Automated Inspection of Structural Components (AISC)

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Presentation Outline

- Motivation
- Project Objectives
- UIUC Approach
- Proof-of-Concept Testing
- Other Methods Considered
- Conclusions
- Acknowledgments
- Questions, Comments and Discussion
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)

- **Automated Car Inspection**
  - Enhances train inspection efficiency and safety
  - Enables trend analysis and preventative maintenance of railcars
  - Part of larger **Technology Driven Train Inspection (TDTI)** and the **Advanced Technology Safety Initiative (ATSI)** initiatives
  - Improved inspections achieve broader industry goals:
    - Increased rolling stock and component life
    - Reduced rolling stock accidents and in-service failures
    - Eliminating reactive maintenance
Motivation: 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
Motivation (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
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
Summary of Initial Project Scope

- CFR Title 49 Part 215.121 – Defective Car Bodies
  - Inspect center sill for breaks, cracks, and buckling
  - Inspect crossbearers for breaks
  - Inspect side sill for breaks
FRA Car Inspection Data

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

The objective of the AISC project 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
Gathering Domain Knowledge

**Norfolk Southern**

**Car Shop Tour - 2/8/08**
- Acquired information regarding car inspection processes from railroad mechanical department management

**Follow-Up Visit - 2/28/08**
- Inspected locomotive repair facilities and took measurements for future testing
- Captured still images of car defects in car shop

**Car Inspection - 7/1/08**
- Reviewed mechanical components of interest as well as the current car inspection process with NS repair program inspector

**Return Trip Post Testing - 7/29/08**
- Took measurements and still images to calibrate video data (pixel to ft. ratio)

**Canadian National**

**Car Repair Shop - 5/19/08**
- Reviewed mechanical components of interest and took still images of defects
- Tested portable image acquisition cart on railcars in yard

**Car Inspection - 7/10/08**
- Observed typical car inspection process with CN carmen
- Reviewed structural components of interest during inspections
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
Common Crack Locations

- Transitions in the geometry or cross-sectional area of structural members

Hopper car center sill from bottom (left) and side view (right)

Body bolster on hopper car with stub-sill design
Common Crack Locations

- Machined components creating discontinuity

In each of these cases, a crack was initiated in the base of the center sill at a location of high stress adjacent to a curved element
Common Crack and Break Locations

- Center sills
- Crossbearers
Common Structural Repairs

- Repaired or patched sections
- Possible violation of AAR patching standards
Common Crack Locations

- Locations where the load is transferred to the center sill
- Intersection points for crossbearers
- Directly below the body bolster
- Areas vulnerable to impact
**Manual Crack Detection**

- Areas of high stress concentration where cracks form are likely in the most challenging locations for a vision system.
- Railroads perform more in-depth inspections as a part of major car repairs:
  - Additional time for inspection
  - Program repairs allow may allow for defect trending
Field Experimentation

Monticello Railway Museum - 12/15/08
- Initial feasibility test - acquired images of hopper car
- Developed procedure for equipment set-up and data collection

Excel Railcar Services - Kenney, IL - 4/9/08
- Tested feasibility of portable image acquisition cart
- Acquired images of flat car

Excel Railcar Services - Kenney, IL - 5/8/08
- Tested feasibility of side mounted camera on image acquisition cart
- Acquired images of cracked center sills on two different flat cars

Transitech - Fordyce, AR - 5/20/08
- Acquired images of flat car with broken center sill
- Improved data collection procedures with portable cart

Norfolk Southern - Decatur, IL - 7/16/08
- 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
Imaging Results: Monticello, IL

- Hoppers
- Center Sill
- Crossbearers
Visible Components: Monticello, IL

- Coupler
- Spring Nest
- Axle
- Knuckle Pin
- Draft Gear Carrier
- Wheels
Imaging Results: NS Decatur, IL

- Covered Hopper Car

- Draft Sill Casting
- Yoke
- Truck Bolster
- Brake Rigging
- Hopper Door Components
- Center Sill
Imaging Results: NS Decatur, IL

- Gondola

- Center Sill
- Brake Rigging
- Crosstie
- Crossbearer
Machine Vision System Approach

