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

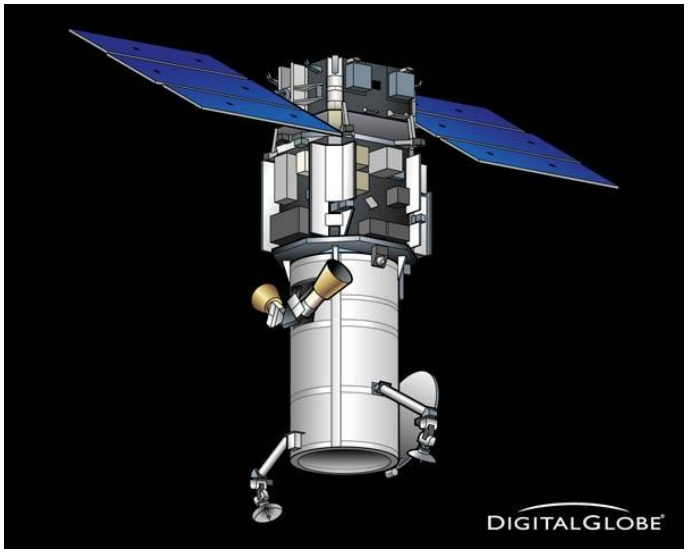
In Situ Data

- 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

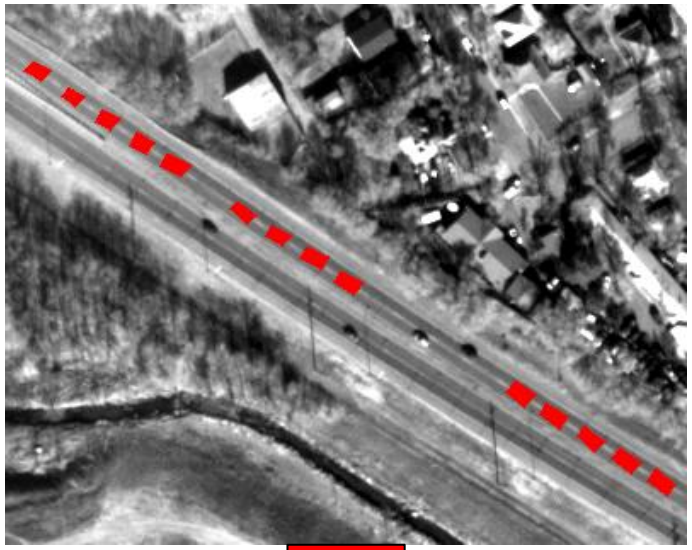


WorldView-2

Digital Number

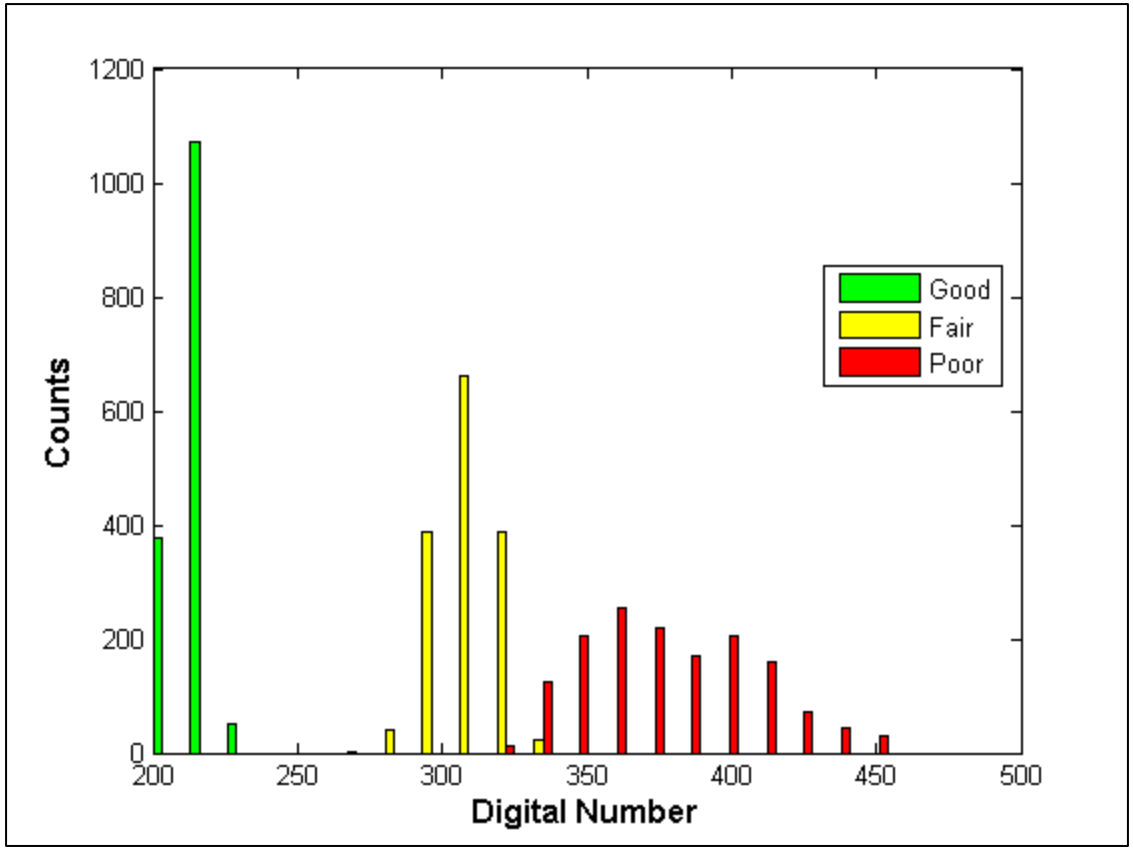
