DUAL MODE SCANNER
for
BROKEN RAIL DETECTION

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Presenting a concept for improved rail safety; not a tested product
DUAL MODE SCANNER for BROKEN RAIL DETECTION
TWO METHODS ARE TYPICALLY USED

• Broken or defective rails are detected by two techniques:

• One technique is by contacting and operating directly on the rail to detect a disruption of energy propagation along the rail caused by a gap or deformation.

• The second technique makes use of equipment mounted aboard a locomotive or rail vehicle for purpose of detecting rail discontinuity while the vehicle is in motion over the rails.

• This briefing considers only the second technique while exploring the potential improvement of existing methods through use of enhanced sensor technology. The concept has not been built or tested.
WHAT DOES “DUAL MODE “ IMPLY?

- Common sensor means for “on board” rail health examination is EO/IR technology such as video camera (daylight, IR, multi-spectral), laser, LIDAR, etc.)

- “Dual Mode” as proposed herein adds a second sensor technology to the EO/IR method. Described is the addition of high resolution millimeter wave, short range radar to be developed and optimized for this application.

- Design approach and description for the MMW radar sensor, as presented herein, is available from recent consideration of other rail industry applications; also in the context of using Dual Mode sensing.
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Objectives for the Proposed Dual Mode Sensor Method

• Use dual sensor measurements to detect and characterize anomalous data thereby indicating change to rail structure from normal specifications

• Characterize the anomalous data in order to classify the threat level indicated by the data

• Use the anomalous threat classification as basis to formulate user action intended to preserve safe rail operation and avoid potential future derailment event
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Features and Benefits for Dual Mode Sensing

• EO/IR camera and MMW radar are to be fixtured and co-boresighted so that when mounted on a rail vehicle, the rail field-of-view is common to both sensors

• Raw signature data from both EO/IR camera and MMW are pre-processed
  • MMW radar and Video cameras produce enormous quantity of information
  • Raw information pre-processed to extract the most relevant features for fusion and detection of a broken rail
  • Computer vision techniques used to reduce the dimensionality of video images
  • Signature pre-processing and feature extraction must be done in real time, as rail vehicle moves at high speeds

• Extracted features used by Fusion algorithm to detect anomalies
  • Fusion algorithm based on supervised machine-learning techniques
  • Fusion algorithm based on statistical signal processing techniques to detect anomalies with low probability of false alarm

• Extracted features also used to characterize environment (fog, raining, snow, day/night)
  • Fusion algorithm detection parameters adapt to environment

• If anomalous data files are indicated; next step is to characterize the anomalous data to determine potential threat to safe rail operations
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EO/IR sensor(s) plus high resolution millimeter wave radar.
Mounting over the rails as shown.
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Radar and Video Footprints are Shown Covering a Rail from Above
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Rail Anomalies to be Measured in Three Planes;
Separation (dz); lateral (dx); vertical (dy)
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Multiple Dual Mode Sensors Positioned for Detailed Characterization of Anomalies
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Continuous Rail Imaging by Motion of Vehicle

• Visual camera facing tracks from around 1m at perpendicular angle
• With a 60-degree Angle of View (AoV), able to image each part of the rail track at least 2x (rail vehicle moving at 100mph)
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Define Dimensional Anomaly at a Rail Gap

• When rail separation (dz) at location of a normal gap (or a break) exceeds established norms for the rail ROW
• When rail elevation (dy) at a gap exceeds established norms for the ROW
• When rail lateral displacement (dx) at a gap exceeds established norms for the ROW
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Recent K-band Radar Sensor with Patch Array Antenna
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Dual Mode Sensors Used in Past Research; radar and three video cameras
# DUAL MODE SCANNER for BROKEN RAIL DETECTION

Key EO Camera Specifications (typical for Basler acA645-100gm)

<table>
<thead>
<tr>
<th>Specification</th>
<th>640x480 (VGA)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>640x480 (VGA)</td>
<td></td>
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<tr>
<td>Pixel Size</td>
<td>9.9um X 9.9um</td>
<td></td>
</tr>
<tr>
<td>Frame Rate</td>
<td>100 frames/Sec</td>
<td>High rate allows image overlap in direction of vehicle motion. Each section of rail captured at least two times</td>
</tr>
<tr>
<td>Mono vs Color</td>
<td>MONO</td>
<td></td>
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<tr>
<td>Pixel Bit Depth</td>
<td>12 BITS</td>
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<tr>
<td>Exposure Time</td>
<td>&gt;20us</td>
<td>Based on train speed 100mph</td>
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<tr>
<td>Signal to Noise Ratio</td>
<td>43dB</td>
<td></td>
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<tr>
<td>Dynamic Range</td>
<td>61dB</td>
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</table>
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Dual Mode Sensor Signature Data Collection for Fusion Algorithm Development
• **Raw signature pre-processing:**
  - **MMW Radar:**
    - Removal of clutter
    - Removal of multipath returns
  - **Video Sensor:**
    - De-blurring algorithms
    - Contrast enhancement

• **Feature extraction**
  - **MMW Radar:**
    - Distribution of range returns at a subset of angles
    - Variance of energy in radar returns
  - **Video Sensor:**
    - Edge detection
    - Energy of DCT transform in select directions of selected sub-images
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Dual Mode Sensor Signature Data Fusion Algorithm Development

- Fusion algorithm uses techniques from
  - Supervised machine learning
  - Statistical detection theory

- Supervised machine learning
  - MMW Radar and Video images collected in experiments prior to deployment
  - Multiple measurements from normal, worn, damaged, and broken rails will be collected
  - Measurements used to learn the distribution of features under each condition

- Statistical detection theory
  - Likelihood ratio for various features computed in real time
  - Algorithm tuned to maximize probability of broken rail detection while keeping probability of false alarm below a specified threshold

- Algorithms adapts to various conditions of weather
  - Separate algorithm classify environmental conditions
  - Fusion algorithm parameters adjusted depending on the environmental condition detected.
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Broken Rail Detection; What Action Options?

• Use of Flashing Rear End Device (FRED) to alert train operators following on the same rail right-of-way. This was suggested by DOT in a recent solicitation for small business.

• One type of FRED includes a communication link to train Operator’s Head of Train Device (HTD) which has a display on which the broken rail detection could be indicated (location and characterization). That communication link is also to the locomotive computer.

• The broken rail detection system should incorporate a GPS receiver so that exact location of the anomaly can be communicated to Operations Control Center.