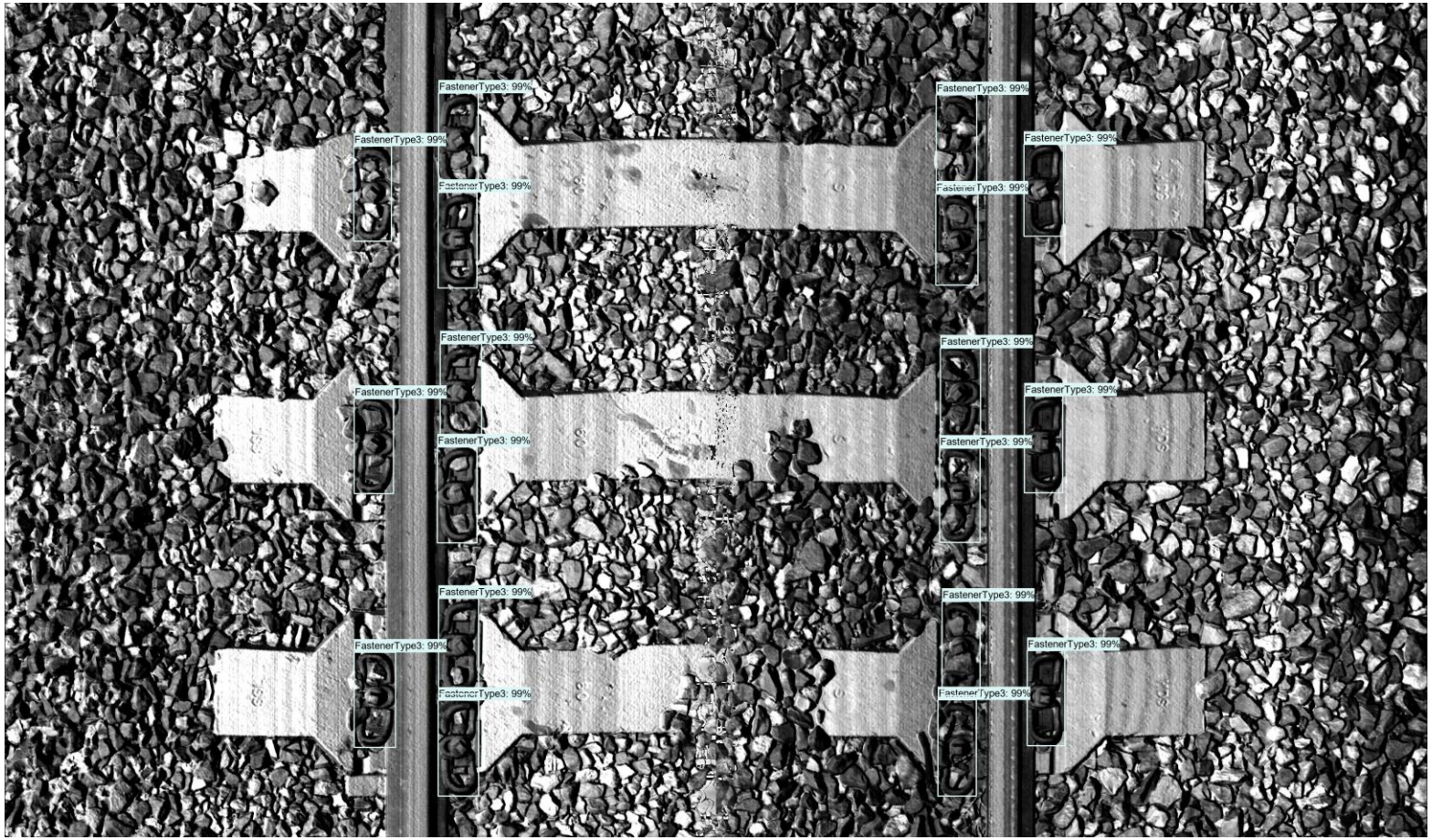

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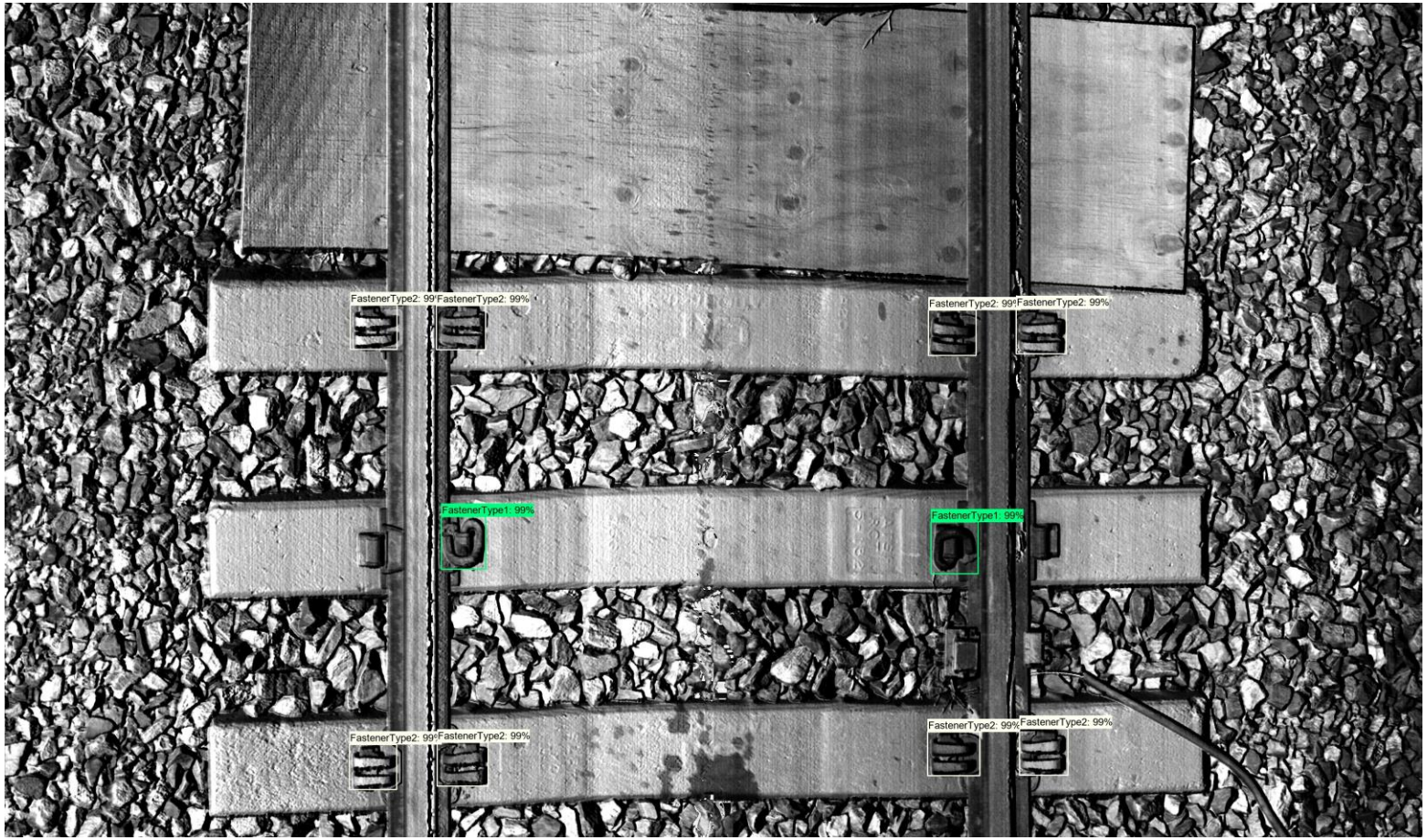
Preliminary Results