21B

115A



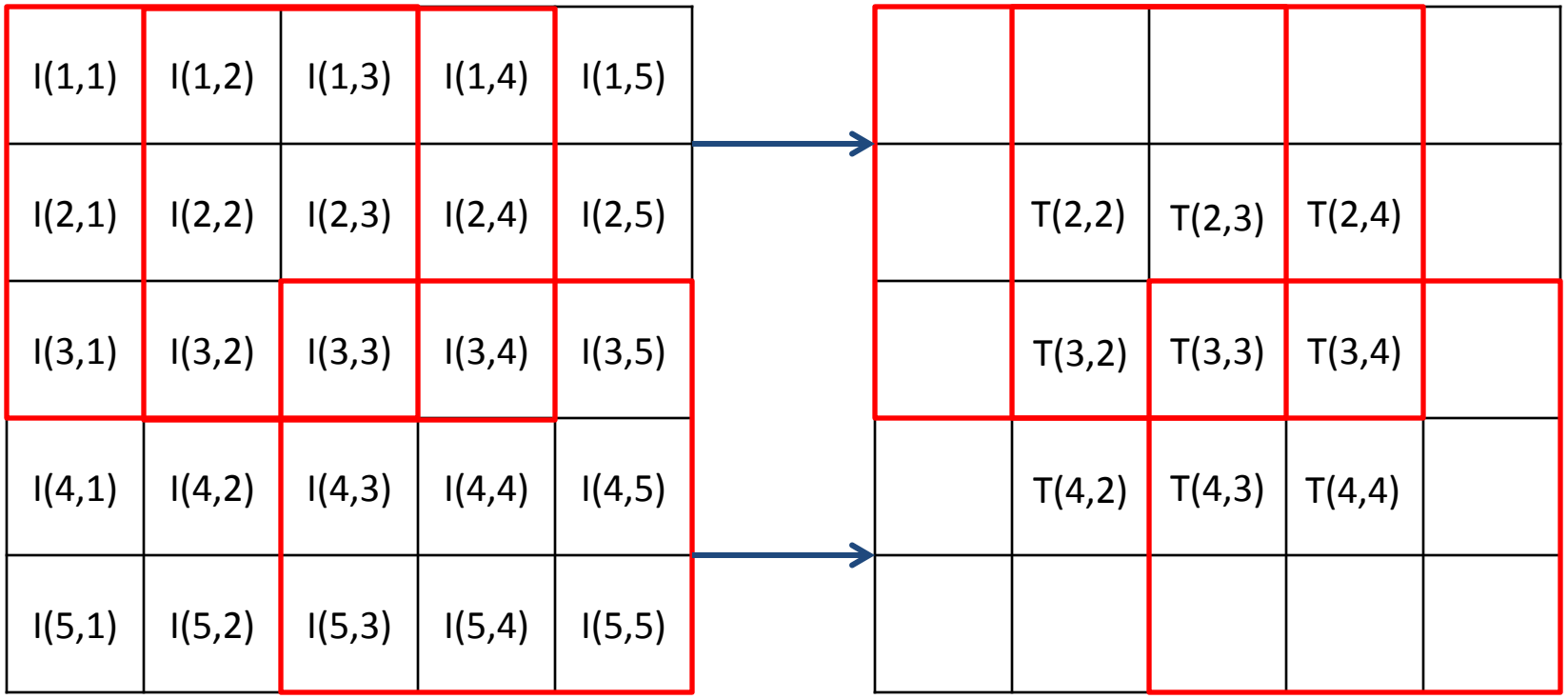
24A

Digital Number



	Good	Fair	Poor
Mean	214.3	307.7	377.7
STD	5.2	10.3	29.5

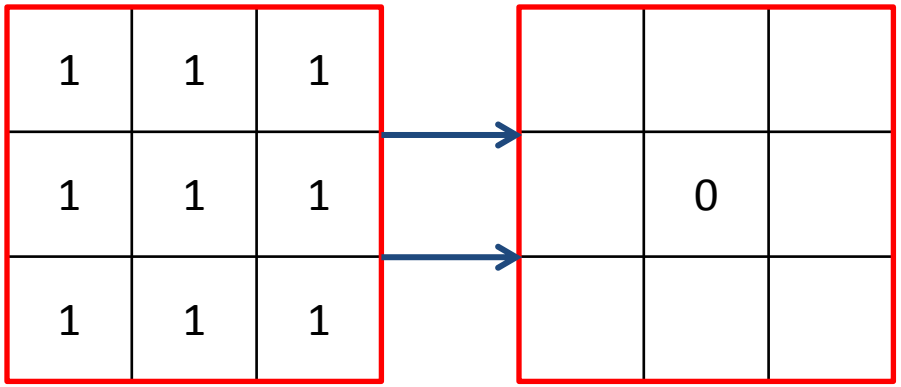
Occurrence-Based Texture Filtering



Original Image

Filtered Image

Data Range

