A Feasibility Study of Machine-Vision Inspection of Railcar Structural Components

William W. Hay Railroad Engineering Seminar Series

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Presentation Outline

- Background
- Scope
- Objectives
- Domain Knowledge
- Field Experimentation
- Data Analysis
- Future Work
- Conclusions
- Questions and Comments

Car Inspection Background

Why are railcars cars inspected?

- Safety
- Efficiency

Inspections address:

- Braking System
- Safety Appliances
- Structural Components
- Other components that relate to the safe operation of a train

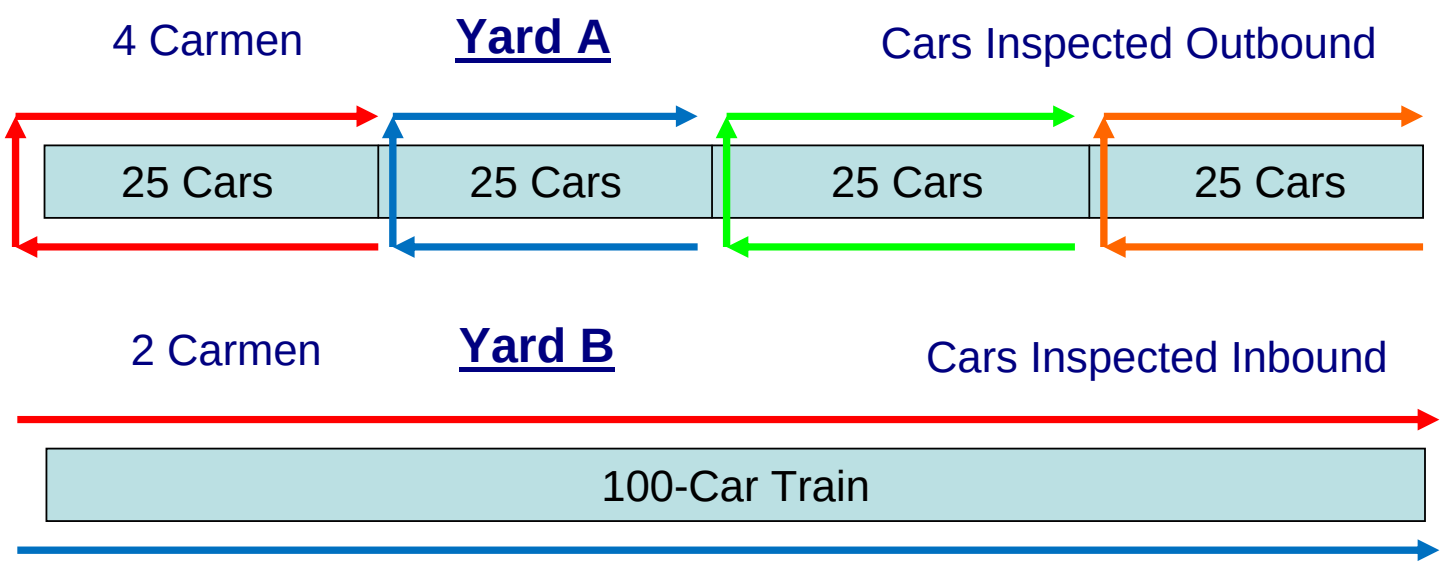
Typical inspection senarios:

- Inbound car inspection
- Outbound car inspection
- Initial terminal air brake inspection
- 1000-mile air brake inspection

Motivation

Current Car Inspection Process

- Labor intensive
- Inconsistent objectivity and effectiveness
- Inspections are not easily documented making defect trending difficult
- Inefficient use of skilled labor (carmen)



Motivation (Cont.)

Automated Car Inspection

- Enhances train inspection efficiency and safety
- Enables trend analysis and preventative maintenance of railcars
- Improved inspections achieve broader industry goals:
  - Increased rolling stock and component life
  - Reduced rolling stock accidents and in-service failures
  - Eliminating reactive maintenance
- Part of **AAR's Technology Driven Train Inspection (TDTI)** and the **Advanced Technology Safety Initiative (ATSI)**

- The inspection of railcar structural components is one example of an automated car inspection system that is currently under development to enhance inspection efficiency and safety

Project Scope: Section 215.121 of the FRA Mechanical Regulations

A railroad may not place or continue in service a car, if:

A. Any portion of the car body, truck, or their appurtenances (except wheels) has less than a 2.5” clearance from the top of the rail

B. The car center sill is:

1. **Broken**
2. **Cracked more than 6”**
3. **Permanently bent or buckled more than 2.5” in any 6’ length**

C. The car has a coupler carrier that is:

1. Broken
2. Missing
3. Non-resilient and the coupler has a type F head

Project Scope (Cont.): Section 215.121

D. After December 1, 1983, the car is a box car and its side doors are not equipped with operative hangers, or the equivalent, to prevent the door from becoming disengaged.

E. The car has a center plate:

1. That is not properly secured
2. Any portion of which is missing
3. That is broken
4. That has two or more cracks through its cross section (thickness) at the edge of the plate that extends to the portion of the plate that is obstructed from view while the truck is in place

F. The car has a broken sidesill, crossbearer, or body bolster

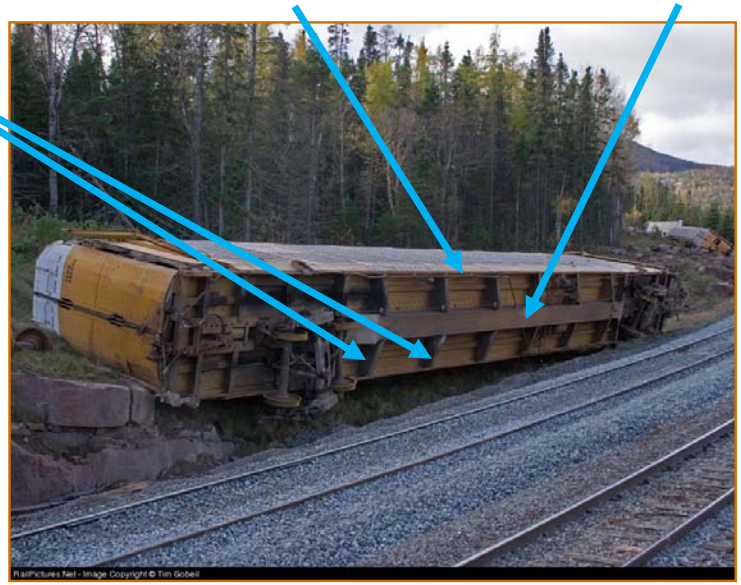
Summary of Scope (CFR 215.121)

- Inspect center sill for breaks, cracks, and buckling
- Inspect sidesills for breaks
- Inspect crossbearers for breaks

