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ILLINOIS - RAILROAD ENGINEERING

Development of Machine Vision Technology for Inspection of Railroad Track

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ASSOCIATION OF AMERICAN RAILROADS

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Presentation Outline

- Background
- Selection of Inspection Tasks
- Camera View Selection
- Data Collection
- Algorithm Development
- Panoramic Image Generation
- Future Work
- Summary

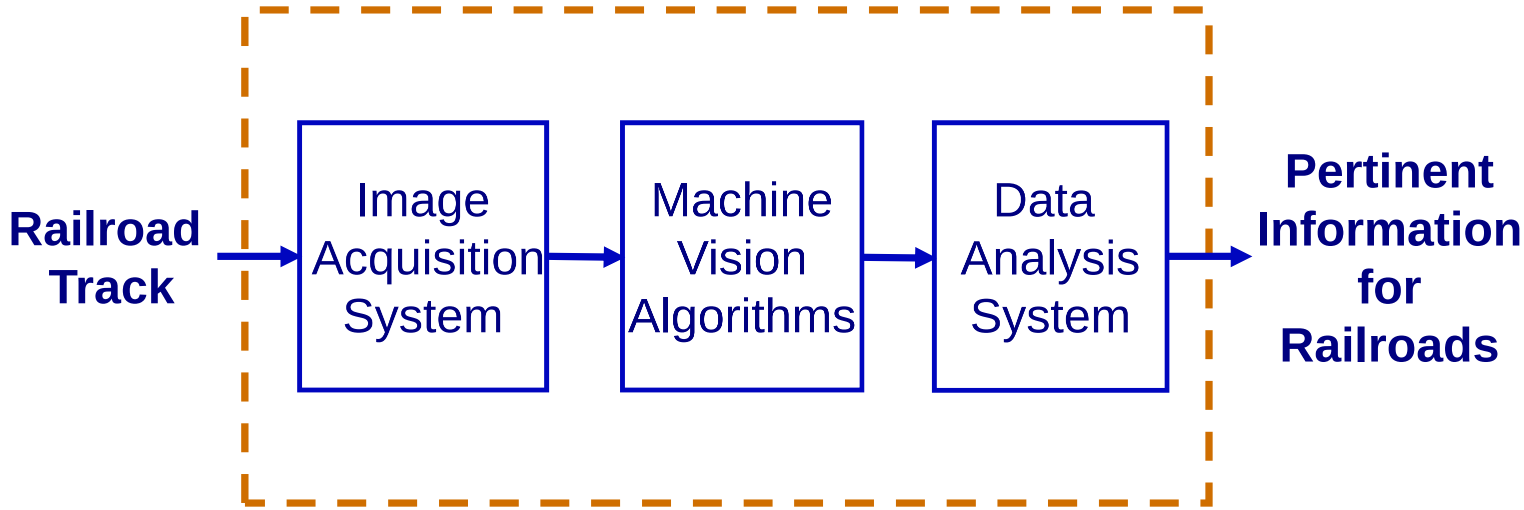
Background

- Inspection of track and track components is a critical, but labor intensive task resulting in large annual operating expenditures
- There are limitations in speed, quality, objectivity, and scope of the current inspection methods
- Machine vision provides a robust solution to facilitate more efficient and effective inspection of many track components

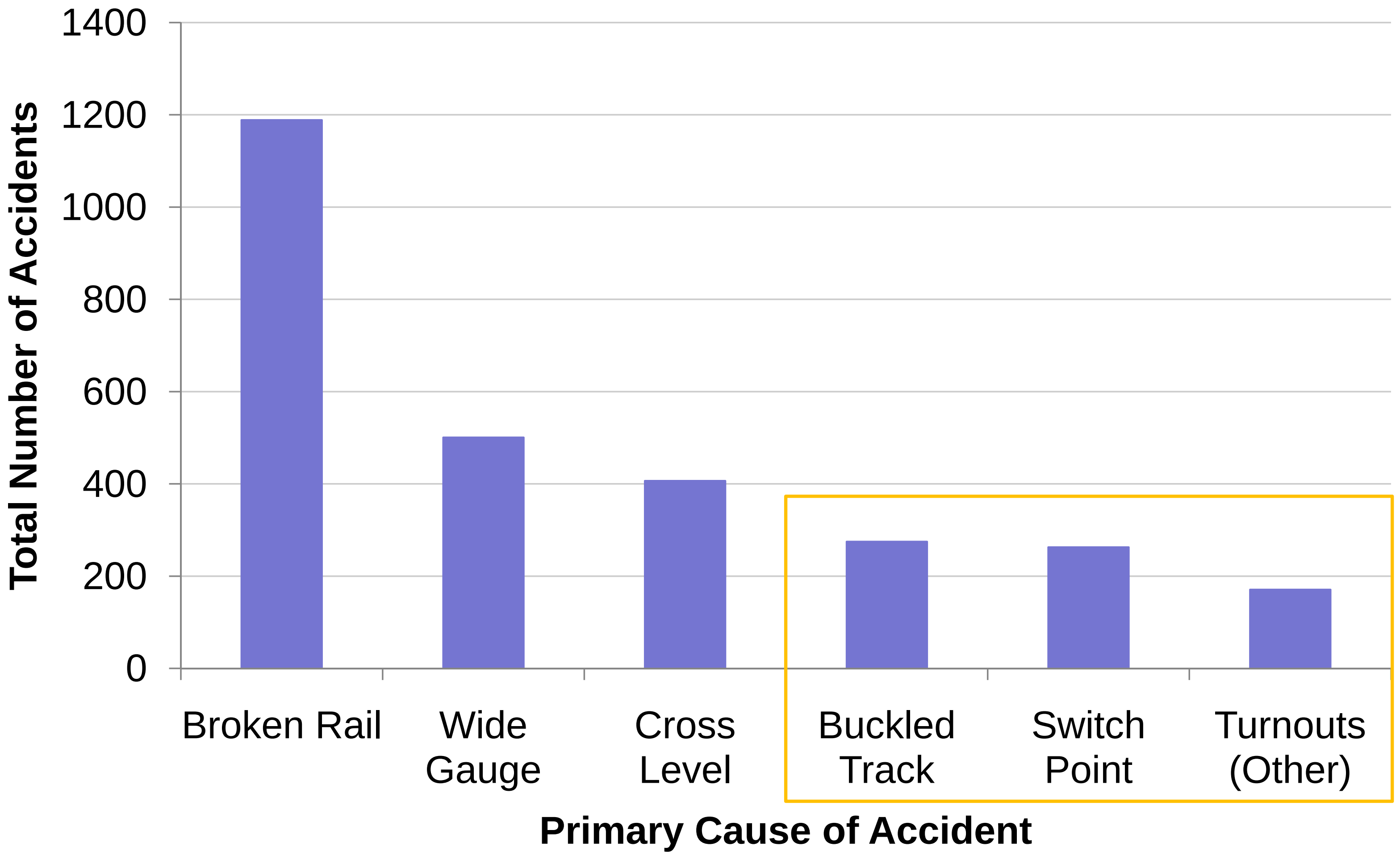
What is Machine Vision?