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Change Detection

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Change Detection Process

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

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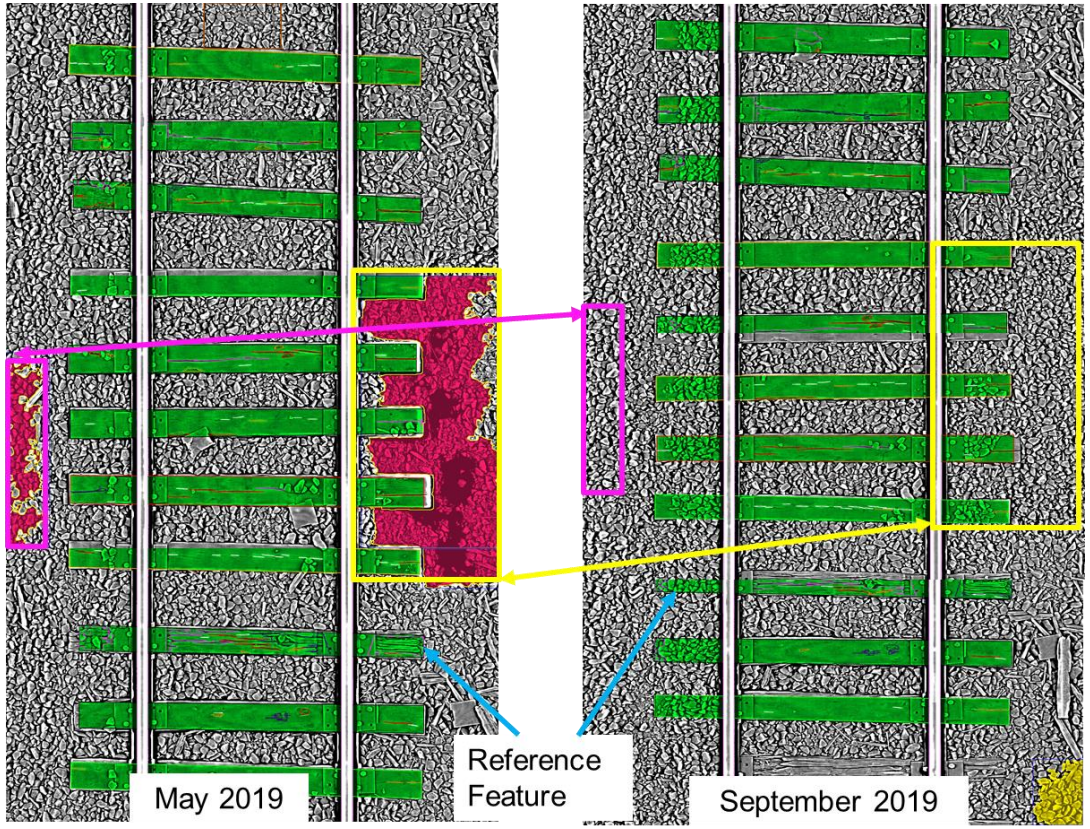
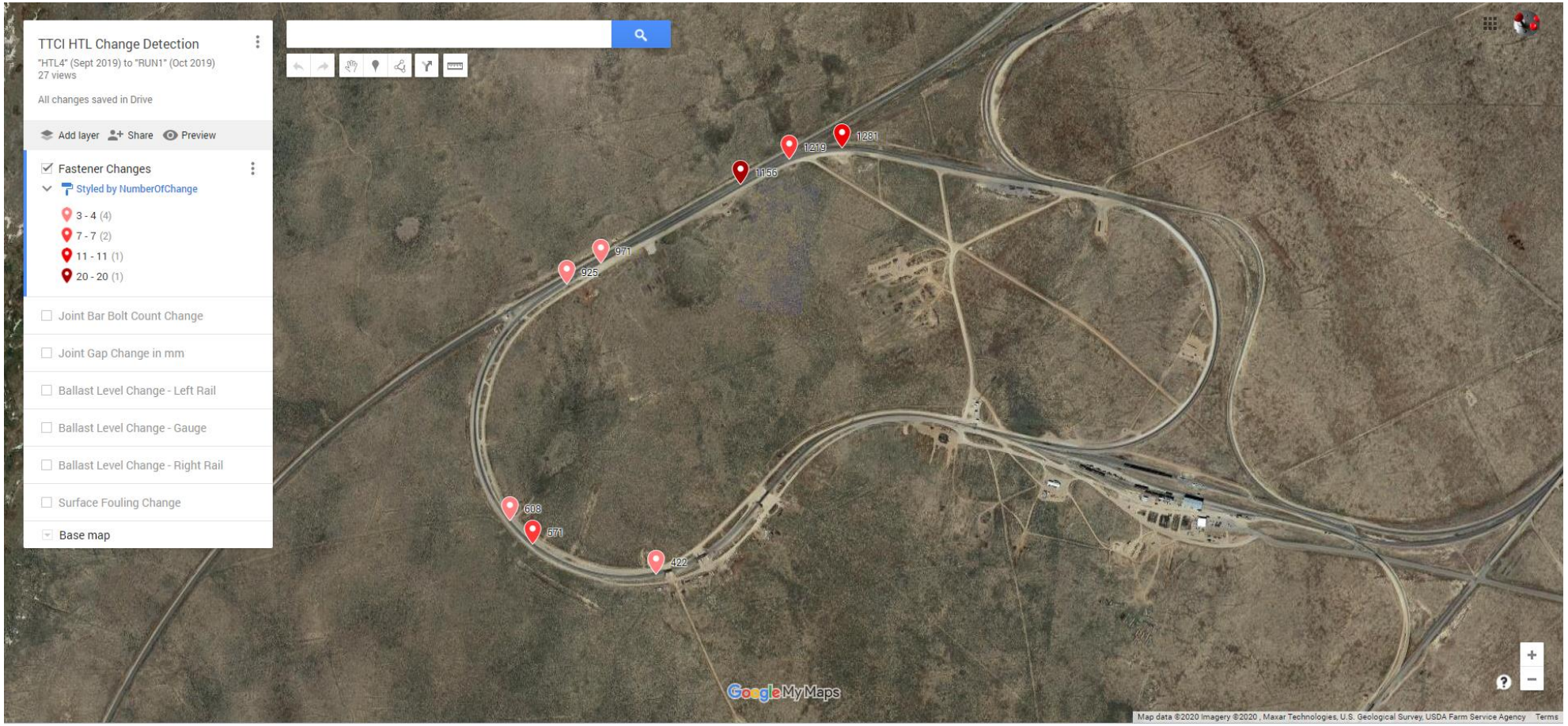
Run-to-Run Alignment