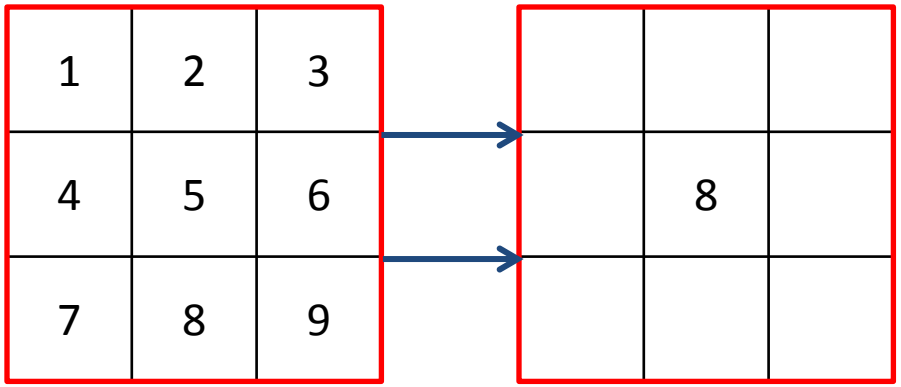


Homogeneous Window

Filtered Pixel

Example of a homogeneous surface typical of good pavement

$$\text{Data range} = \max I(i,j) - \min I(i,j)$$

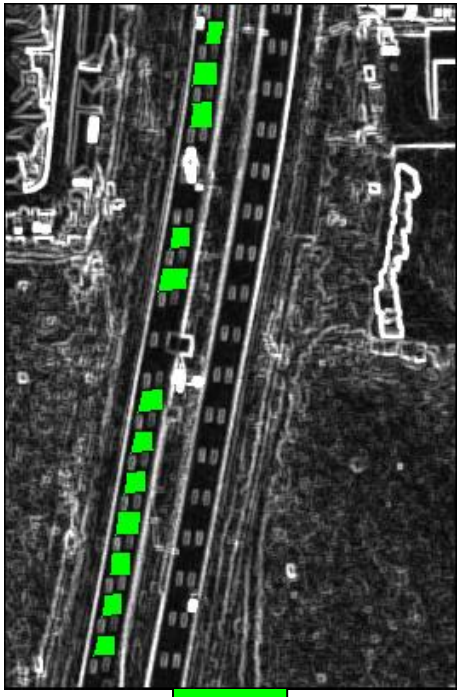


Heterogeneous Window

