Sensing Highway Surface Conditions with High-Resolution Satellite Imagery

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Motivation

• *In situ* surveillance of highway surfaces
  – Slow and tedious
  – Analysis done by eye
  – Limited coverage

• Remote sensing of highway surfaces
  – Comparatively quick and effortless
  – Analysis done by machine
  – Full area coverage

• Latter technique can be used as a precursor to the former or as a compliment
In Situ Data

• Provided by the Colorado Department of Transportation
• Collected by Pathway Services Inc.
• Road parameters of interest
  – Roughness (IRI)
  – Rutting
  – Cracking (fatigue, etc.)
• Remaining service life
  – >10 years: Good
  – 5-10 years: Fair
  – <5 years: Poor

Pathway Services Inc. Surveillance Van
Remotely Sensed Data

• Provided by DigitalGlobe
• Collected by WorldView-2 spacecraft
• Panchromatic images
  – 450-800 nm
  – Spatial resolution 46-52 cm
  – 11-bit digital numbers

WorldView-2
Digital Number

21B

115A

24A
Digital Number

<table>
<thead>
<tr>
<th></th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
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<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>214.3</td>
<td>307.7</td>
<td>377.7</td>
</tr>
<tr>
<td><strong>STD</strong></td>
<td>5.2</td>
<td>10.3</td>
<td>29.5</td>
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## Occurrence-Based Texture Filtering

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**Original Image**

**Filtered Image**
Data Range

Example of a homogeneous surface typical of good pavement

Data range = $\max l(i, j) - \min l(i, j)$

Example of a homogeneous surface typical of poor pavement
Data Range

21B

115A

24A
## Data Range

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<th></th>
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<th>Poor</th>
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<tr>
<td><strong>STD</strong></td>
<td>3.5</td>
<td>6.2</td>
<td>15.6</td>
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</table>
Mean

Example of a homogeneous surface typical of good pavement

\[ \text{Mean} = \mu = \frac{1}{N} \sum I(i, j) \]

Example of a homogeneous surface typical of poor pavement
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<tbody>
<tr>
<td>Mean</td>
<td>214.5</td>
<td>307.8</td>
<td>378.3</td>
</tr>
<tr>
<td>STD</td>
<td>3.1</td>
<td>8.8</td>
<td>26.4</td>
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</tbody>
</table>
Variance

\[ \text{Variance} = \sigma^2 = \frac{1}{N} \sum (I(i,j) - \mu)^2 \]

Example of a homogeneous surface typical of good pavement

Example of a homogeneous surface typical of poor pavement
Variance
Variance

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<tbody>
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<td>31.5</td>
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Entropy

Example of a homogeneous surface typical of good pavement

\[ \text{Entropy} = - \sum p \ln p \]

Example of a homogeneous surface typical of poor pavement
Entropy
Conclusions

• Highway pavement becomes lighter in panchromatic grayscale shade as it degrades
  – Digital number increases
  – Mean increases

• Highway pavement becomes less uniform as it degrades
  – Data range increases
  – Variance increases
  – Entropy increases

• These changes are detectable through satellite remote sensing techniques and can likely be used to classify road surface conditions such as good, fair, poor and to justify repaving needs