- 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



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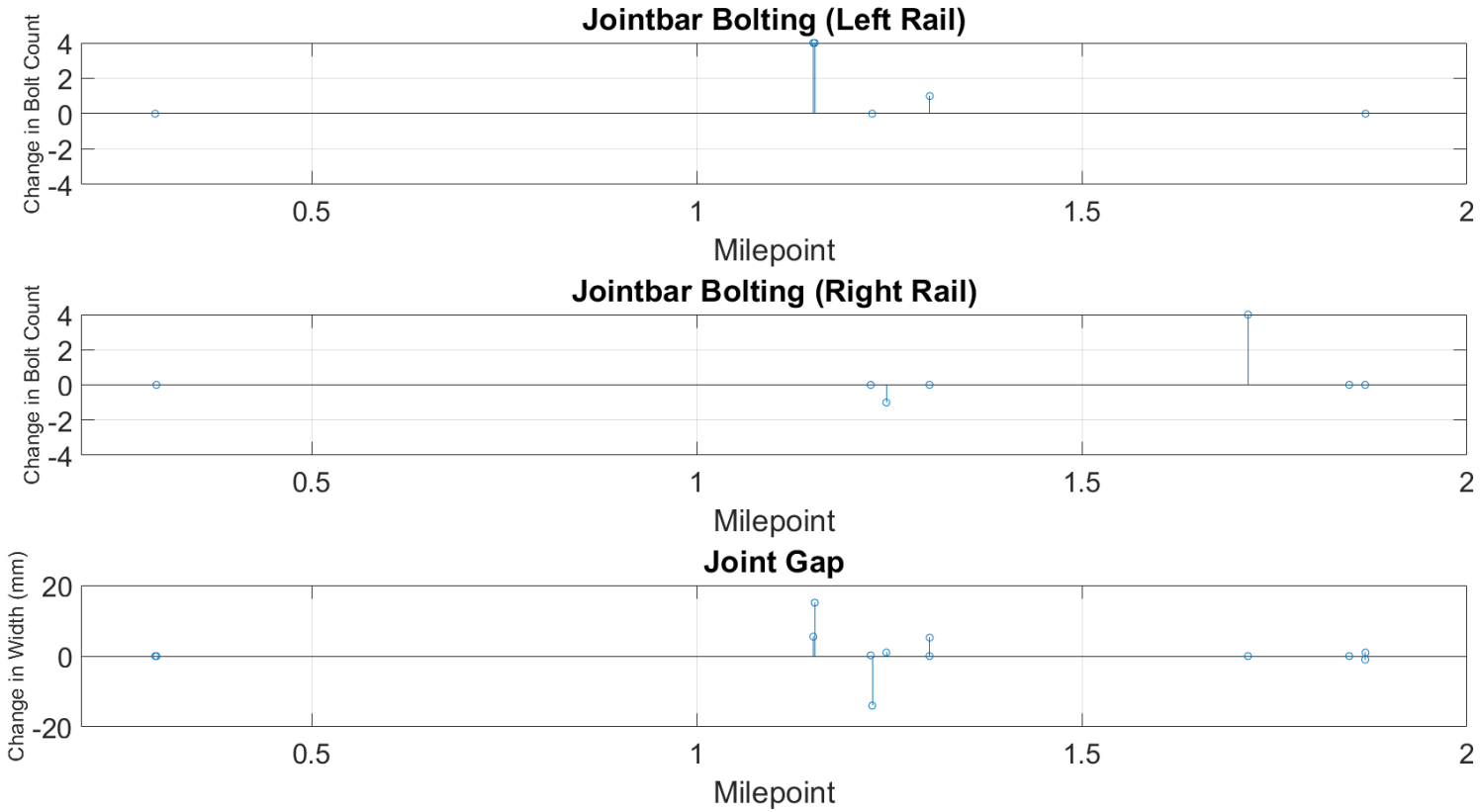
Initial Change Detection Results from TTCI (Joint Bar Bolting)