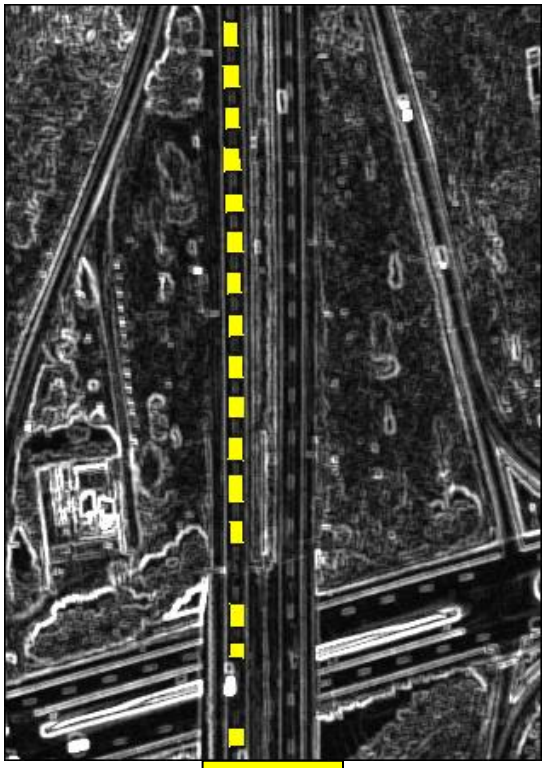
Filtered Pixel

Example of a homogeneous surface typical of poor pavement

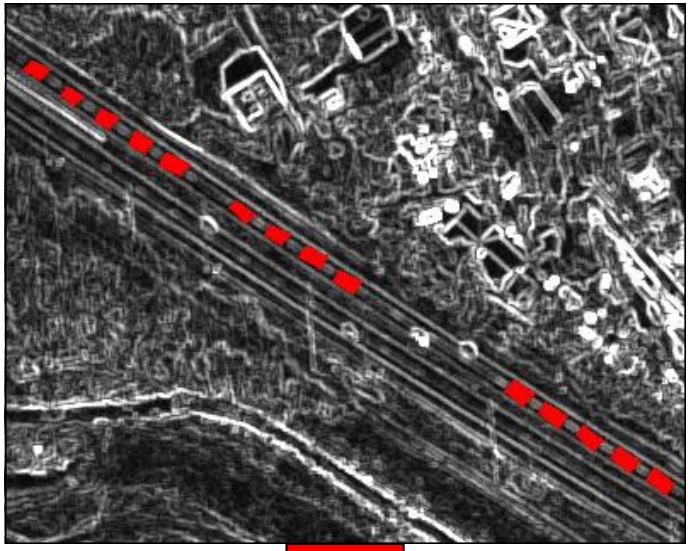
Data Range



21B

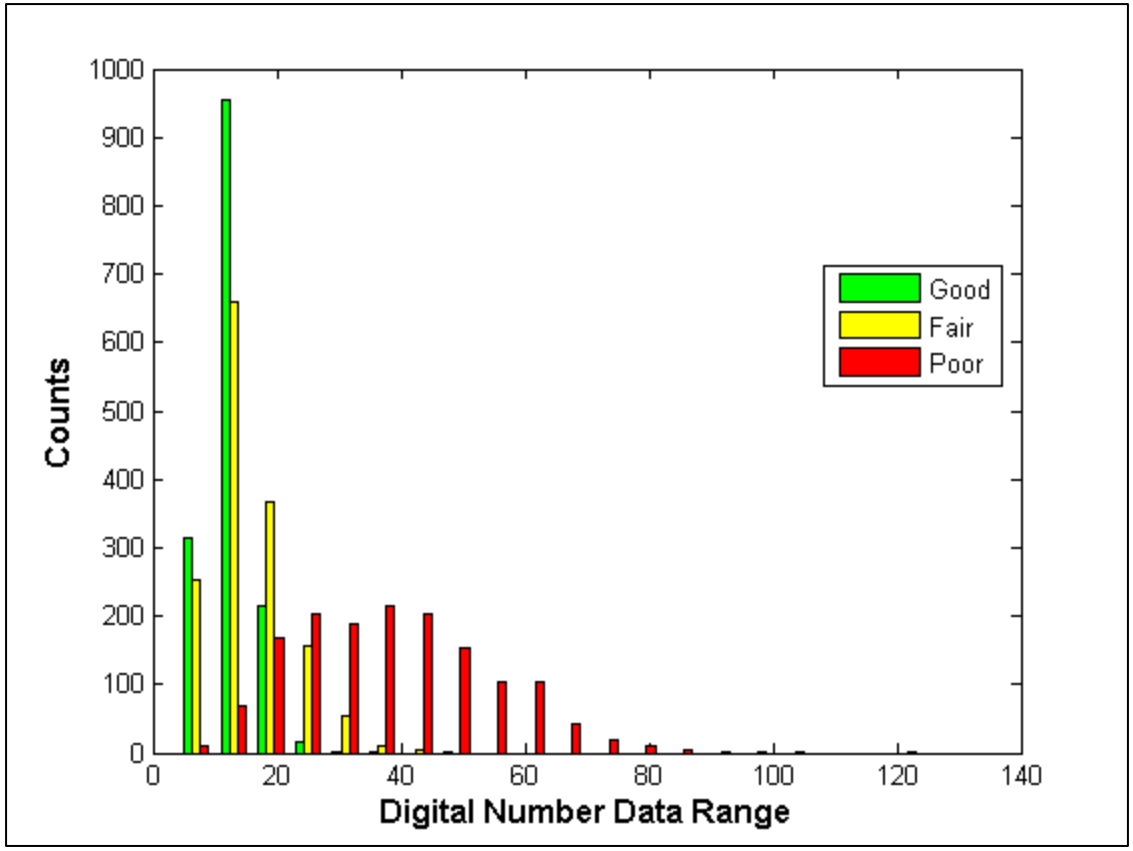


115A



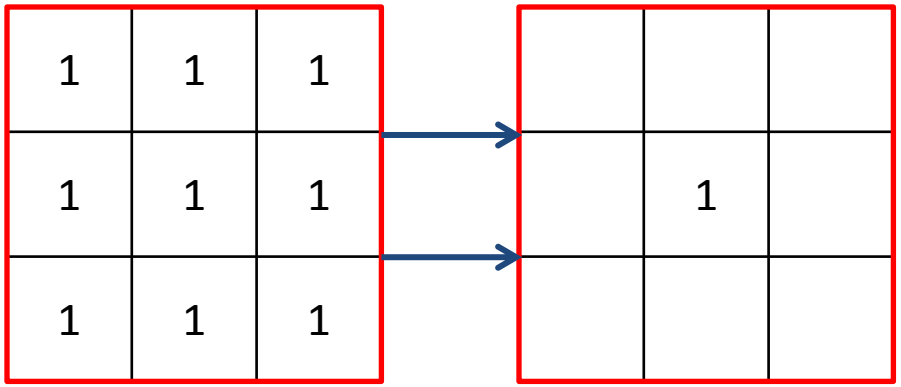
24A