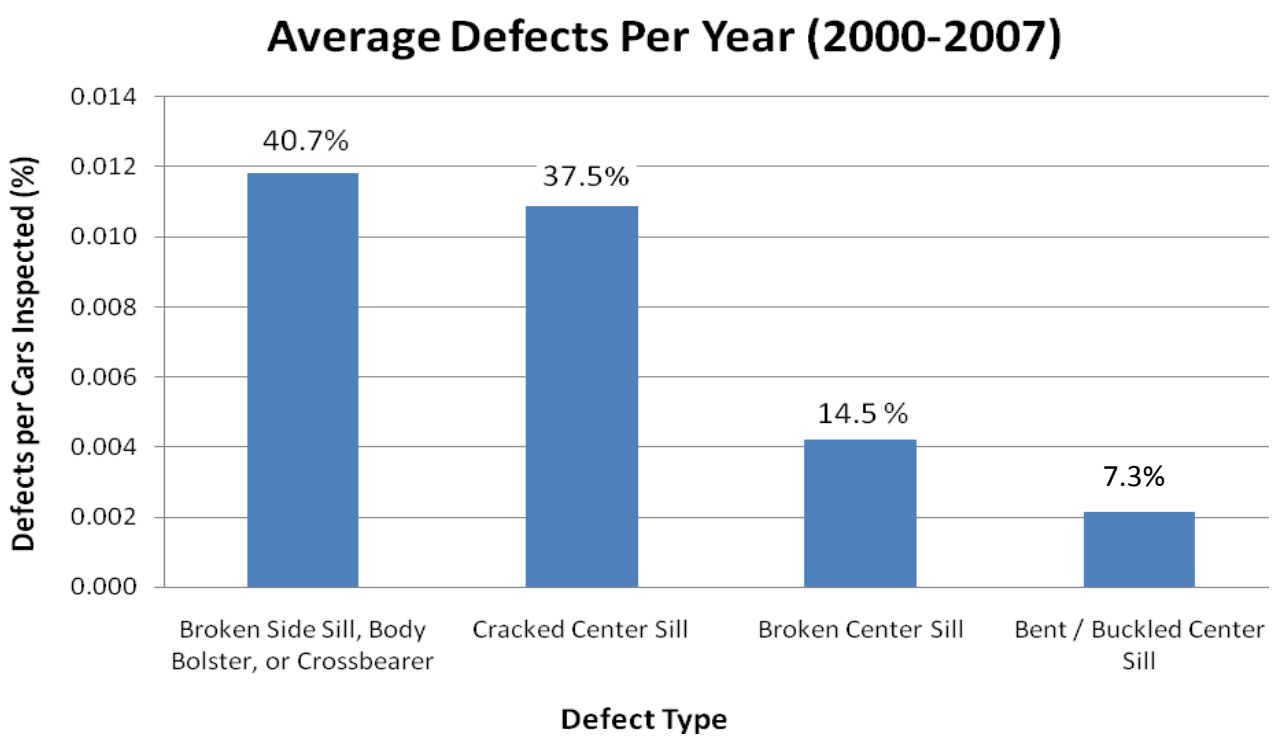
Crossbearers

Sidesill

Center Sill



FRA Car Inspection Data



- Data only includes components within the initial project scope
- Center sill defects represent approximately 60% of defects within scope

Objectives

The objective of Automated Inspection of Structural Components (AISC) is to increase the effectiveness and efficiency of railcar structural car component inspections through the use of machine vision technology.

The machine vision system must be capable of:

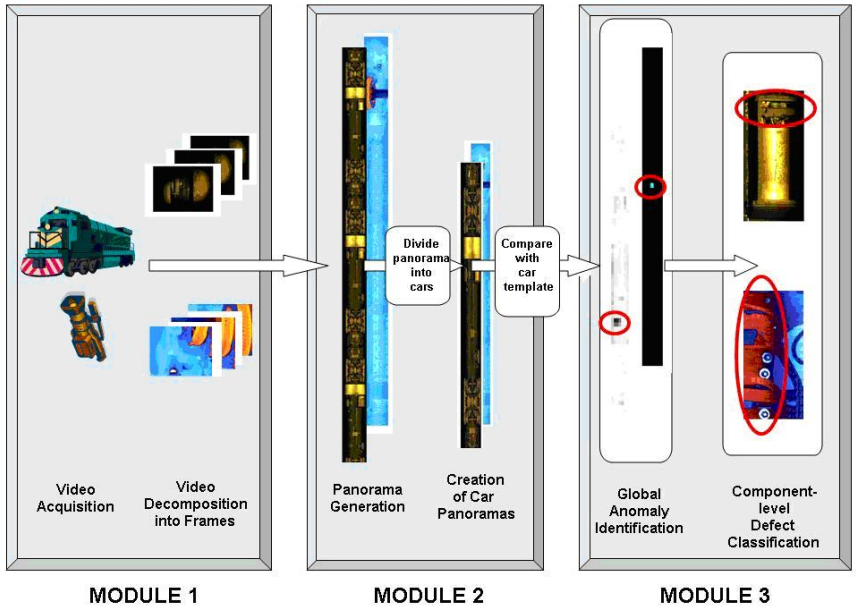
1. Capturing digital images of railcar structural components
2. Analyzing images to detect defects and deformations
3. Reporting necessary information to the interested parties
4. Collecting and storing historical inspection data for trend analysis to facilitate preventative maintenance

Work at the University of Illinois has focused on demonstrating the feasibility of this system.

Background / Previous Work

Machine Vision System for Railroad Equipment Undercarriage Inspection Using Multi-Spectral Imaging

- Acquired images from visible and infrared video cameras
- Three Modules:
  1. Video Acquisition
  2. Panorama Generation
  3. Anomaly ID and Defect Classification
- Developed image acquisition methods and multispectral Machine Vision techniques for railcar and locomotive underbody inspection



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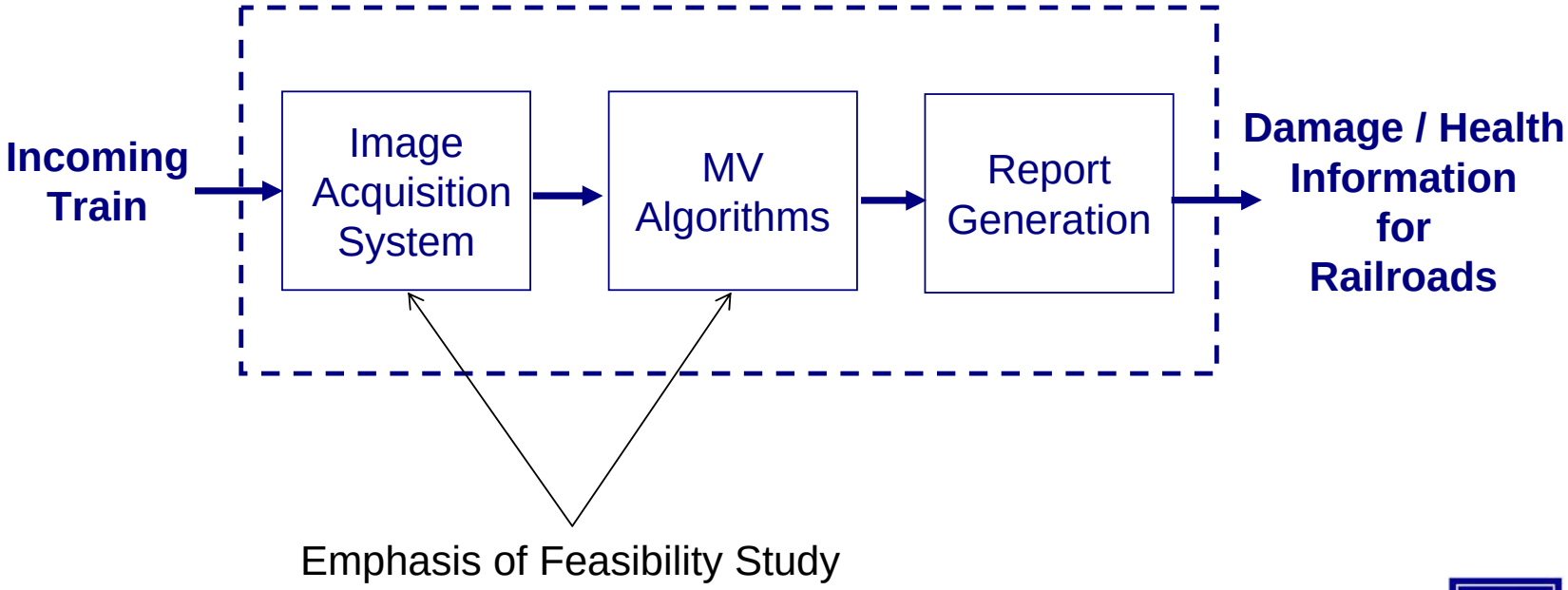
Machine Vision