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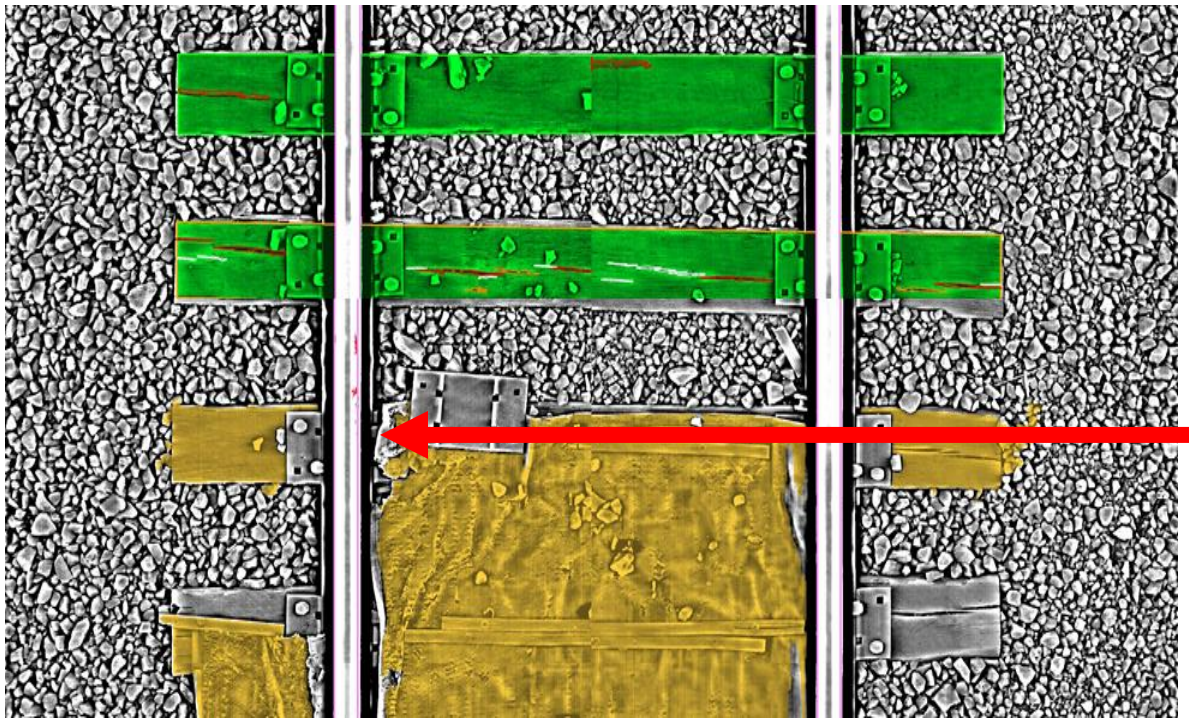
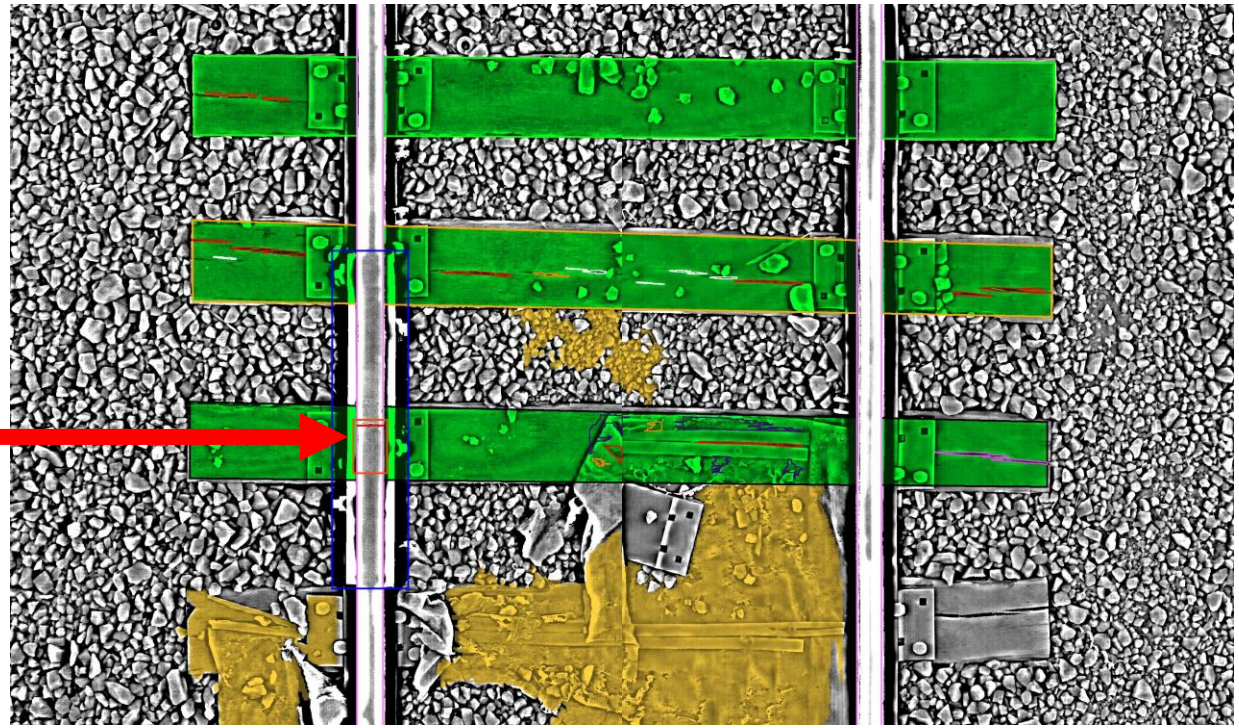
Joint Bar Change (Sept 10 vs. Oct 23, 2019)