- Image Acquisition Methods
  - Camera Views
  - Lighting Set-ups
- Data Collection
  - Hardware / Software
- Proof-of-Concept Field Work
- Panoramic Image Generation
- Machine Vision Inspection Algorithms
UIUC Approach: Equipment Setup

- Center Sill
- Axle
- Camera 1: 6" height, 28" and 29" between axles
- Camera 2: 8" height, 48" and 30" between axles, angled at 45°
- Camera 3: 30" height, 48" and 30" between axles
Camera Angles: Pros & Cons

90° Straight-Up View

- **Pros:**
  - Capable of panorama development
  - Capable of detecting defects in center sill and crossbearers, especially the flange

- **Cons:**
  - Rails occlude view of sidesills
  - Trucks occlude view of body bolster
  - Requires pit for optimal image acquisition
Camera Angles: Pros & Cons

45° Side-Angle View

- Pros:
  - Capable of panorama development
  - Capable of detecting defects in sidesills and on the side of center sill

- Cons:
  - Trucks occlude view of body bolster
  - Requires pit with sufficient width
UIUC Approach: Equipment Setup

[Diagram showing equipment setup with labels 30° and 45°]
Camera Angles: Pros & Cons

45° Longitudinal View

- Pros:
  - Capable of detecting defects on the sides of crossbearers and crossties
  - Provides additional views of sidesill

- Cons:
  - Not conducive for panorama development (requires alternative algorithms for analysis of video data)
  - Requires pit for optimal image acquisition
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
- Showed very good view of centersill and truck components
- Lighting needed improvement to better expose crossbearers and hopper details
- Needed location where in-service cars could be imaged
- Also need to image cars with deformations in components
Other 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
Other 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: 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 cropped
- Consecutive frames compared to determine speed
- Center strip length adjusted based on speed
- Strips ‘stitched’ together to create panoramic image of entire train
- Separated into car panoramas by detecting the couplers
Test Results: Comparison

- Monticello Hopper: wider angle lens (spring nest visible)

- Decatur Hopper: improved lighting for irregular underbody heights

- Decatur Gondola: even lighting, crossbearers highly visible
Panorama Measurement Calibration

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

1 pixel ~ 0.13 inches
Proof-of-Concept: Data Analysis

- Step 1: Multiscale Segmentation
Proof-of-Concept: Data Analysis

- Step 2: Center Sill Detection

Detection is based on template matching
Proof-of-Concept: Data Analysis

- Step 3: Measurement of centersill deformation

Estimation error: ± 2 pixels (± 0.3”)
Deviation from the straight line is within reasonable margins of estimation error
Proof-of-Concept: Data Analysis

- 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

- Step 2: Center Sill Detection

Large peaks identify outer edge of center sill
Proof-of-Concept: Data Analysis

- 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.
Detection Methods: Pros & Cons

- Template Matching:
  - More Accurate
  - Slower Processing Time

- Pixel Summation:
  - Faster Processing
  - Less Accurate
Deviation from a straight line will be estimation error
Approach for Inspection of Cracks

- 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
Crossbearer Inspection Approach: 45 degree Longitudinal view

- Move Through Video Frames Stopping When Crossbearers are Detected in Center of Field of View
- Measure Crossbearer for Bends and Buckles
- Search Crossbearer Area Using Segmentation and Crack Model
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.
  - 45° side view allows detection of side of the centersill and sidesill.
  - 45° longitudinal view allows detection of sidesill, the sides of the crossbearers and crossties, and possibly parts of the body bolster.
  - Body bolster is most difficult structural component to detect due to occlusion by the truck components.

- **Lighting**: even illumination provides a considerable challenge, particularly for varying underframe geometries, these may require dynamic lighting based on knowledge of approaching car types (AEI).

- **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.
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 and center plates
- 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 quality and efficiency of freight car inspection

- This work provides the basis for the development of a robust structural underbody inspection system which may utilize machine vision algorithm techniques including:
  - Multiscale Image Segmentation
  - Template Matching
  - Row and Column Pixel Summation
  - Development of a crack model based on examples

- Future work will be required using multiple camera views, higher resolution, improved illumination, and robust algorithms
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Common Crack Locations

- Machined Components