Machine Vision provides a means of performing inspections by acquiring digital images and analyzing the images using image processing software



Gathering Domain Knowledge

Norfolk Southern

Car Repair Shop Tour

- Acquired information regarding car inspection processes from railroad mechanical department management

Site Survey

- Inspected locomotive repair facilities and took measurements for future testing
- Captured still images of car defects in car shop

Car Inspection

- Reviewed mechanical components of interest as well as the current car inspection process with NS repair program inspector

Post Testing Measurements

- Took measurements and still images to calibrate video data (pixel to ft. ratio)

Canadian National

Car Repair Shop Tour

- Reviewed mechanical components of interest and took still images of defects
- Tested portable image acquisition cart on railcars in yard

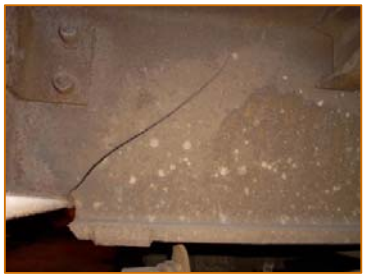
Car Inspection

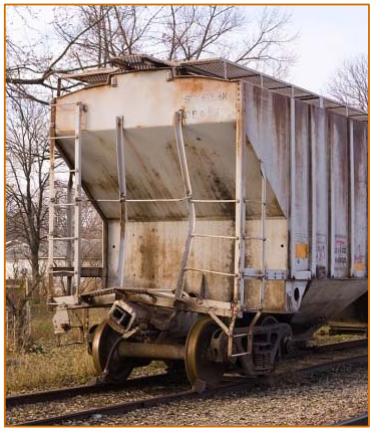
- Observed typical car inspection process with CN carmen
- Reviewed structural components of interest during inspections

Defect Definitions

- Break – a fracture resulting in complete separation into parts*
- Crack – fracture without complete separation into parts, except castings with shrinkage cracks or hot tears that do not significantly diminish the strength of the member*
- Bend – curved or crooked, warped, not straight
- Buckle - bulge or kink





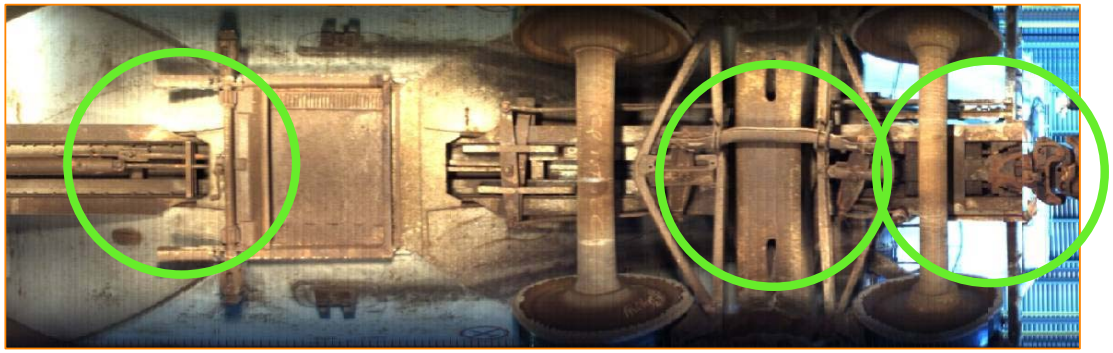



*From CFR Title 49 Part 215.121

Pictures from AAR and M. Wnek

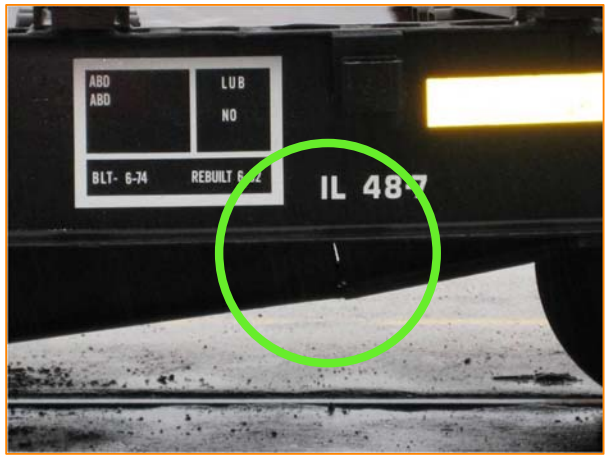
Common Crack Locations

- Locations where the load is transferred to the center sill
- Machined components creating discontinuity
- Transitions in the geometry or cross-sectional area of structural members
- Areas vulnerable to impact



Sources of Structural Damage

- Structural defects form as a result of repeated loading and unloading and generally initiate at areas of high stress concentrations resulting from:
  - Unbalanced loading
    - Most cars are constructed to support uniform loads, but in practice, they can be loaded improperly
    - Heavy loading in the center of the car can lead to high dynamic forces while moving
  - Improper use of the railcar
    - Overloading
    - Adapting cars to carry lading they were not designed for
    - Inappropriate coupling or hump yard practices



Field Experimentation

Monticello Railway Museum – Monticello, IL

- Initial feasibility test - acquired images of hopper car
- Developed procedure for equipment set-up and data collection

Image acquisition of cracked and broken components

Excel Railcar Services - Kenney, IL

- Tested feasibility of portable image acquisition cart
- Acquired images of flat car

Excel Railcar Services - Kenney, IL

- Tested feasibility of side mounted camera on image acquisition cart
- Acquired images of cracked center sills on two different flat cars

Transitech - Fordyce, AR

- Acquired images of flat car with broken center sill
- Improved data collection procedures with portable cart

Norfolk Southern - Decatur, IL

- Acquired images of gondolas and a covered hopper
- Improved procedure for collecting data from locomotive repair facility pits
- Tested image recording from three different camera angles

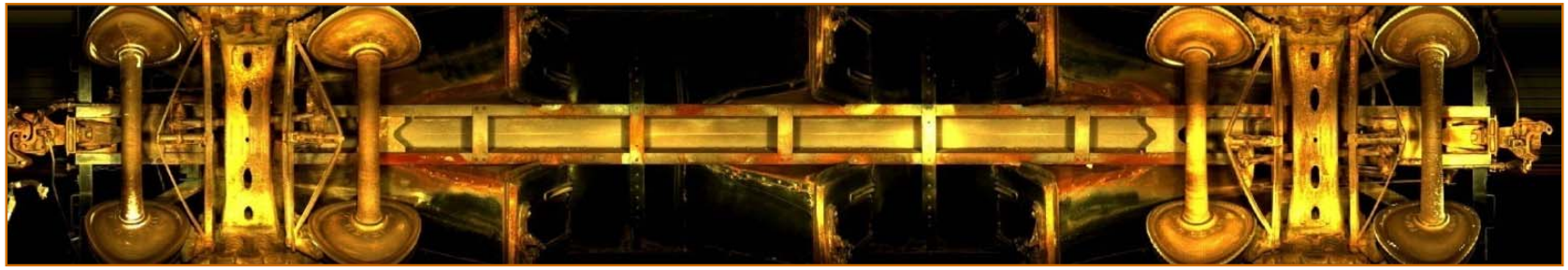
Proof of Concept: Image Acquisition

Experimental Setup: Monticello, IL

- Marlin CCD Camera (640x480)
- Eight movie production lights
- Lighting control board
- Wide angle lens (3.6mm)
- 36” Deep Repair Pit