Continuous Rail



Joint and Bar Added

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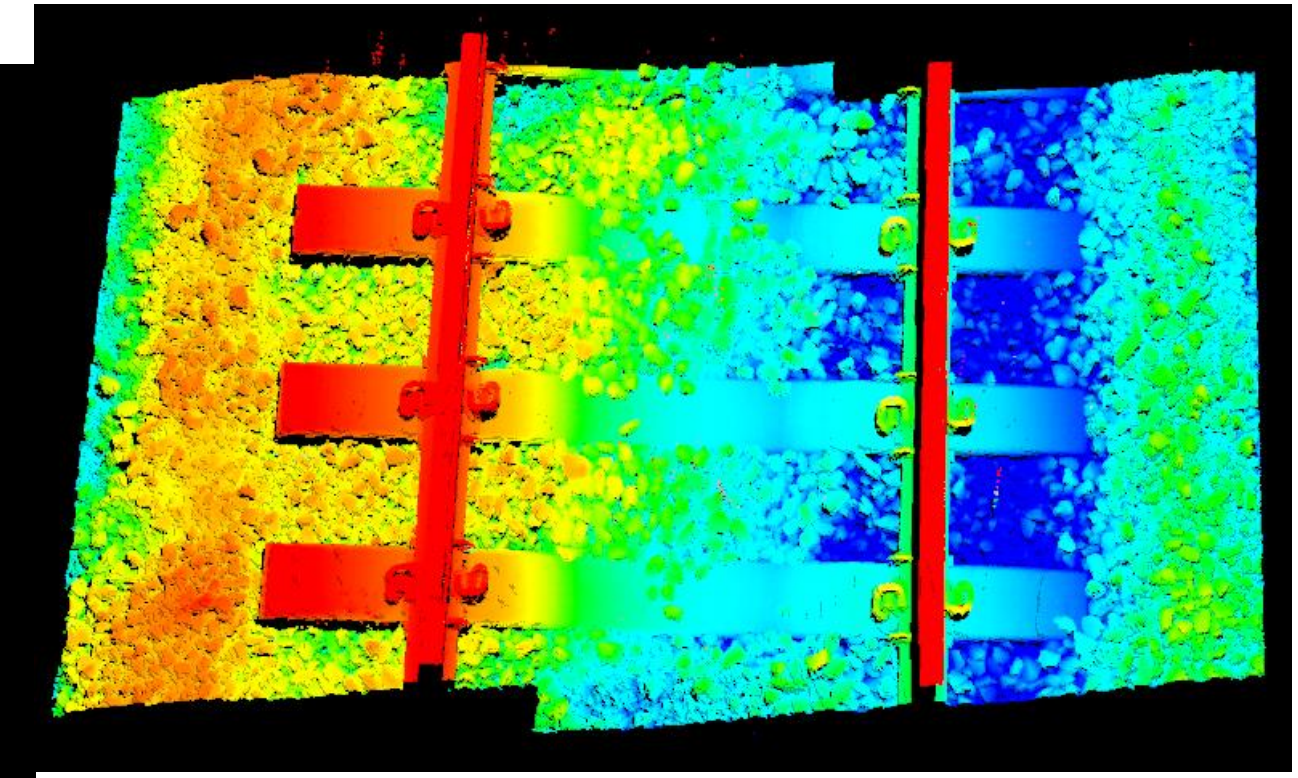
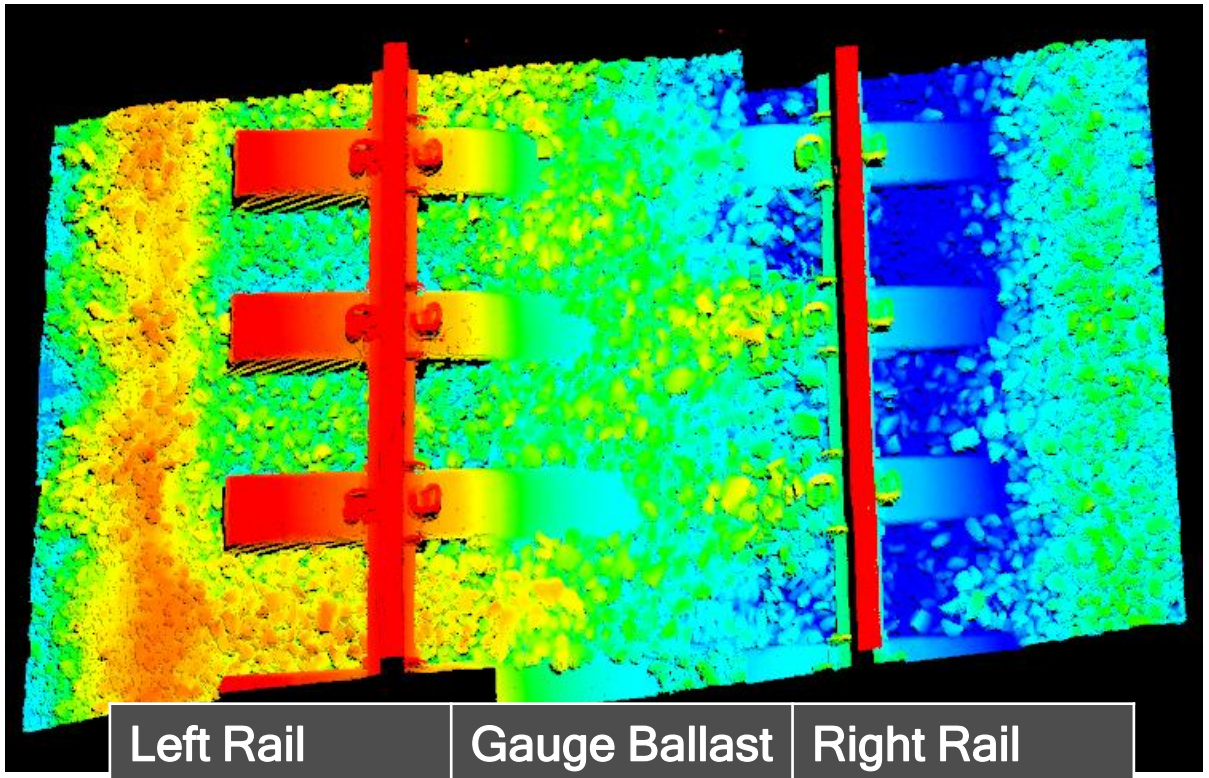
Ballast Level Change (Sept 10 vs. Oct 23, 2019)





