A Machine Vision System for Safety Appliance Inspection

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Project Scope

- Develop a wayside machine vision system to inspect the safety appliances on freight cars. The system will perform these inspections based on the regulations of Title 49 Part 231 of the Code of Federal Regulations (CFR).

- An image acquisition system will capture digital videos of the freight cars while the train is moving. Machine vision algorithms will analyze the videos to identify the safety appliances and learn to detect if they are in compliance with the standards.

- From this analysis a report will be generated detailing recommendations for repair or further inspection of any safety appliances determined to be in violation.
Focus of the Current Effort

- Focus on Coal Cars as Representative Railcar Type
- Focus on Two Groups Safety Appliances (SAs)
- Consider Operational SA Defects Only
- Generalize Machine Vision (MV) Inspection Methods
- Allow for Railcar Type Expansion
- Develop Semi-Permanent Image Acquisition System
- Prepare for Day and Night Image Acquisition
Safety Appliance Focus

- **Car Types:**
  - Open Top Hoppers
  - Gondolas

- **Initial Set of Appliances:**
  - Ladders
    - Side and End
  - Handholds
    - Side and End
  - Brake Wheel

- **Remaining Set of Appliances**
  - Sill Step, Uncoupling Lever, and Brake/Crossover Step
Project Progress and Accomplishments

A. Results of Processing Complete Train Videos
B. Variations in Current Railcar Type
C. TTC Work on Sill Step Deformation and Identification
D. Sill Step and Uncoupling Lever Classification
E. Improvements in Virtual Railcar Model
F. Site Design at Local Yard for Acquiring New Views
G. Next Steps for 2007
Video Acquisition of Coal Trains in the Field

- Two Days of Video Recording at Each Site
  - NS’s Roanoke, VA yard and CSX’s Erwin, TN yard
- Recorded Videos of 19 Trains Total
  - 16 coal trains
  - 3 mixed freight
Inspection of Train Videos

- Employed an edge-detection algorithm to automatically select optimal images from the 19 field videos
- Inspected these images manually and automatically, recording any deformations, defects, or missing safety appliances observed
- Inspected individual appliances for isolated bending, not for the relationship between appliances
Filtering the Inspection Results

- Removed cars without deformations or defects (1450 cars → 65 cars)
- Ignored cars with appliances that were not visible to either the human or the algorithm (65 cars → 30 cars)
- Focused on side ladder treads and side and corner sills
- Resulted in 260 inspected safety appliances
Results

- Total appliances found to be deformed or defective:
  - Ground Truth = 47
  - Algorithm = 44

- Agreed that an appliance was either deformed or defective 42 out of 48 such judgments (88%)

- Agreed on the severity of the deformation/defect 28 out of 48 such judgments (58%)
Recall and Precision

- Measure the algorithm’s ability to identify an appliance as deformed or defective

\[
\text{Recall} = \frac{\text{Retrieved Relevant Objects}}{\text{Set of Relevant Objects}} \\
\text{Precision} = \frac{\text{Retrieved Relevant Objects}}{\text{Set of All Objects Received}}
\]

- In this case:
  - Recall = 89%
  - Precision = 95%
Conclusions

- Algorithm correctly identifies deformations and defects based on isolated bending

- Next steps:
  - Identify deformation/defect based on relationships between appliances (clearance, spacing, alignment)
  - Adjust sensitivity level of algorithm to better match ground truth
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Design Variations in Safety Appliances

- Introduce a systematic method for classifying design variations
- Design variations may be used in virtual modeling of different cars
- Anticipate what problems design variations may pose to the machine vision inspection system
Design Variables

Quantity (N) – Nladtr, Nendhh, Nsidhh, Nsilst
Alignment (A) – Abrast, Abrawh, Aslosh
Geometry (G) – Gsilst, Gendhh, Gsidhh
Length (L) – Lsilst
Count the treads and spaces between treads from the top down

For alignment variables, use,
as with the brake wheel example,

\[ Abrawh = \frac{\text{ladder space}}{Nladtr} \]

Gives a “fraction of the way down” meaning
History of the Investigation

- Initially used images acquired from Roanoke, VA and Erwin, TN yards in March 2006
- Needed a way to look only at cars of a certain type
- Needed a larger, more random sampling of images
- Needed a way to estimate the relative frequency of each car design
- Found all of this in the “RR Picture Archives” <http://www.rrpicturearchives.net/default.aspx>
RR Pictures Archive