Proof of Concept: Image Acquisition

Experimental Setup: Monticello, IL



- Successfully provided first image of a freight car underbody
- Displays very good view of center sill and truck components
- Lighting needed improvement to better illuminate crossbearers and hopper details
- Need location where in-service cars could be imaged
- Also need to image cars with deformations in components

Alternate Data Collection Methods

Inspection of Jacked Car - Kenney, IL

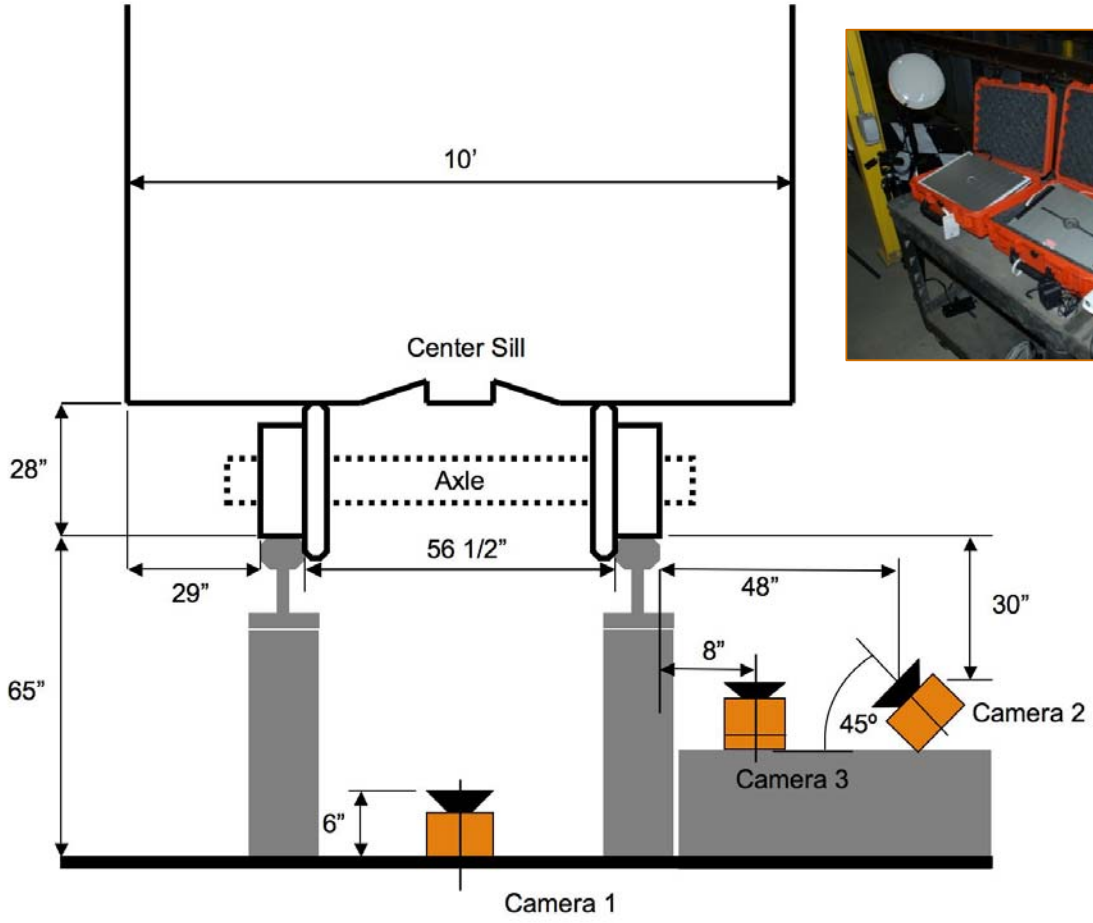
- Track cart equipped with camera at 90° angle
  - Only center sill; visible additional cameras required to inspect other structural components (e.g. side sills or crossbearers)
  - Close proximity to center sill may be favorable for crack detection
- Side attachment for acute angle view
  - Used to acquire images of sidesill and side view of center sill
  - Video data results provided basis for improving pit testing setup by using a side angle camera

Alternate Data Collection Methods

Inspecting Cars on Yard Tracks - Fordyce, AR

- Developed more portable data acquisition cart
  - Laptop
  - Car battery
  - Flourescent light
  - Dragonfly 2 Camera w/ wide angle lens
- Acquired images of underbody between trucks
- Only center sill visible; additional cameras required to inspect other structural components (e.g. side sills or crossbearers)
- Capable of acquiring images of defective cars that cannot be moved under AAR Interchange Rules

Proof-of-Concept: Equipment Setup



Proof of Concept: Image Acquisition

Class I Repair Facility Testing, Decatur, IL

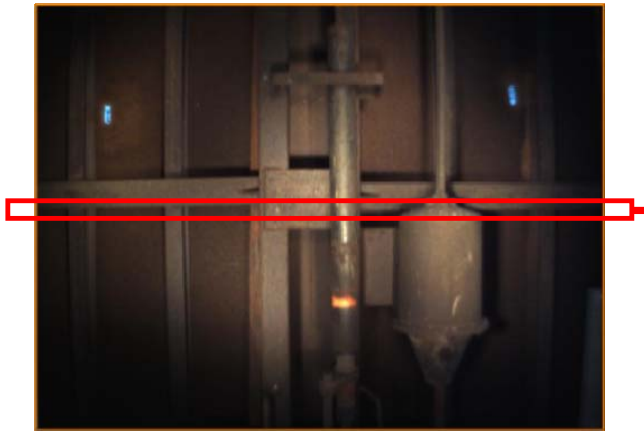
- Camera:
  - Dragonfly 2 Camera (640x480)
  - Wide angle lens (4.8mm f1.8)
  - Frame Rate: 15 fps
  - PVC camera mount
  - FlyCap software
  - 54 1/2” from camera to TOR
- Lighting:
  - Eight stage lights
  - Maximum 3900 FC per light
  - NSI 16 channel light controller
- Repair pit with elevated track

Proof of Concept: Image Acquisition

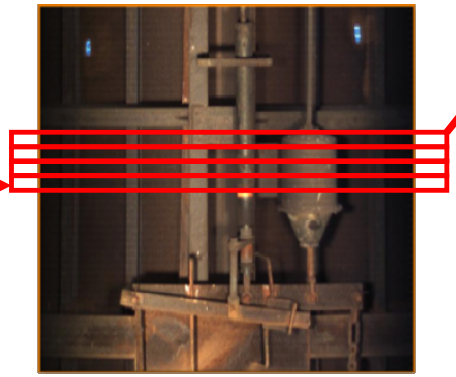
Class I Repair Facility Testing, Decatur, IL