- Machine vision consists of recording digital images and videos and using algorithms to detect certain attributes in these images
- Has advantages and disadvantages as compared to manual visual inspection
  - Advantages:
    - Greater objectivity and reliability
    - Increased speed, precision and repeatability
    - Data archiving and trending capabilities
  - Disadvantages:
    - Challenges in providing controlled lighting conditions
    - Difficulties coping with unforeseen events
    - Higher initial capital cost

System Outline



Top Track Related Accident Causes from 2001-2005 (Class I Mains & Sidings)



Survey of Track Inspection Technologies

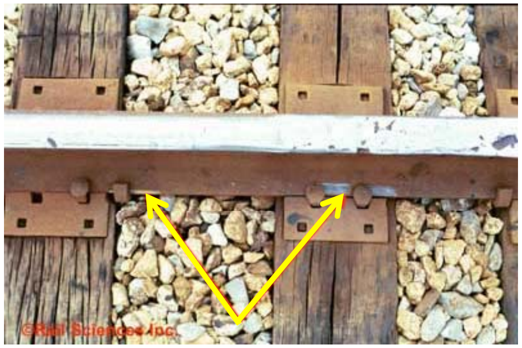
- Existing technologies
  - Ultrasonic rail flaw detection
  - Eddy current
  - Radiography
  - Split-load axle
- Emerging technologies
  - Inertial accelerometers
  - Ground Penetrating Radar (GPR)
  - Light Detection And Ranging (LIDAR)
  - Machine vision

Survey of Closely Related Technologies

- Light Detection And Ranging (LIDAR)
  - Measures distance by analyzing properties of reflected light
  - Used for measurement of tunnel clearances and shoulder ballast profiles
- Other Machine-vision systems for track inspection inspect:
  - Joint bars
  - Elastic rail clips
  - Ties
  - Rail, tie plates and gauge

Defect Severity Levels

- Critical
  - Detection of such defects constitutes a hazard
  - i.e. Buckled track
- Non-critical
  - Individual defects are not a hazard, however, detection of several can constitute a critical defect
  - i.e. Low crib ballast between a pair of ties
- Symptomatic
  - Do not represent defects, but indicative of a potential problem
  - i.e. Shiny spots on rail base not a defect, but indicative of longitudinal rail movement



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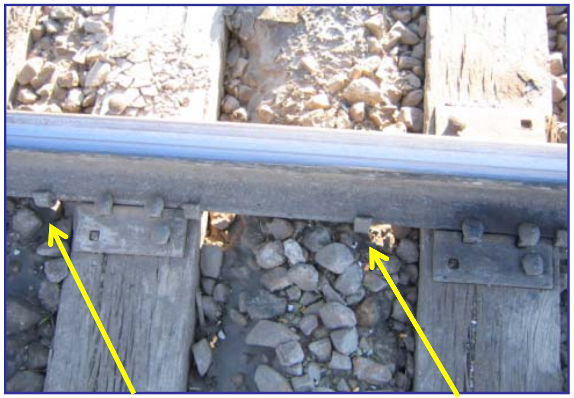
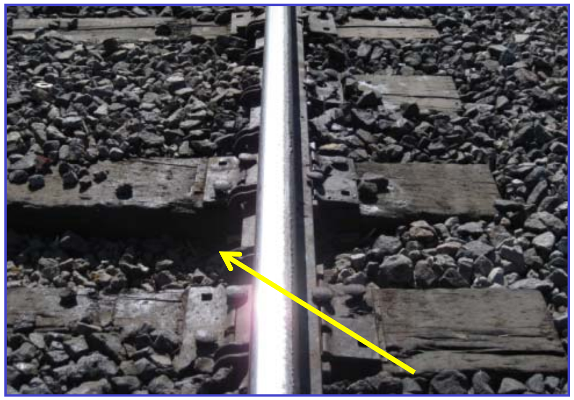
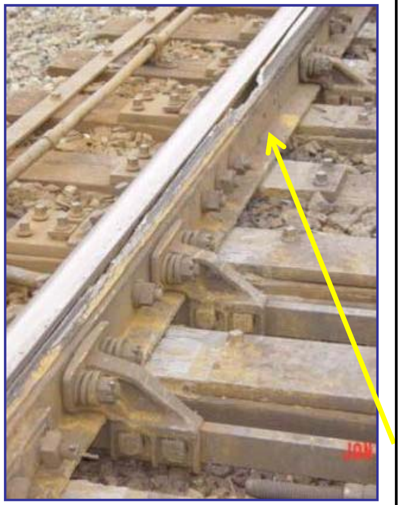
Inspection Focus

- Cut spikes
  - Missing
  - Raised
  - Inappropriate patterns
- Rail anchors
  - Missing
  - Shifting
  - Inappropriate patterns
- Ballast
  - Insufficient crib ballast
  - Identify improper breathing on curves
- Turnouts
  - Missing bolts
  - Missing cotter pins
  - Switch point inspection







Virtual Track Model

- Used to model track components and their defects for determination of initial camera views
- Utilized the AREMA Manual and Class I Railroad standards
- Incorporated AAR clearance plates