Left Rail Ballast Change	Gauge Ballast Change	Right Rail Ballast Change
-23.82	8.44	0.33

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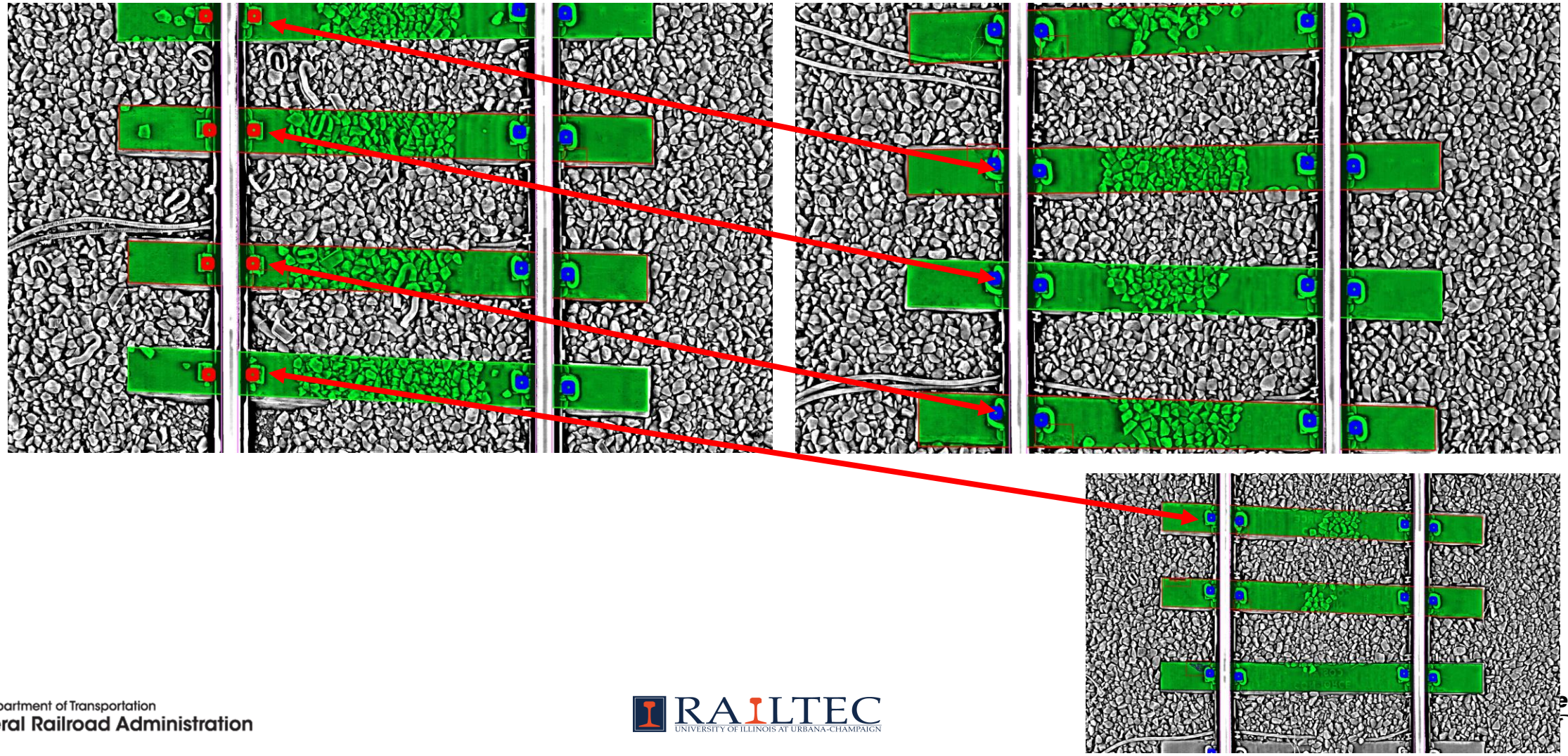
Fastener Change (Sept 10 vs. Oct 23, 2019)



