Distress Image Library for Precision and Bias of Fully Automated Pavement Cracking Survey

Kelvin C.P. Wang, Ran Ji, and Cheng Chen
kelvin.wang@okstate.edu
Oklahoma State University/WayLink
School of Civil and Environmental Engineering

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Blacksburg, VA
Outline

- Challenges of Distress Detection
- Benchmark Database and Evaluation Methods
- Case Studies of Algorithm Comparison
Manual Distress Survey

- Tedious manual measurement and rating processes
- Substantial manpower
- Access to pavement
- Traffic control
- Difficult or inconvenient in archiving and retrieving detailed quantitative information

Photo from: https://www.nevadadot.com/About_NDOT/NDOT_Divisions/Planning/Aviation/Pavement_Condition_Index.aspx
Challenges of Cracking Survey

- Analysis and Processing
  - Detection/Identification
  - Classification

- Precision and Bias
  - Reference???
PaveVision3D Ultra Systems
PaveVision3D Ultra - New
Green Lasers for 3D Ultra
3D Ultra Data at 60MPH (100KM/h)
3D Data at 60MPH (100KM/h)
3D Data at 60MPH (100KM/h)
3D Ultra Current Status

- Sensor technology: mature
- Challenges to software solutions
  - To be simple and usable to pavement engineers
  - Confidence in quality of data
  - Utilization and analysis of 1mm data sets
Data Analysis Challenges

- Detection Algorithms
  - Accuracy
  - Robust
  - Fast

- Result Evaluation
  - No benchmark database
  - No widely accepted evaluation criteria
Evaluation Methods

- Desired distress detection algorithms
  - Fast
  - Achieve high scores in both precision and recall rate
Need of Image Library

- What is the reference?
- Is there a “Ground-Truth”?
- What to use in benchmarking?
- Therefore: an Image Library
  - Manually developed with marked cracks
  - Multiple-checking for precision/bias
  - Expensive; but necessary
Precision Recall Analysis

- Precision: correctly identified cracks over total identified cracks
- Recall: correctly identified cracks over total crack

Example of good precision score

Example of good recall score
Precision Recall Analysis

Example of good precision score

Example of good recall score
## Precision Recall Analysis

- **Confusion Matrix**

<table>
<thead>
<tr>
<th></th>
<th>Actual positive</th>
<th>Actual negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predicted positive</td>
<td>True Positive</td>
<td>False Positive</td>
</tr>
<tr>
<td>Predicted negative</td>
<td>False Negative</td>
<td>True Negative</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Crack</th>
<th>Non-crack</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predicted crack</td>
<td>True Positive</td>
<td>False Positive</td>
</tr>
<tr>
<td>Predicted non-crack</td>
<td>False Negative</td>
<td>True Negative</td>
</tr>
</tbody>
</table>
Precision Recall Analysis

\[
\text{Precision} = \frac{\text{True Positive}}{\text{True Positive} + \text{False Positive}}
\]

\[
\text{Recall} = \frac{\text{True Positive}}{\text{True Positive} + \text{False Negative}}
\]

\[
F = \frac{2 \times \text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}}
\]
ROC Curve

- Receiver Operating Characteristic (ROC curve)

- A perfect classifier: at the upper left corner (only the true positives, no false positives & no false negatives)
PR Curve

- **PR curve**: Precision vs Recall
  - Precision as Y axis
  - Recall as X axis
- **Goal**: select an algorithm at the upper right corner
Class Imbalance Problem

- The total # of a class of data (positive): far less than the total # of another (negative)

- Example
  - Model 1: 7 out of 10 cracks and 10 out of 10000 normal pavement pixels WRONG
  - Model 2: 2 out of 10 cracks and 100 out of 10000 normal pavement pixels WRONG

- If the classifier’s performance is determined by the number of mistakes,
  - Model 1 (17 mistakes) VS. Model 2 (102 mistakes)
PR Curve Vs ROC Curve

- Imbalance pavement image data set:
  - Distress pixels are far less than normal pixels

- ROC curve uses false positive, which is affected by the number of negative samples

- PR curve focuses on the detection performance of positive samples only

\[
\text{tpr} = \frac{tp}{tp + fn} \quad \text{fpr} = \frac{fp}{fp + tn}
\]

\[
\text{Recall} = \frac{tp}{tp + fn} \quad \text{Precision} = \frac{tp}{tp + fp}
\]
Benchmark Image Sources
3D Benchmark Image Library