Initial Camera Views

- Spike pattern and rail anchor view
  - Optimal view for measuring the distance between the ties and rail anchors
  - Used to verify spike heights measured in other views
- Raised spike view
  - Used to determine spike height with respect to the base-of-rail
- Ballast view
  - Used for determining the profile of the shoulder ballast
  - Also used for measuring the crib ballast level with respect to the top of the ties

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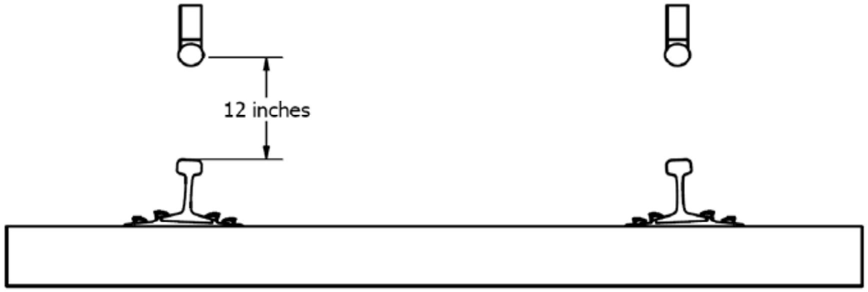
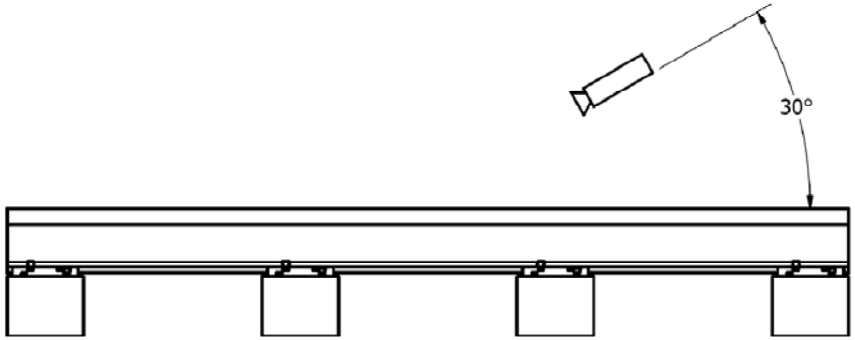
Over-the-rail View

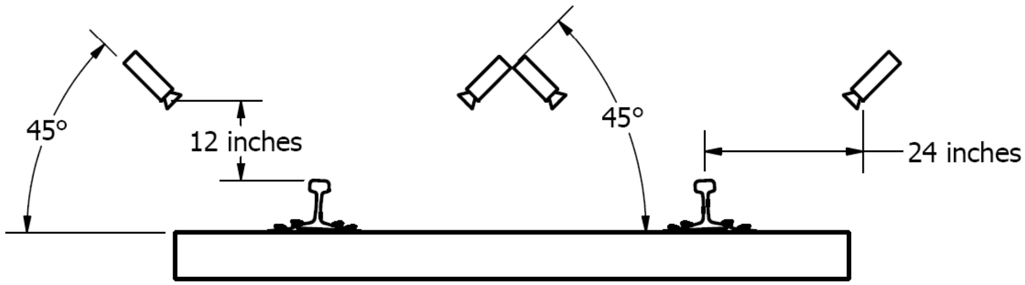
- Used for measuring the distance between the spike head and the base-of-rail and verifying spiking patterns
- Also used to measure crib ballast level with respect to the top of the tie





Lateral View

- Optimal view for measuring the distance between the rail anchors and the edge of the ties and verifying anchor patterns
- Used to verify spike heights measured in the over-the-rail view
- Conducive to panorama generation

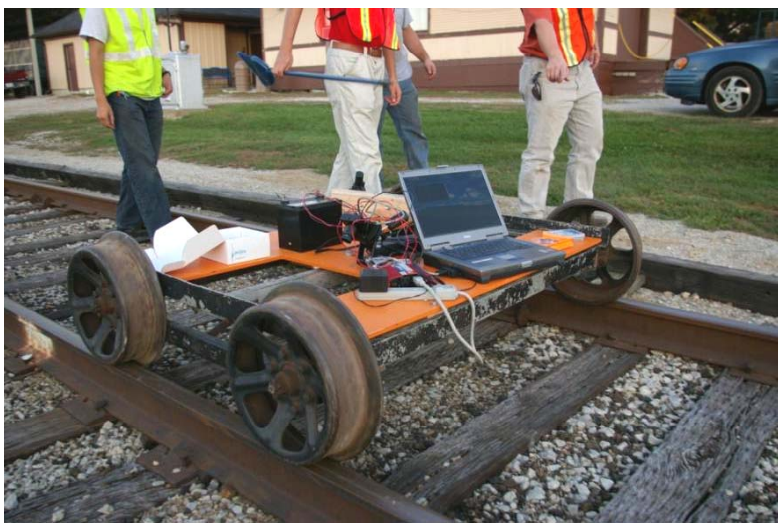


Data Collection

- Initially used handheld cameras to take images
  - Obtained insights on later challenges, such as variability in component appearance
- Developed Video Track Cart for field data acquisition
  - Used on low density track for verifying camera views and experimenting with lighting
- Optimizing lighting is a challenging task
  - Reviewed lighting solutions from existing machine-vision systems

Video Track Cart

- Equipped with two camera mounts for the over-the-rail view and a gauge-side lateral view
- Geared tripod heads for precise adjustment of camera views
- Deep-cycle marine battery supplies power for all electronics
- Rugged laptop resistant to environmental conditions



Video Data Collection

- Visit to Advanced Transportation Research and Engineering Laboratory (ATREL) in Rantoul, IL
  - 14’ track panel
  - Experimented with differing focal lengths
  - Developed video capture procedure for future field testing