Data Range



	Good	Fair	Poor
Mean	13.3	16.1	38.7
STD	3.5	6.2	15.6

Mean

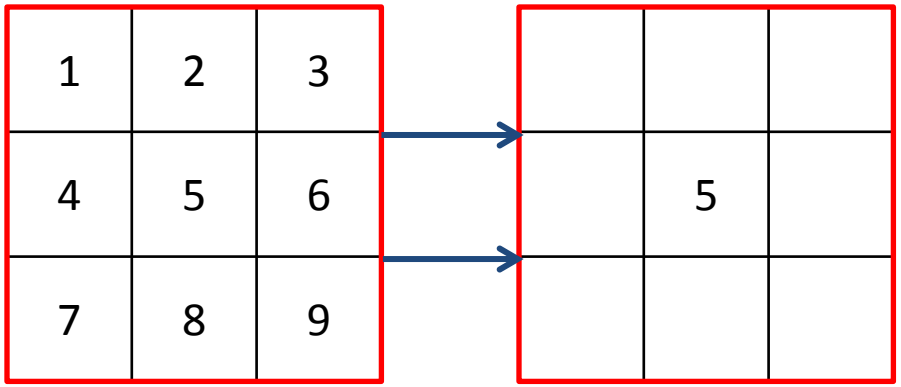


Homogeneous Window

Filtered Pixel

Example of a homogeneous surface typical of good pavement

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