Panoramic Image Generation

- Frames extracted from video
- Center strip of frame extracted
- Consecutive frames compared to determine speed
- Center strip length adjusted based on speed
- Strips ‘stitched’ together to create panoramic image of entire train / car



Video frames



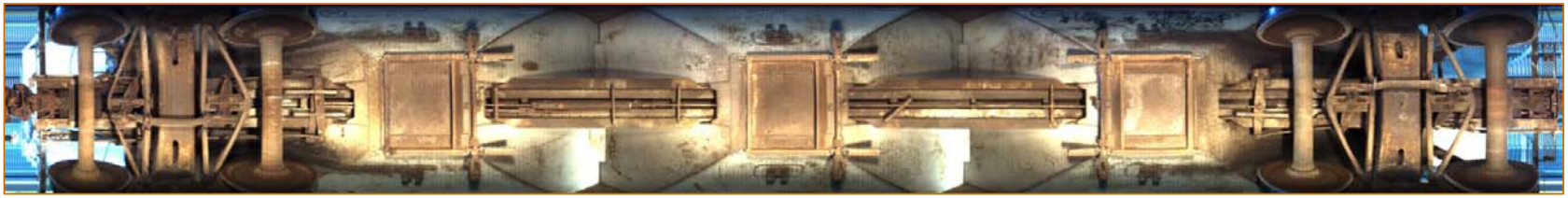
Stitched image

Railcar Panorama

Test Results: Comparison

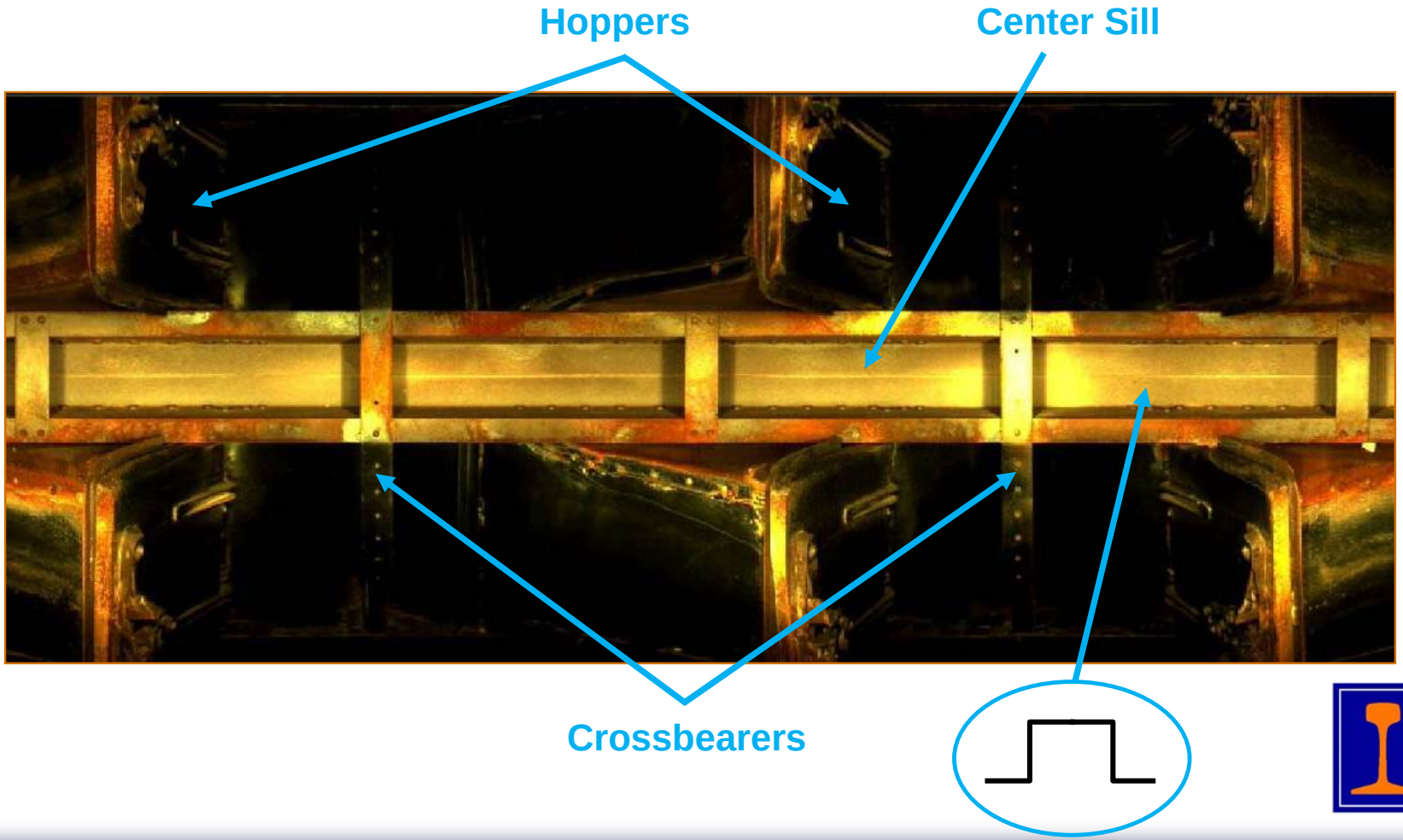
- Monticello Railway Museum Hopper - Monticello, IL