Video Data Collection

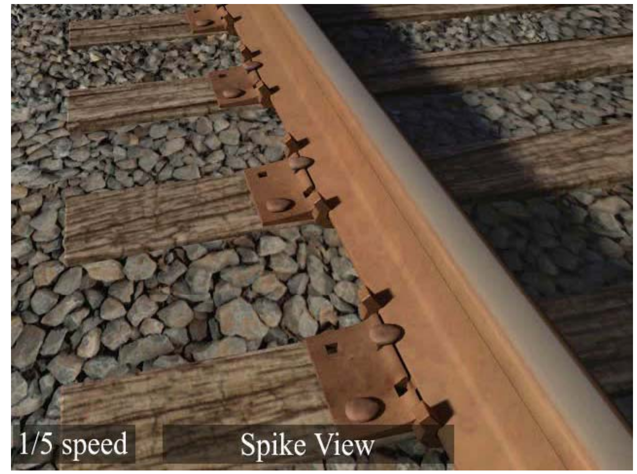
- Monticello Railway Museum (MRM) visits
  - Recorded video from both camera views
    - Improved lateral view and over-the-rail view mounts
  - Manually measured and catalogued track defects for algorithm verification

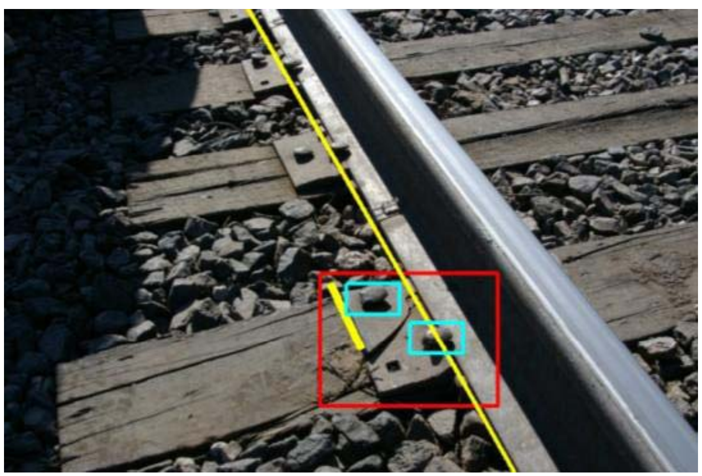
Lighting Considerations

- Reviewed lighting systems of similar machine-vision systems
  - University of Central Florida's track inspection system
    - Lasers and timed strobe lights
    - Sun shields
  - ENSCO's joint bar inspection system
    - High-powered xenon lights
    - No sun shields
  - Georgetown Rail's Aurora system
    - Lasers with light filters on cameras
- Lighting solutions are unique to each system's data collection requirements, with our system requiring even illumination over a large area of track

Algorithm Development

- Initial development used Virtual Track Model
  - Simulation of component defects
- Development using still-images
  - Changed from tie-based detection to rail-based detection for reliability
  - Began using texture information to make algorithms more robust

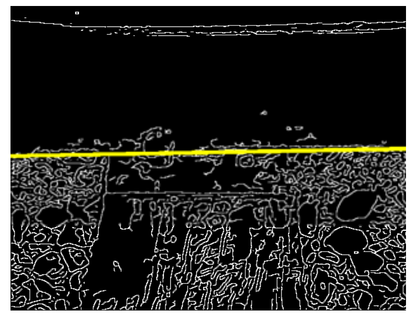




Track Component Isolation

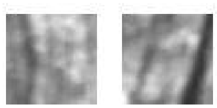
- Delineate ties, ballast, and rail using edge detection

Original image

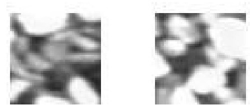


Edge image
(base-of-rail highlighted)

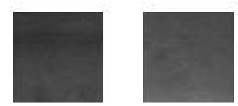
- Incorporate texture classification to make edge detection robust
  - Extract patches of texture from a hand-labeled training image
  - Compare new texture patches against known textures
    - Use Gabor filter outputs to classify patches from new video frames