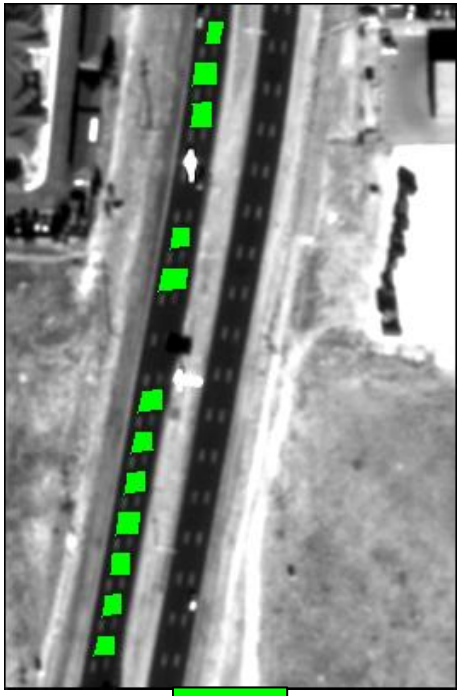


Heterogeneous Window

Filtered Pixel

Example of a homogeneous surface typical of poor pavement

Mean

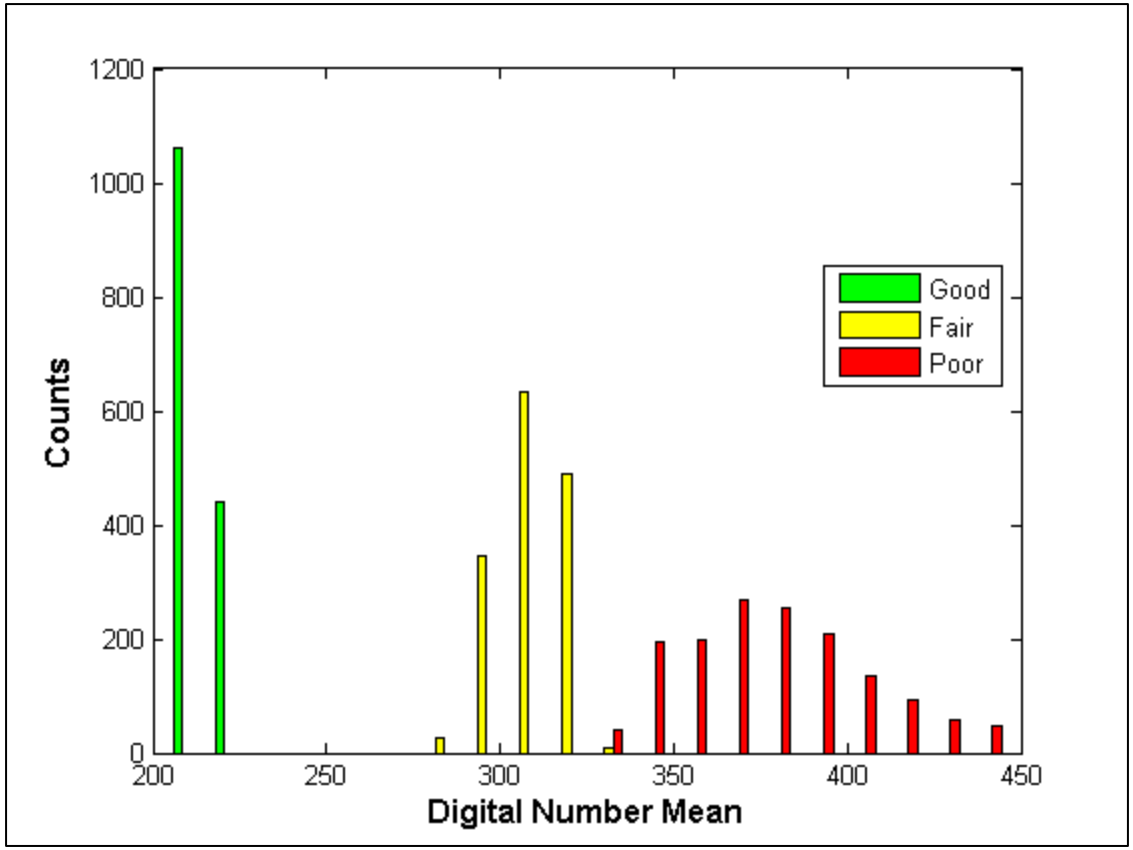


21B

115A

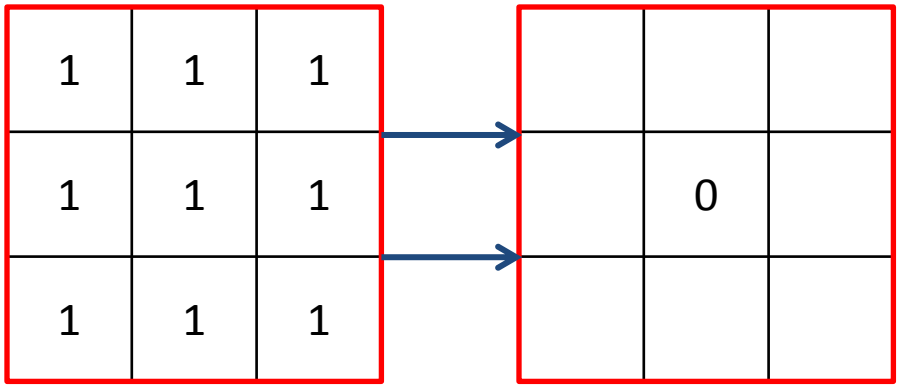
24A

Mean



	Good	Fair	Poor