- Norfolk Southern Hopper - Decatur, IL

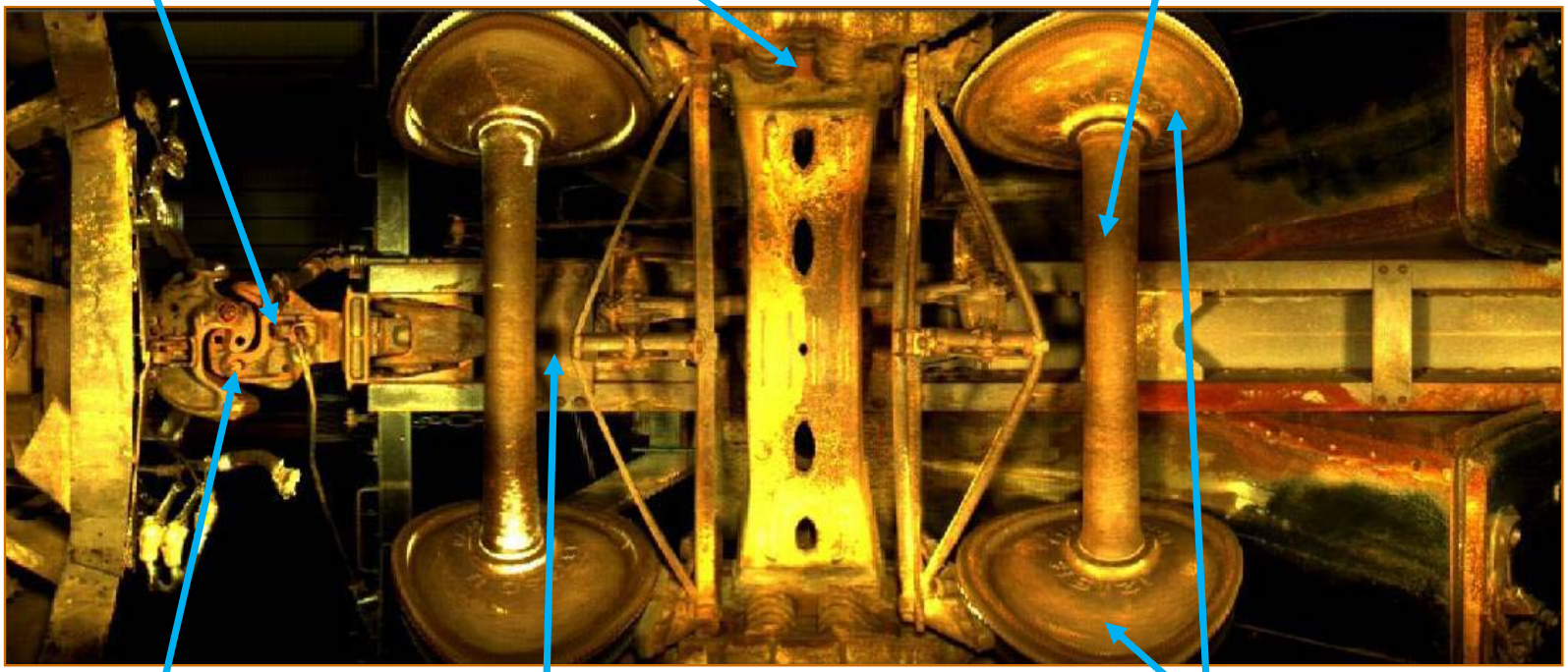


- Norfolk Southern Gondola - Decatur, IL

Imaging Results: Monticello, IL



Visible Components: Monticello, IL



Imaging Results: NS Decatur, IL

- Covered Hopper Car

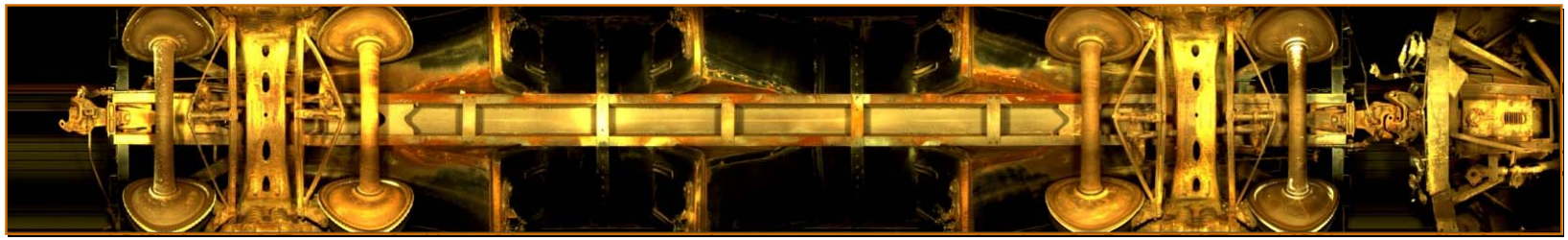
Imaging Results: NS Decatur, IL

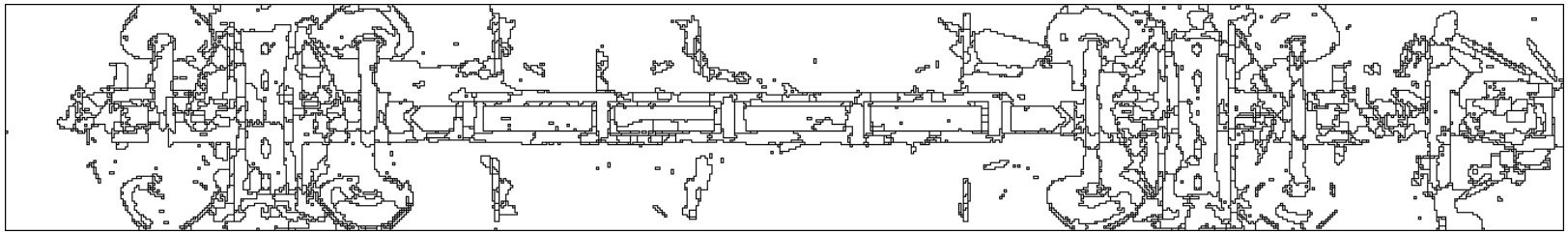
- Gondola

Proof-of-Concept: Data Analysis

Method 1: Multi-scale Image Segmentation

- Step 1: Multi-scale Segmentation



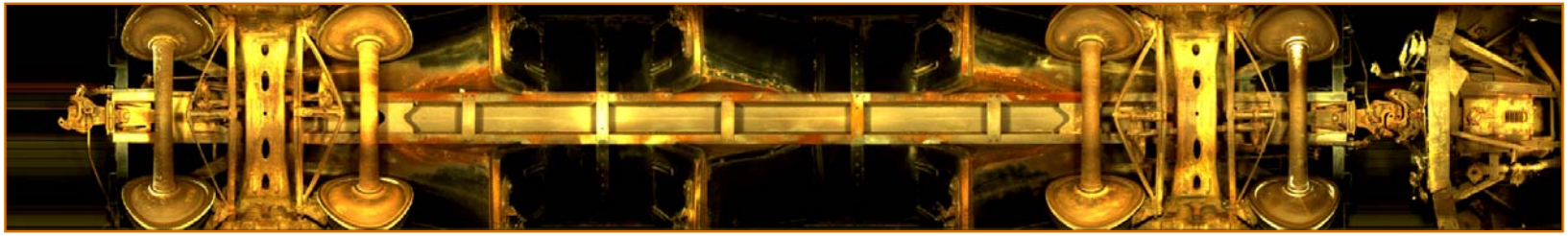


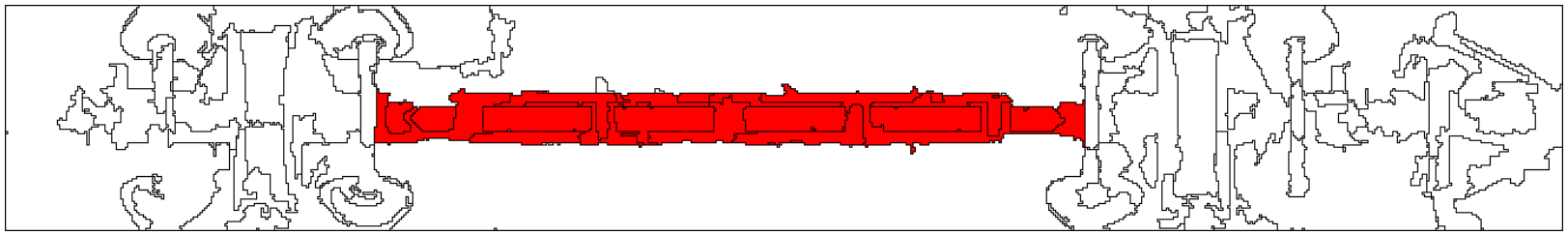
- Finds regions of certain pixel intensity at different scales
- Searches through levels of hierarchy to find best match
- Different templates matched at different levels