Wood patches



Ballast patches

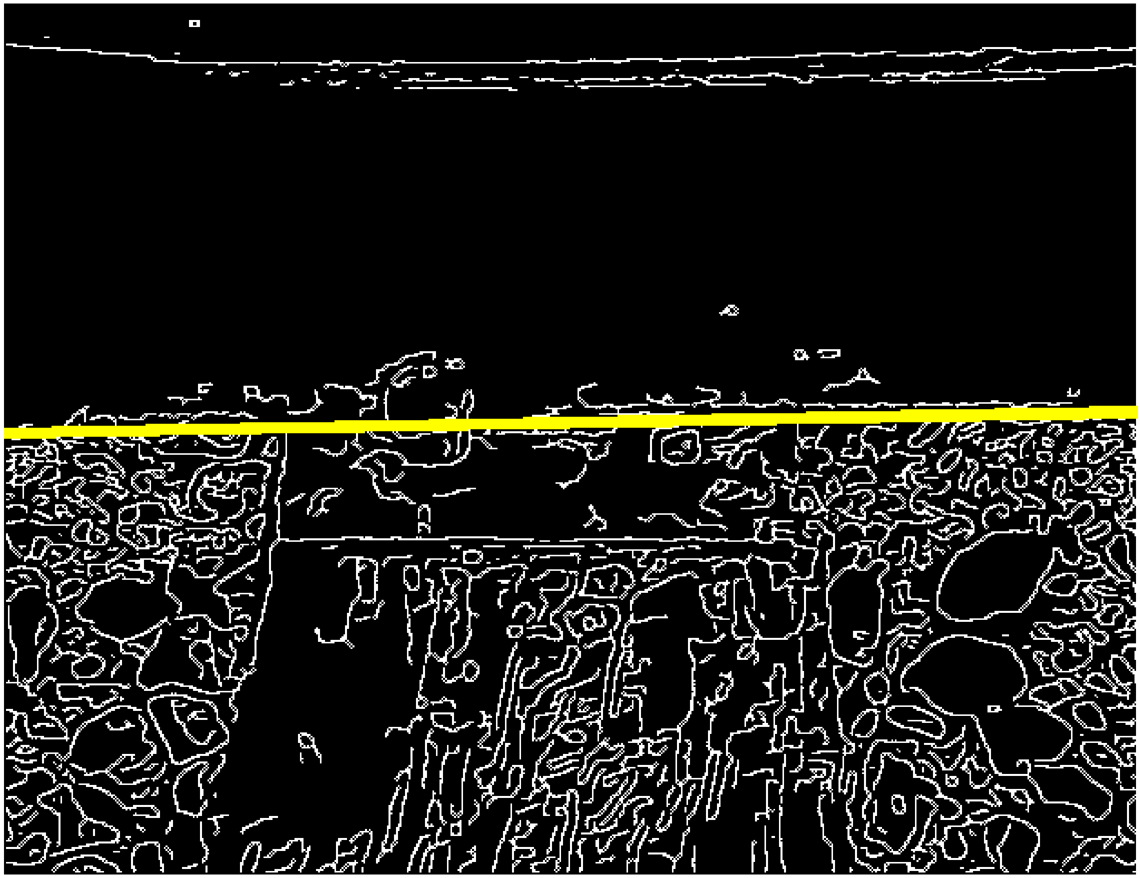


Metal patches

Base-of-Rail Delineation

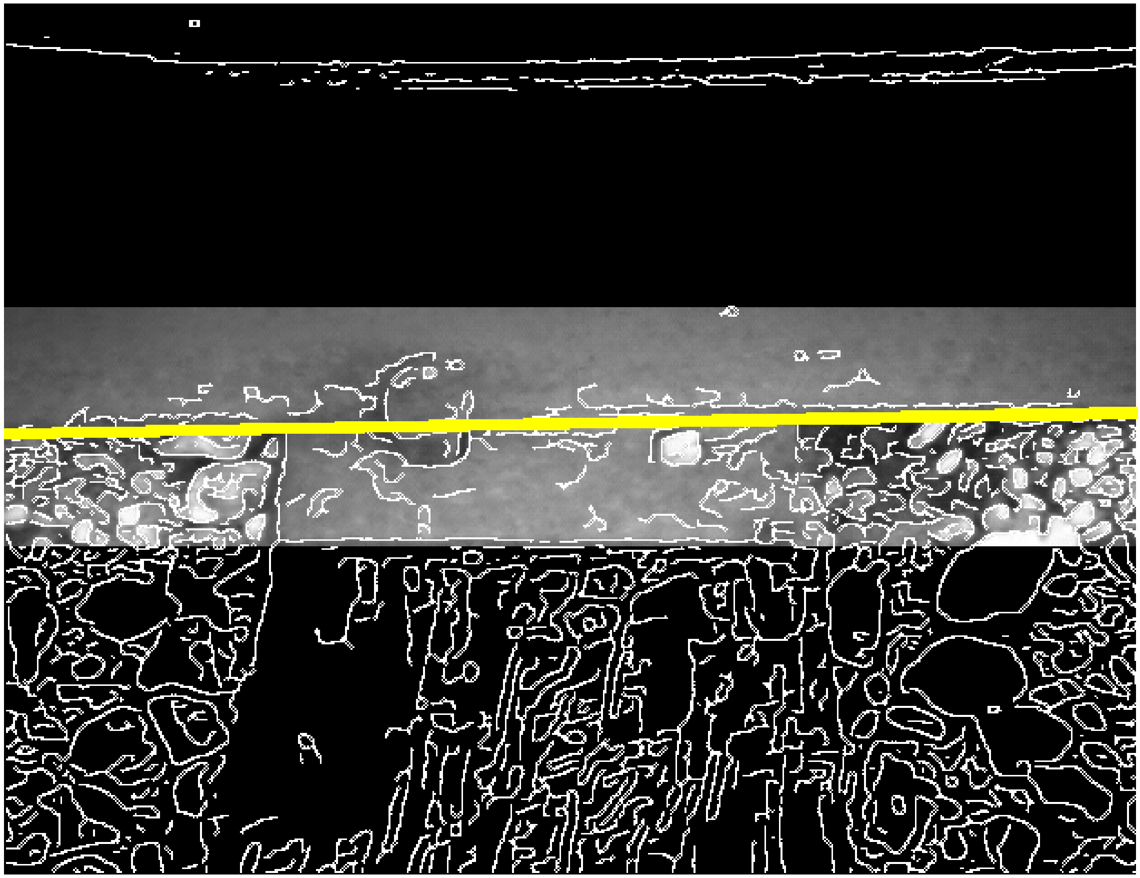
Original image from field video

Base-of-Rail Delineation



Strong horizontal edges are detected
(candidate base-of-rail edge is shown)

Base-of-Rail Delineation



Surrounding pixels above and below candidate edge are examined for expected textures