- Website that contains hundreds of thousands of images of cars, locomotives, and other railroad equipment
- Images submitted by individuals
- Images of freight cars are classified according to AAR Class (H350), Reporting Marks (BN), and Identification Numbers (50000-59999) among other things
Data Collection and Analysis

- Estimated the frequency of each design by weighting it by the number of images in the database
- Selected 43 unique designs of open-top hoppers and high-sided gondolas
- Analyzed the data to understand the range, mean, coefficient of variation, and most frequent qualities of each appliance
Ladder Design Variations

common

common

less common

rare

Nladtr 7
Aslosh 0.57

Nladtr 6
Aslosh 0.67

Nladtr 7
Aslosh 0.29

Nladtr 7
Aslosh 0.71
Brake Wheel Alignment

rare

Abrawh 0.14
Abrastrap 0.43

common

Abrawh 0.29
Abrastrap 0.57

common

Abrawh 0.71
Abrastrap 1.00
Sill Step Design Variations

<table>
<thead>
<tr>
<th>Nsilst</th>
<th>Gsilst</th>
<th>Lsilst</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0</td>
<td>0.80</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0.75</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0.50</td>
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<tr>
<td>2</td>
<td>1</td>
<td>0.75</td>
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## Results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Min</th>
<th>Max</th>
<th>Average</th>
<th>C.O.V.</th>
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</thead>
<tbody>
<tr>
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<td>5</td>
<td>2.10</td>
<td>0.27</td>
</tr>
<tr>
<td>Nladtr</td>
<td>6</td>
<td>9</td>
<td>7.01</td>
<td>0.09</td>
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<tr>
<td>Nsidhh</td>
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<td>5</td>
<td>2.16</td>
<td>0.21</td>
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<tr>
<td>Nsilst</td>
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<td>2</td>
<td>1.90</td>
<td>0.16</td>
</tr>
<tr>
<td>Abrast</td>
<td>0.43</td>
<td>1.00</td>
<td>0.71</td>
<td>0.33</td>
</tr>
<tr>
<td>Abrawh</td>
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<td>0.71</td>
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<tr>
<td>Gsidhh</td>
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<td>1</td>
<td>0.33</td>
<td>1.42</td>
</tr>
<tr>
<td>Gsilst</td>
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<td>1</td>
<td>0.79</td>
<td>0.52</td>
</tr>
<tr>
<td>Lsilst</td>
<td>0.50</td>
<td>0.80</td>
<td>0.64</td>
<td>0.21</td>
</tr>
</tbody>
</table>
Average Hopper Car

The average hopper car has

- 7 ladder treads
- 2 side and end handholds, not in a ladder style
- Brake wheel and slope sheet are located about 2/5 the way down
- 2 sill step treads, arranged with an angled style
Most Variable Appliances

By having the highest coefficient of variations (c.o.v.), these safety appliances have the most variable designs:

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</tr>
<tr>
<td>Abrast</td>
<td>0.33</td>
</tr>
</tbody>
</table>
Conclusions

- Handholds sometimes are arranged as ladders with styles, but usually they are not.
- Brake wheels and brake steps vary in vertical alignment (sometimes cross-over step and brake step are both present).
- Sill steps usually have angled styles, but they can be rectangular.
- Slope sheets provide another “edge” between treads, and they vary in vertical alignment.
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TTC Image Acquisition of Manually Deformed Sill Steps - April 2007

View A
Perpendicular Angle

View B
30°-Angle from the Rail
Sill Step and Uncoupling Lever Detection: Challenges

- Sill step and uncoupling lever appear as elongated thin objects in clutter.
- For locating sill step and uncoupling lever in the image we cannot use a simple edge detection algorithm, as we do for analyzing ladder rungs.
Detection of Sill Step and Uncoupling Lever: Results

- Detected sill step and uncoupling lever (target objects)
- Detected bottom edge and corner post of the car
- Estimated angles between target objects and the car’s bottom edge
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Review of Visual Learning Approach

• Provides an optimal FRA defect detection: high recall and precision

• Alternative to compiling a database of every safety appliance configuration
Sillstep and Uncoupling Lever