Mean	214.5	307.8	378.3
STD	3.1	8.8	26.4

Variance

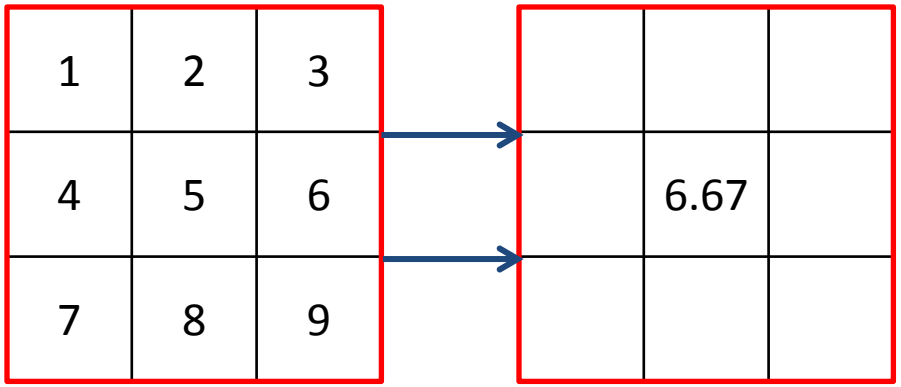


Homogeneous Window

Filtered Pixel

Example of a homogeneous surface typical of good pavement

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

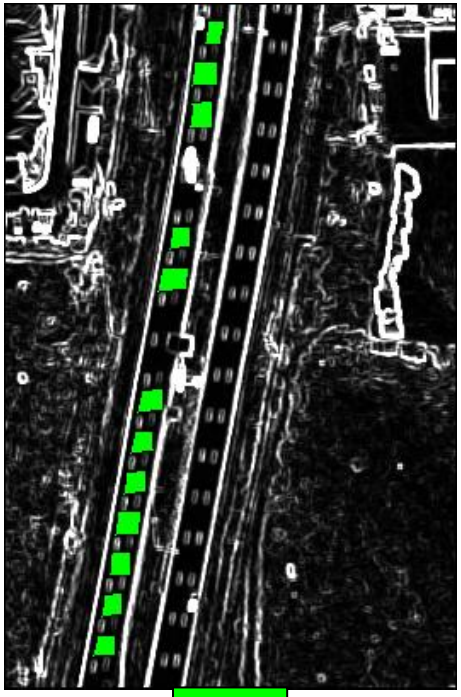