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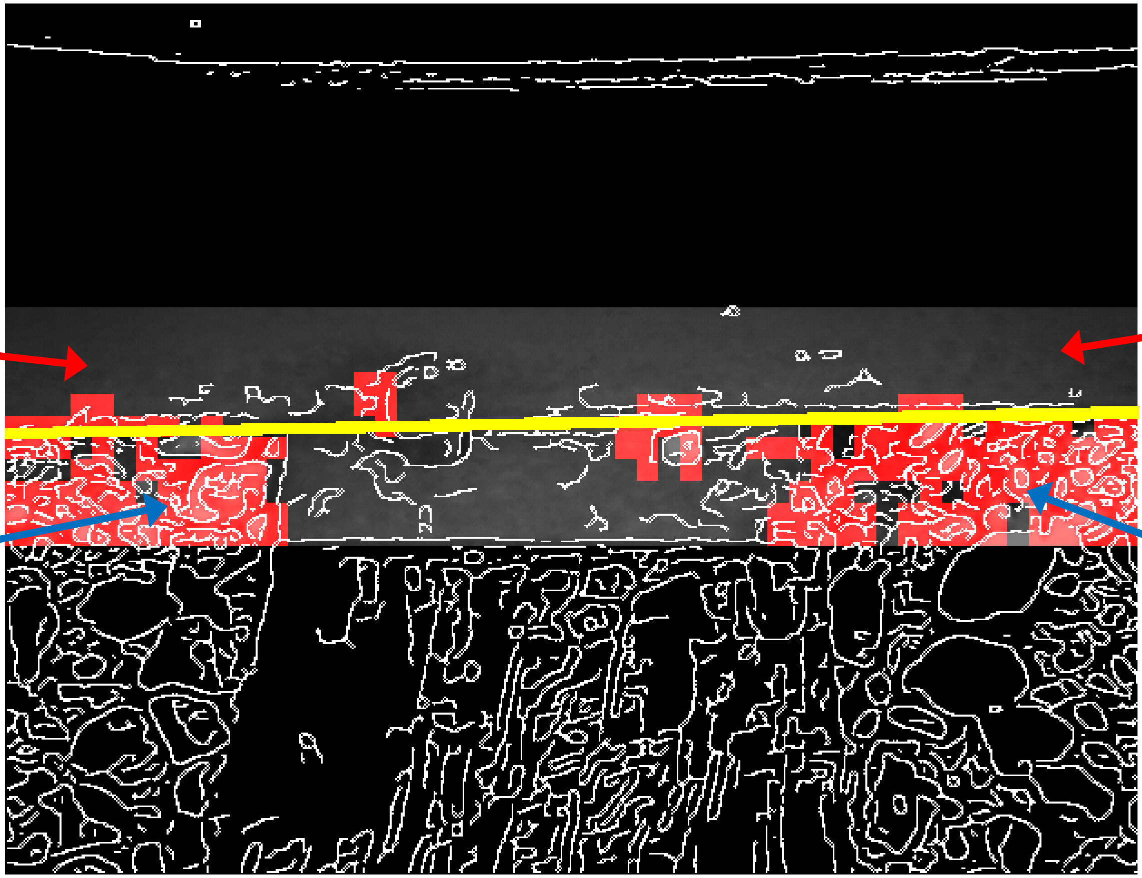
Base-of-Rail Delineation

Metal *above* edge



Metal *above* edge

Ballast *below* edge

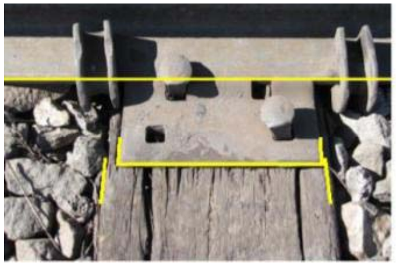
Ballast *below* edge

Base-of-rail is confirmed by confirming ballast below the edge and metal above the edge

Tie, Tie Plate, and Spike Detection

- Detect ties and tie plates using similar edge/texture method
  - Edge detection, verified with texture classification

Original image



Delineated components

- Hypothesize the spike locations (and missing spike locations) using prior knowledge of tie plate structure
  - Spikes and spike holes are located with template filters
  - Spike height is measured relative to the base-of-rail

Spikes and spike holes

Rail Anchor Detection

- Uses prior knowledge of anchor location (since tie plate and rail bottom have been delineated)
- Find parallel edges to achieve anchor detection
  - Robust to changes in anchor orientation