GOOD

DEFECT

1.5in

2in

2.5in

DETECTOR
Sillstep and Uncoupling Lever

GOOD

DEFECT

1.5in

2in

2.5in

DETECTOR
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Railcar Model Improvements

- Sampled realistic colors
- Added rust texture mapping
- Overall more realistic textures
- Refined truck model
- Refined wheel models
- Refined brake step model
- Refined coupler model
- Added uncoupling lever
- Realistic lighting setup
We began simulating theoretical bends in only one direction at a time on the sill step and ladder rungs.
More Realistic Sill Step Deformation

- From these cases, more realistic multi-directional bends may be created and tested.
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Semi-Permanent Site Design

- Digital video acquisition of passing trains with a consistent viewing angle
- Captures safety appliances with emphasis on hopper cars
- Operation manual initially, then partially automated
- Located on CN mainline underneath I-74 bridge
- Provides controlled lighting environment (ie, not in direct sunlight)
Semi-Permanent Site Elevation View Facing East

- Bridge Pier: 126’-2.5”
- Ballast: 8’-9.5”, 7’, 6’-10”
Semi-Permanent Site Plan View

Battery Box

Diameter = 3'

9'-9"

9'-5"

8'

Bridge Pier

Bridge Abutment

3'-7"

9'-5"

15'-4"
Semi-Permanent Site Ballast Slope

Bridge Pier

~ 20ft

4'

3'

3'

1'

9’-5”

Ballast
Semi-Permanent Site Design

- Installation will include a 20ft pole extending out of a 2ft x 2ft concrete base
- Several cameras mounted on the pole inside of weatherproof enclosures
- Experiment with external lighting
- All equipment kept outside of plate clearances (ORER 2004) and well marked for safety of carmen and crew members
- Requires advance schedules of trains containing coal and hopper cars
New Camera Views from Car Model

- We have used our railcar model to generate new camera views for our current safety appliance inspection.

- When the railcar passes by the camera tower, virtual video images are taken by the camera shown in red. A flash also shows when the image is being taken.
The first view to be taken is of the sill step and uncoupling lever.

The camera capturing the view is parallel to the ground and at a 30 degree angle from the track. The resulting image of the sill step and uncoupling lever is shown on the lower right.
The second view is of the safety appliances concentrated around the railcar’s end post.

The three cameras capturing these views are pointed 45 degrees downward and 45 degrees from the track. The three simultaneous images of the ladders are shown along the top.
• The third view is of the safety appliances at the very end of the railcar.

• The two cameras capturing these views are perpendicular to the track. The resulting two images of the brake wheel and step are shown at the top right and also lower right.
The forth view to be taken is of the sill step and uncoupling lever.

The camera capturing this view is also perpendicular to the track. The resulting image is shown at the center of the top row.
Second Sill Step Capture

- The fifth view to be taken is of the safety appliances at the other end of the railcar.

- The camera capturing this view is also perpendicular to the track. The resulting image of the sill step is shown at the bottom right.
Second Brake Step & Wheel Capture

• The sixth view to be taken is of the other end of the railcar. These image are taken assuming only one pole for simplification.

• The two cameras capturing these views are perpendicular to the track. The two resulting images of the brake wheel and step are shown at the top left.
Second End Post Capture

- The seventh view is of the safety appliances around the railcar’s other end post.

- The three cameras capturing these views are pointed 45 degrees downward and 45 degrees from the track. The three simultaneous images of the ladders are shown at the top.
The Eighth view to be taken is of the Sill Step at the other end of the railcar.

The camera capturing the view is parallel to the ground and at a 30 degree angle from the track. The resulting image of the sill step is shown on the lower right.
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Next Steps for 2007

• Continue to Map Out Variations in SA Configurations of Current Car Types (eg, Open Top Hoppers and Gondolas)

• Refine Categorization of Deformation to Increase Accuracy through Additional Visual Learning

• Develop Semi-Permanent Site on CN Mainline

• Capture Images from New Angles for Remaining SAs: Sill Step, Uncoupling Lever, and Crossover/Brake Step

• Experiment at Semi-Permanent Site with Imaging in Daytime and Nighttime Conditions using Lighting

• Advise Contracted Vendors on Implementation of Inspection Software
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