- Total size: 1535
- Image group:
  - Flexible Pavement: 4
  - Rigid Pavement: 4
  - High Friction Surface
- Ground truth generation
  - Crack map images
  - Manual visual inspection
## 3D Benchmark Image Library

<table>
<thead>
<tr>
<th>Group</th>
<th>Flexible Pavement</th>
<th>High Friction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coarse Surface</td>
<td>Good Quality</td>
</tr>
<tr>
<td>Size</td>
<td>224</td>
<td>255</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group</td>
<td>Rigid Pavement</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complex Condition</td>
<td>Good Quality</td>
</tr>
<tr>
<td>Size</td>
<td>260</td>
<td>285</td>
</tr>
</tbody>
</table>
Examples Images

Intensity

3D Range data in grey image format

Range data openGL visualization

Ground truth manually labeling
Case Studies

- Performance
- Sensitivity
Performance Analysis

- Asphalt Bad Quality

<table>
<thead>
<tr>
<th>Test</th>
<th>F-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SeedGrow</td>
<td>0.80</td>
</tr>
<tr>
<td>Lighting Model</td>
<td>0.72</td>
</tr>
<tr>
<td>Lighting 3D Image Model</td>
<td>0.73</td>
</tr>
<tr>
<td>ADA3D</td>
<td>0.56</td>
</tr>
</tbody>
</table>

![Graph showing performance analysis](image)
Performance Analysis

- Asphalt Good Quality

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>F-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SeedGrow</td>
<td>0.90</td>
</tr>
<tr>
<td>Lighting Model</td>
<td>0.86</td>
</tr>
<tr>
<td>Lighting 3D Image Model</td>
<td>0.94</td>
</tr>
<tr>
<td>ADA3D</td>
<td>0.74</td>
</tr>
</tbody>
</table>
Performance Analysis

- Concrete Complex Condition

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<tr>
<th>Test</th>
<th>F-value</th>
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<tr>
<td>SeedGrow</td>
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</tr>
<tr>
<td>Lighting 3D Image Model</td>
<td>0.80</td>
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<tr>
<td>ADA3D</td>
<td>0.66</td>
</tr>
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</table>

Diagram with Precision on the Y-axis and Recall on the X-axis, showing different models with their respective F-values.
Performance Analysis

Concrete Good Condition

- **SeedGrow**: F-value 0.88
- **Lighting Model**: F-value 0.82
- **Lighting 3D Image Model**: F-value 0.86
- **ADA3D**: F-value 0.72
## Performance Analysis - F score

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<tr>
<th>Test Group</th>
<th>SeedGrow</th>
<th>Lighting Model</th>
<th>Lighting 3D Image Model</th>
<th>ADA3D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Bad Quality</td>
<td>0.80</td>
<td>0.72</td>
<td>0.73</td>
<td>0.56</td>
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<td>0.72</td>
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<td>0.66</td>
</tr>
<tr>
<td>Concrete Good Condition</td>
<td>0.88</td>
<td>0.82</td>
<td>0.86</td>
<td>0.72</td>
</tr>
<tr>
<td>Average</td>
<td>0.85</td>
<td>0.78</td>
<td>0.83</td>
<td>0.67</td>
</tr>
</tbody>
</table>

SeedGrow > Lighting 3D > Lighting Model > ADA3D
Sensitivity Analysis

- Calculate SD of discrete PR points from top 40% F score

\[ SD = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{X})^2}{n} + \frac{\sum_{i=1}^{n}(y_i - \bar{Y})^2}{n}} \]

<table>
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<tr>
<th>Test Group</th>
<th>SeedGrow</th>
<th>Lighting Model</th>
<th>Lighting 3D Image Model</th>
<th>ADA3D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Bad Quality</td>
<td>0.092</td>
<td>0.062</td>
<td>0.015</td>
<td>0.021</td>
</tr>
<tr>
<td>Asphalt Good Quality</td>
<td>0.069</td>
<td>0.062</td>
<td>0.020</td>
<td>0.032</td>
</tr>
<tr>
<td>Concrete Complex Condition</td>
<td>0.058</td>
<td>0.049</td>
<td>0.008</td>
<td>0.018</td>
</tr>
<tr>
<td>Concrete Good Condition</td>
<td>0.053</td>
<td>0.034</td>
<td>0.017</td>
<td>0.020</td>
</tr>
<tr>
<td>Average</td>
<td>0.068</td>
<td>0.052</td>
<td>0.015</td>
<td>0.023</td>
</tr>
</tbody>
</table>

Lighting 3D < ADA3D < Lighting Model < SeedGrow
ADA3D Interface
Questions?

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