Isolated anchors

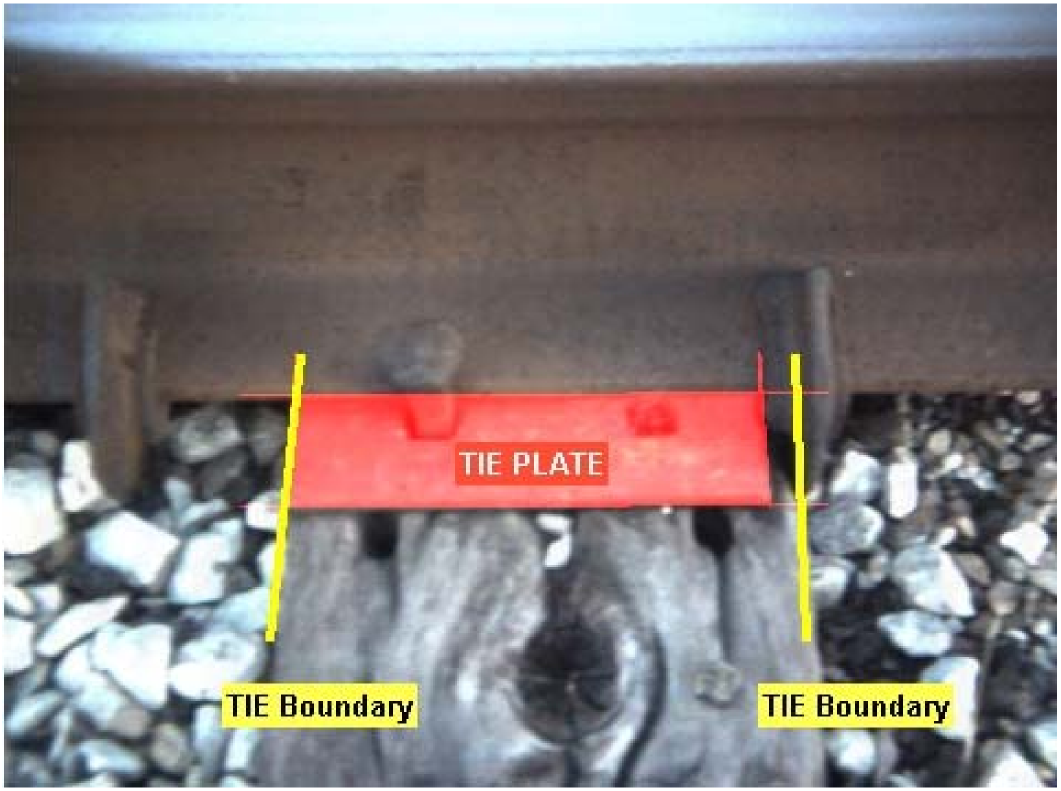
Component Detection on Field Video

Field data video

Defect Detection

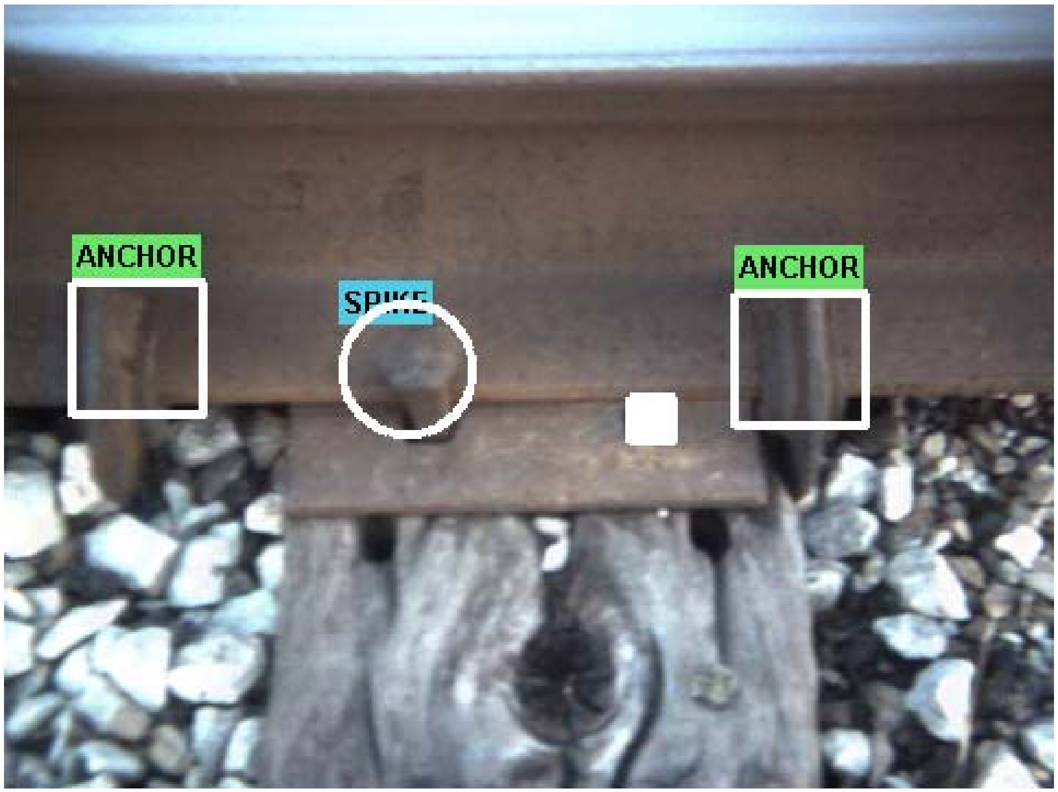
Original image for spike detection and anchor displacement measurement

Defect Detection



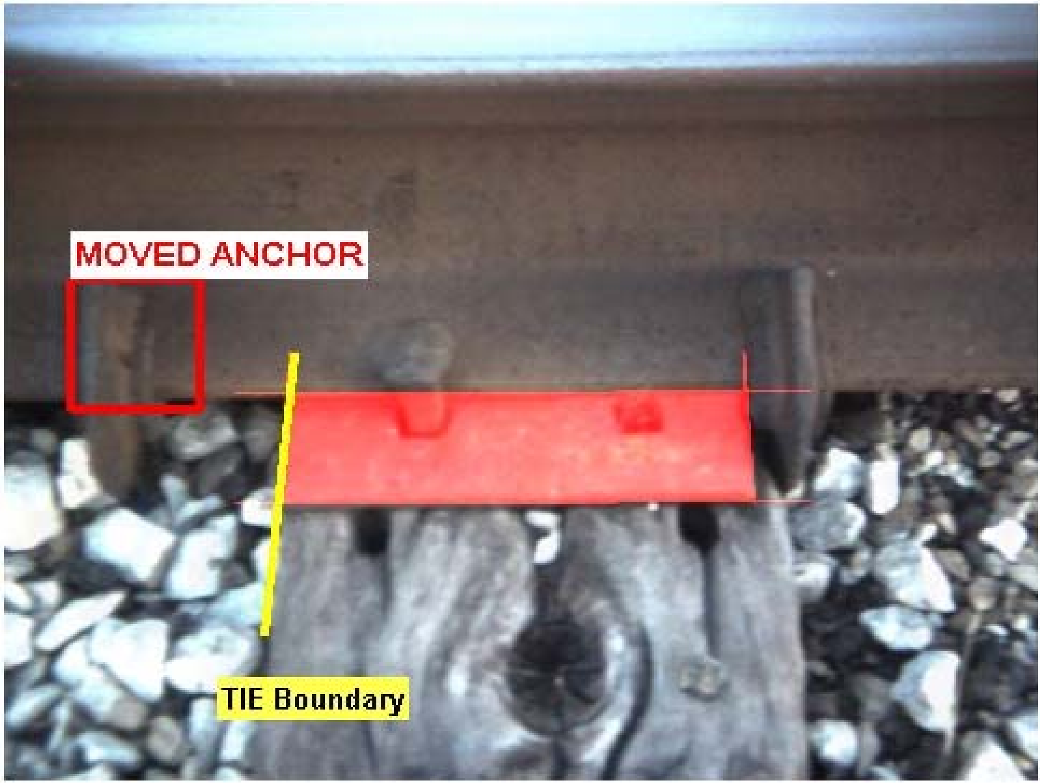
Tie plate area identified and tie boundaries located