Proof-of-Concept: Data Analysis

Method 1: Multi-scale Image Segmentation

- Step 2: Center Sill Detection



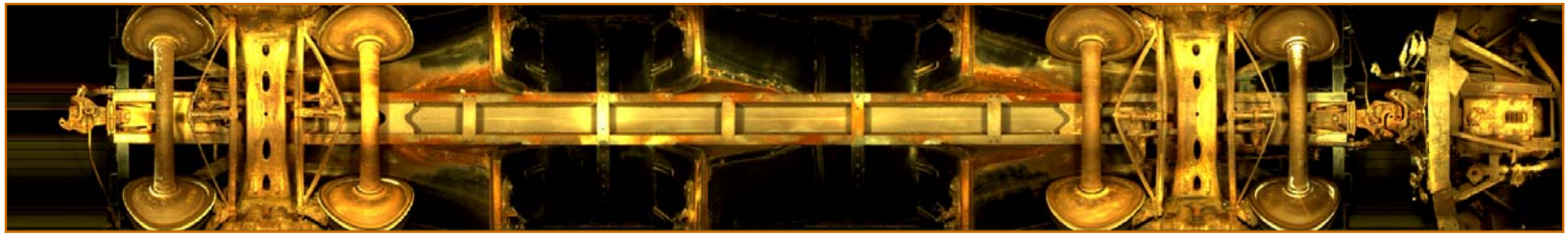


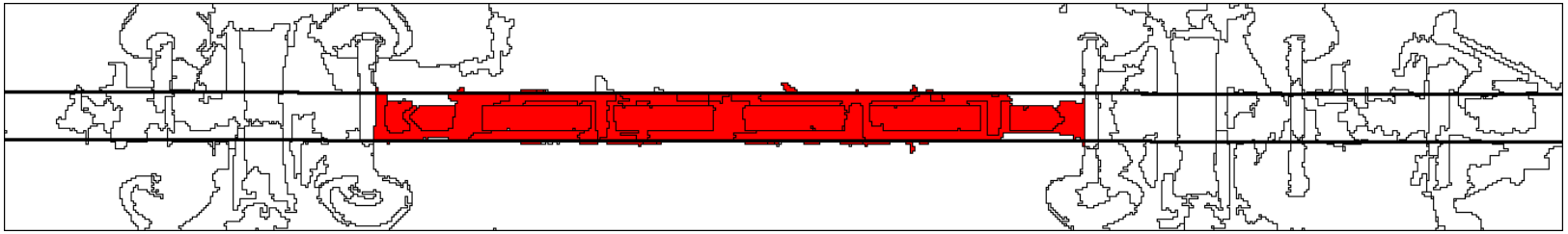
Detection is based on template matching

Proof-of-Concept: Data Analysis

Method 1: Multi-scale Image Segmentation

- Step 3: Measurement of centersill deformation





Estimation error: ± 2 pixels (± 0.3’’)
Deviation from the straight line is within reasonable margins of estimation error

Panorama Measurement Calibration

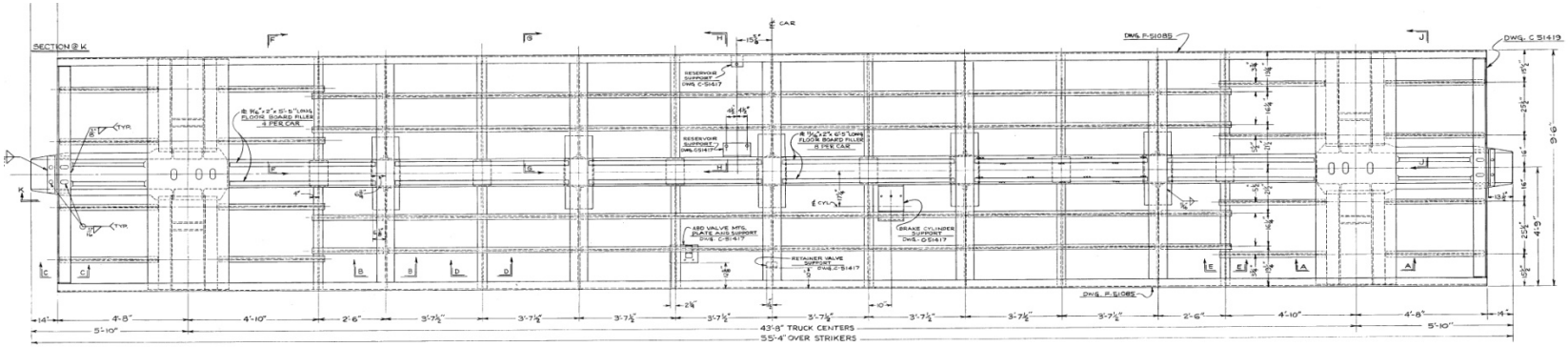


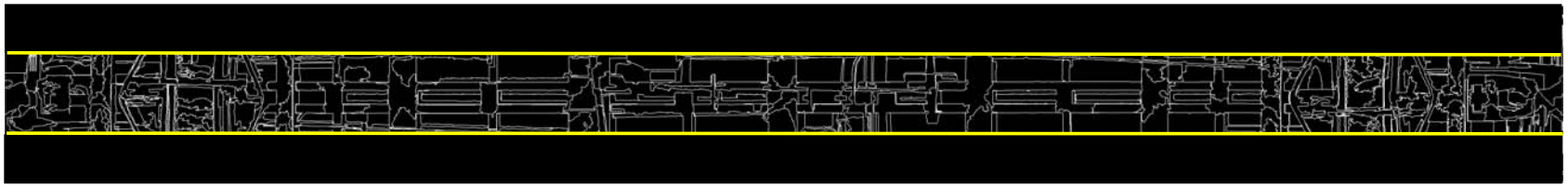
Image Calibration: 93.7 pixel/ft = 7.8 pixel/inch