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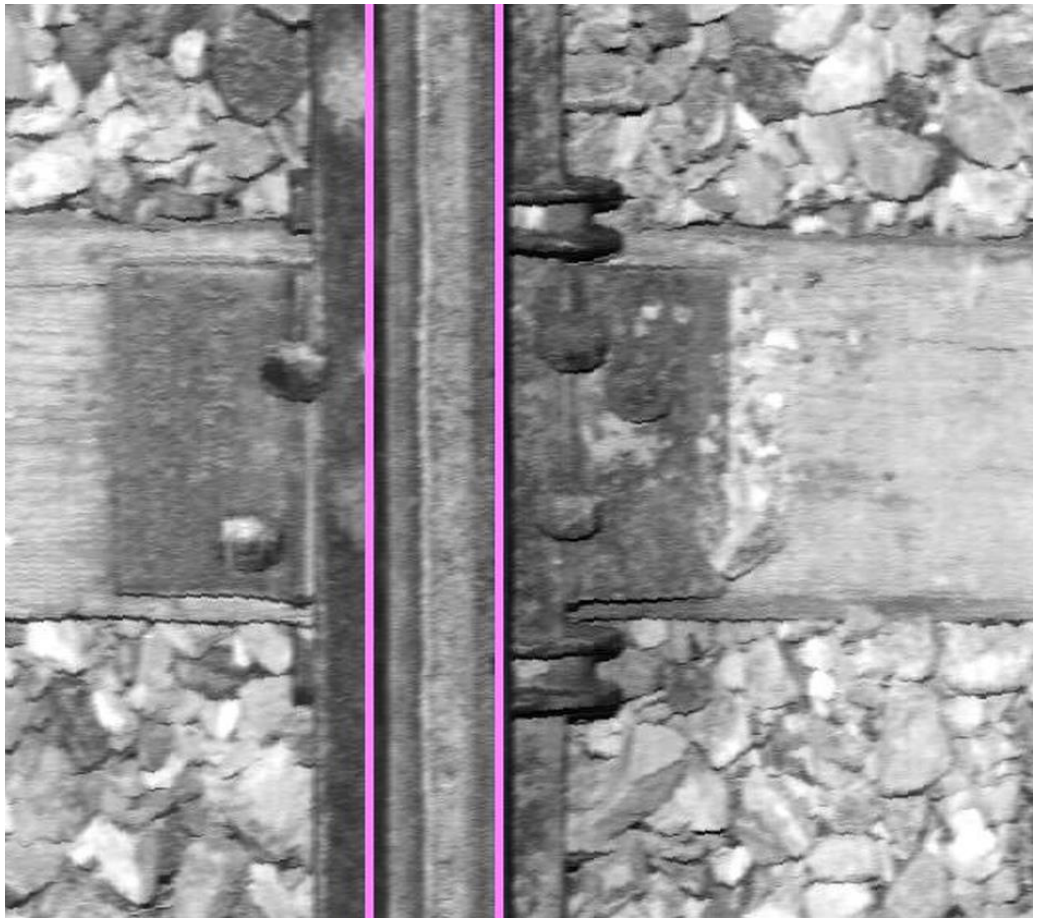
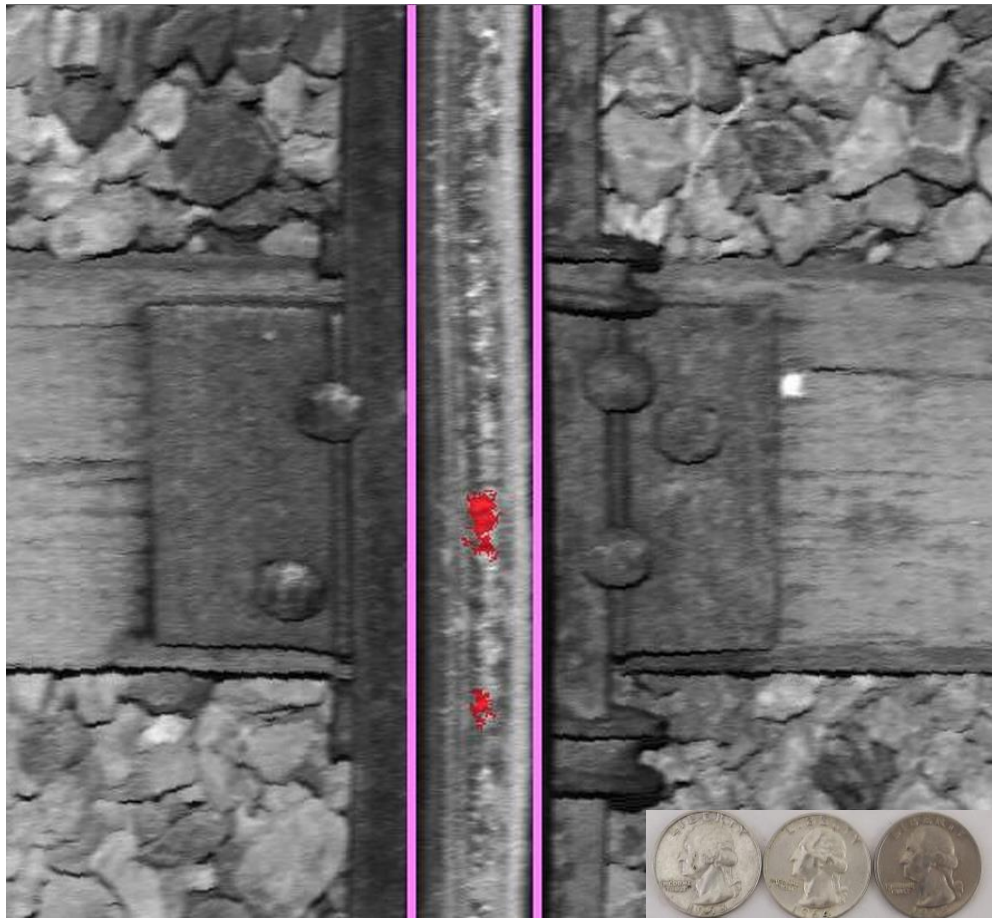
Rail Surface Defect Change (Increase, Sept 10 vs. Oct 23, 2019)