Defect Detection



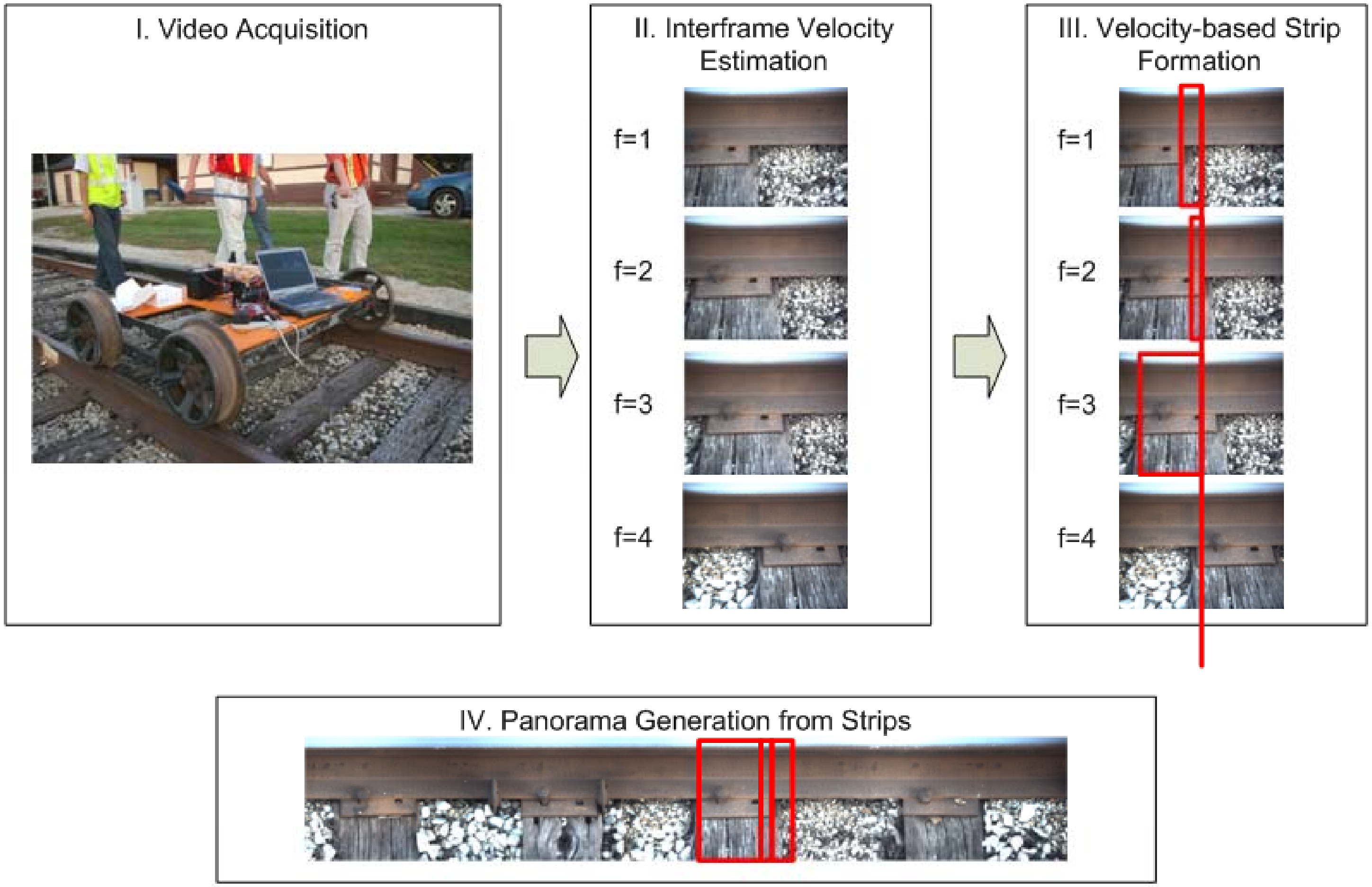
Spikes, anchors and spike holes are located

Defect Detection



Defects detected if anchor displacement exceeds a defined threshold

Panoramic Generation



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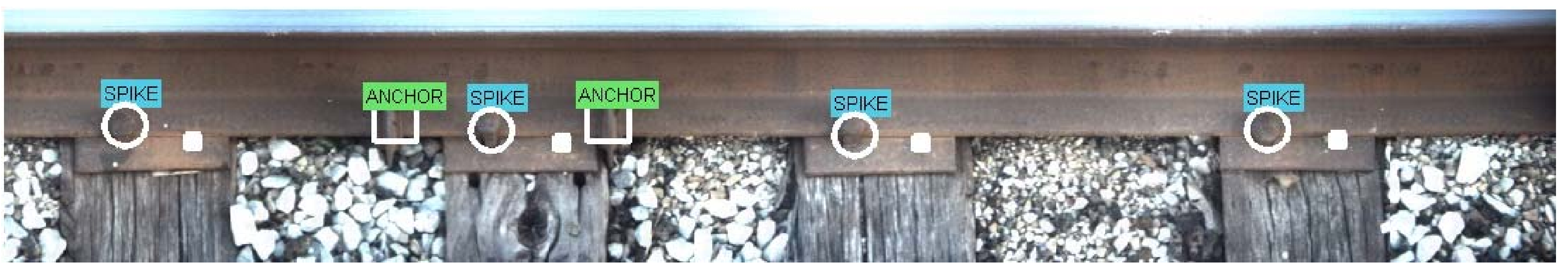
Track Panorama

- Visualization of cumulative track components using panoramic stitching
  - Minimizes errors due to lens distortion

Tie / Tie plate delineation on Test Panorama



Component detection on Test Panorama

System Implementation

- Future system likely to be mounted on either
  - Track geometry car
  - Rail defect detector car
  - High-rail vehicle
- Possible initial implementation on defect detector car
  - Inspections occur with acceptable frequency
  - Crews better trained with advanced inspection equipment
  - Already equipped for massive data storage and upload
- The system will be adapted for high-rail vehicle use

Future Work

- Plan for 2009
  - Continue testing spike and anchor algorithms on field-acquired video
  - Develop an approach to detecting adequate crib ballast level
  - Initiate study on methods to inspect for turnout defects
  - Begin lighting experimentation
  - Record more videos at MRM and on other local tracks
- Approach for 2010
  - Investigate cameras which can run at higher speeds and in a greater variety of environmental conditions
  - Develop and test crib ballast profile inspection algorithms
  - Develop and test algorithms for turnout defects
  - Adapt acquisition system for trial runs on a track vehicle

Summary and Discussion

- Current inspection tasks
  - Raised or missing cut spikes
  - Displaced or missing rail anchors
- Future inspection tasks
  - Low crib ballast and curve breathing
  - Turnouts and other special trackwork
- System benefits
  - Detailed trending of track health over time and space for predictive maintenance planning
  - Improved understanding of the contributions of individual track components on track behavior
    - Can be used to help develop an advanced failure prediction model

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