1 pixel ~ 0.13 inches

Proof-of-Concept: Data Analysis

Method 2: Pixel Summation

- Step 1: Create Edge Image of Gondola Panorama

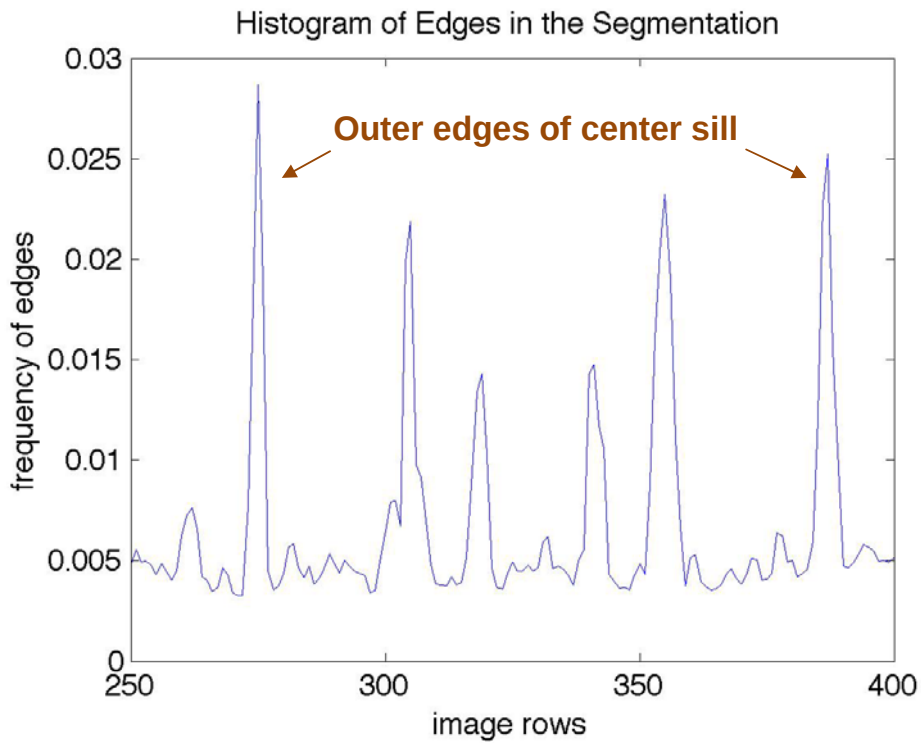


Detection is based on summing of pixels in the horizontal direction for each row

Proof-of-Concept: Data Analysis

Method 2: Pixel Summation

- Step 2: Center Sill Detection



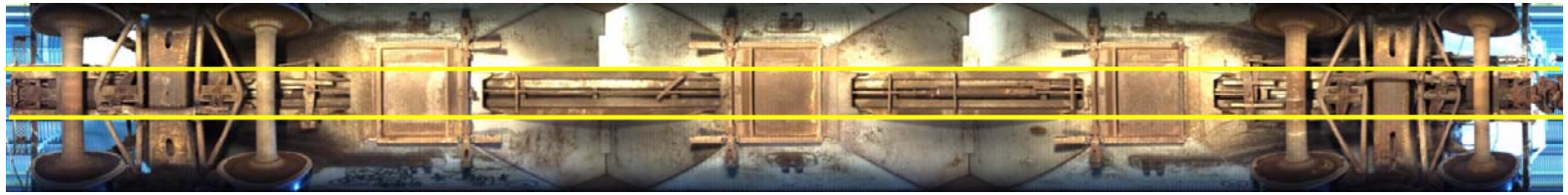
Large peaks identify outer edge of center sill

Proof-of-Concept: Data Analysis

Method 2: Pixel Summation

- Step 3: Measurement: Deviation from the straight line is estimation of error

Results for Gondola



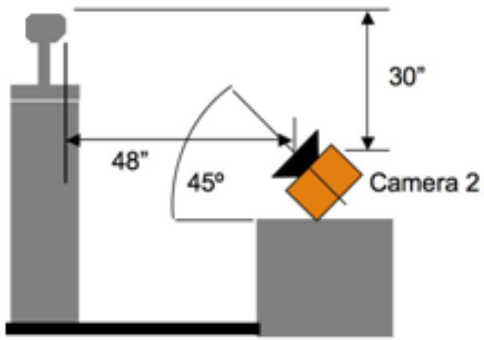
Results for Hopper Car

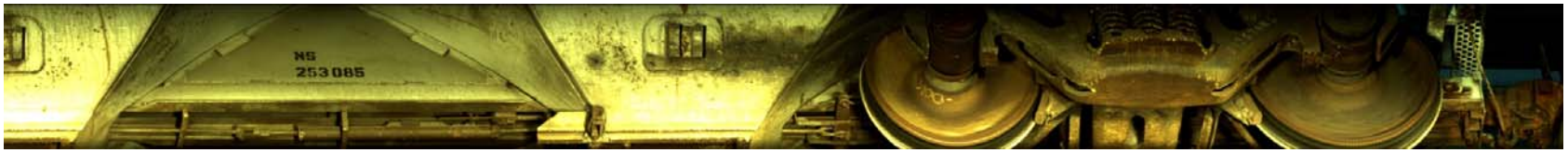
This method can also be used in the vertical direction for finding crossbearers and crossties

Alternate Camera Views

45 Degree Side Angle View

- Capable of panorama development
- Capable of detecting defects in sidesills and center sill

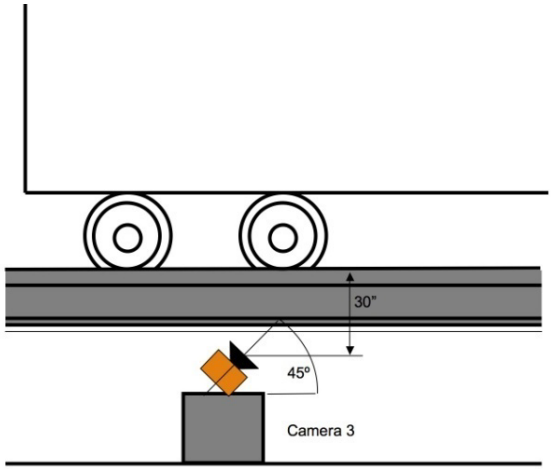




Deviation from a straight line (beyond reasonable estimation error) will indicate deformation

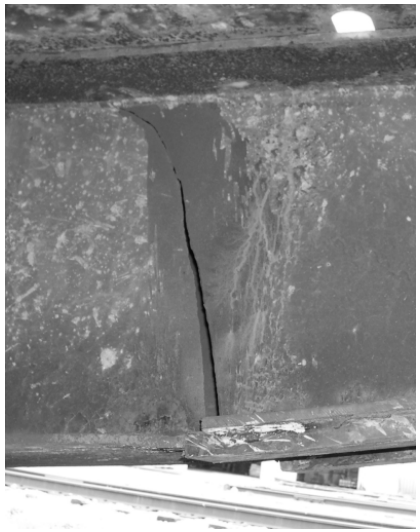
Alternative Camera Views

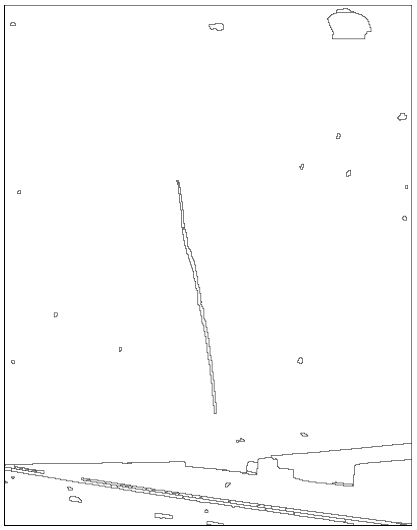
- 45 Degree Longitudinal View: side profile of crossbearers
- Scans video frames, stopping when crossbearers are detected in center of field of view
- Measure crossbearers for bends and buckles
- Search crossbearer area using segmentation and crack model



Possible Approach for Crack Inspection

- Need for higher resolution camera
- Need for Hierarchical Segmentation and Crack Model
- Model crack as a homogeneous, elongated region that appears darker than the center sill
- Recursively search smaller subregions and contrast them with the model for the crack or break





Summary of Test Results/Analysis

- **Feasibility**: automated car inspection using machine vision is promising, especially for the inspection of center sill, crossbearers, and crossties
- **Camera views**:
  - 90° straight-up view allows the detection of the flange of the center sill, crossbearers, and crossties.
  - Additional views will be used for improved detection of these components as well as the sidesill
- **Lighting:** even illumination provides a considerable challenge, particularly for varying underframe geometries
- **Camera resolution:** sufficient for detecting deformations, but higher resolution cameras will be required for crack and break detection, along with a database of crack image for developing a crack model
- **MV Algorithms:**
  - Multi-scale image segmentation provides accurate component detection and inspection capabilities
  - Template matching through segmentation or pixel summation

Remaining Challenges

- Acquiring a sufficient image pool of structural component defects (e.g. cracks and breaks)
- Detecting and identifying cracks with minimal false alarms
- Adequately inspecting body bolsters
- Properly illuminating different car types with variable floor heights
- Expanding algorithms to detect structural components of different car types and models

Conclusions

- Machine Vision Technology has the potential to improve the effectiveness and efficiency of freight car inspection by:
  - reducing inspection subjectivity
  - improving resource utilization
  - increasing train and employee safety
  - improving terminal and railroad network efficiency
- This work provides the basis for the development of a more robust structural underbody inspection system that utilizes machine vision algorithm techniques
- Future work will be required using multiple camera views, higher resolution, improved illumination, and more robust algorithms

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