1,708 square mm…(17 sq cm, 2.65 sq inches)…about the size of 3 quarters

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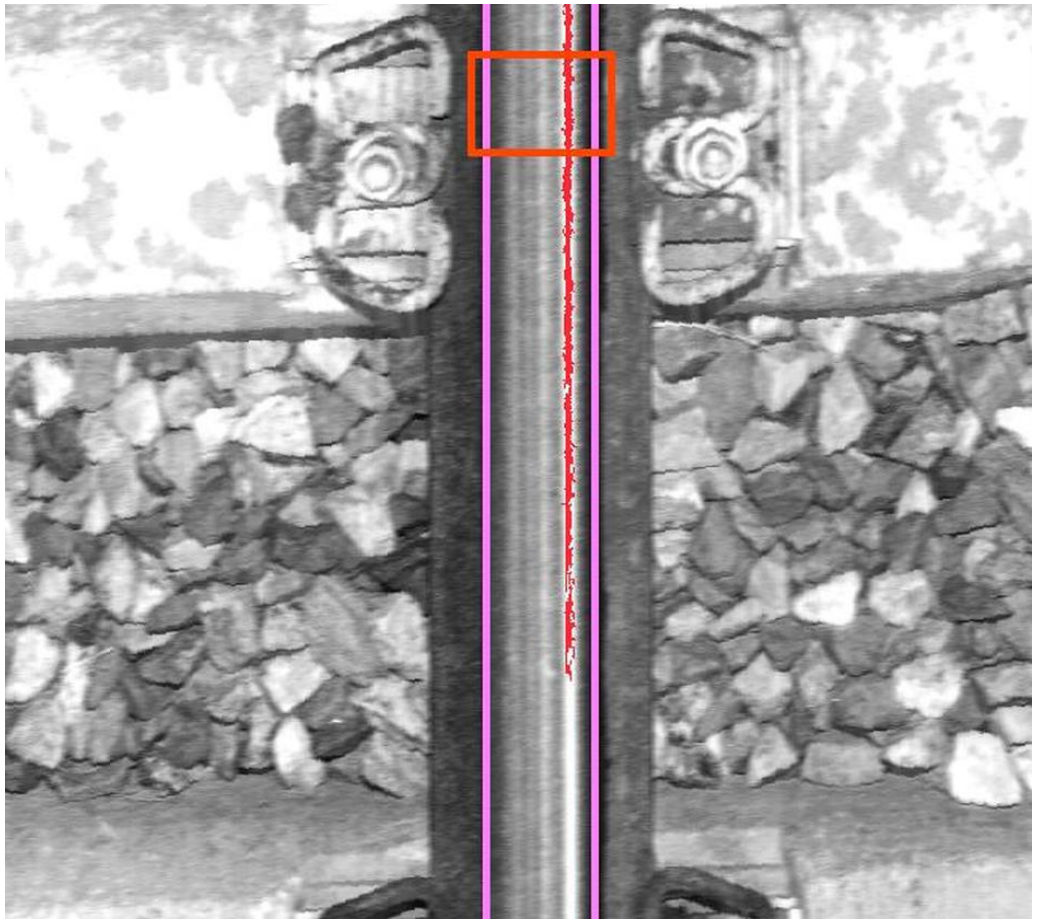
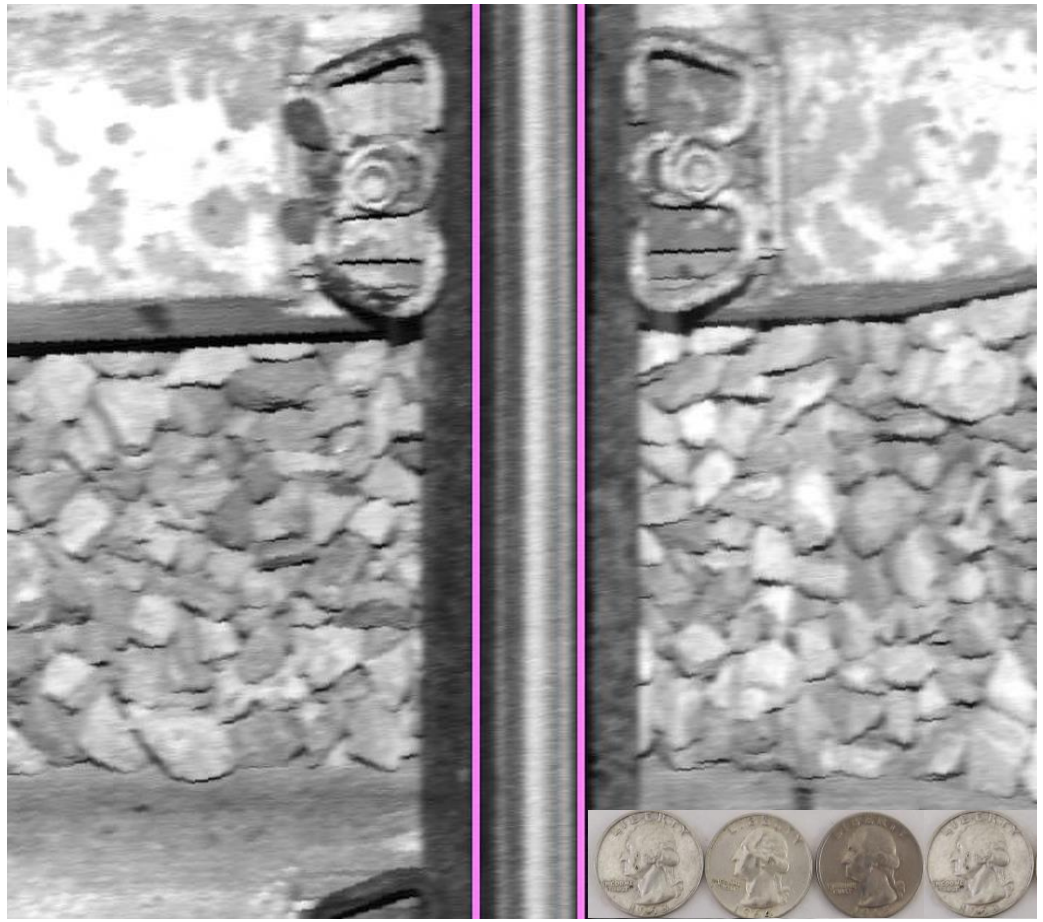
Rail Surface Defect Change (Decrease, Sept 10 vs. Oct 23, 2019)





1,933 square mm…(19 sq cm, 3 sq inches)…about the size of 4 quarters

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