Heterogeneous Window

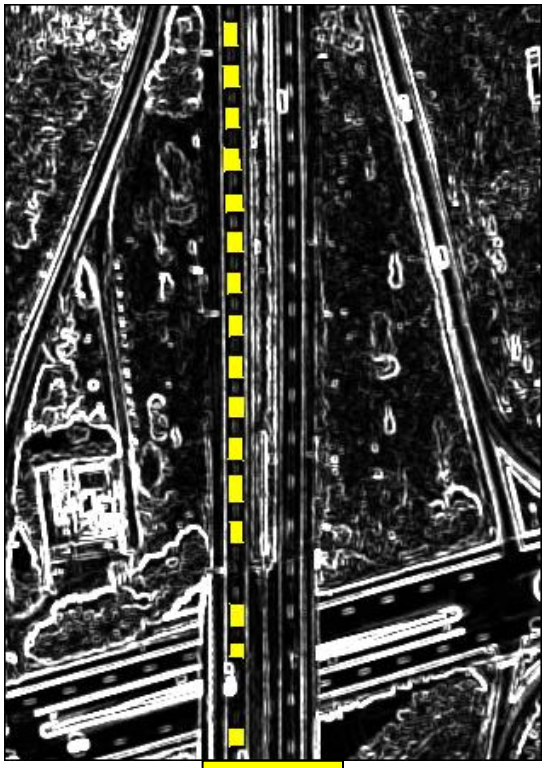
Filtered Pixel

Example of a homogeneous surface typical of poor pavement

Variance



21B



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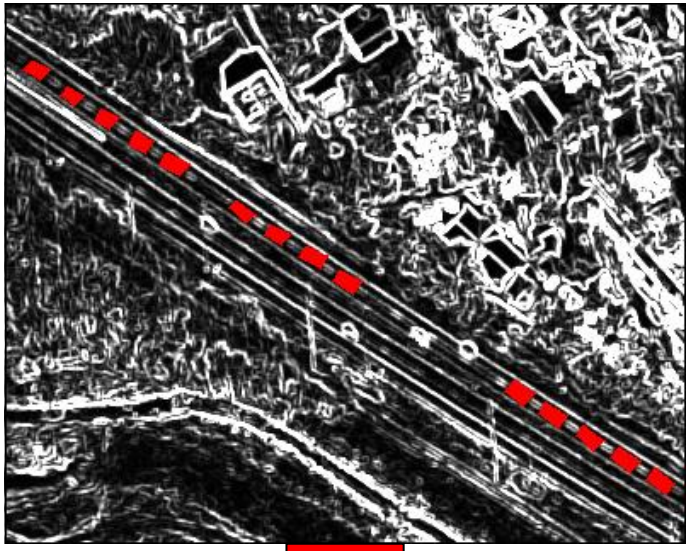
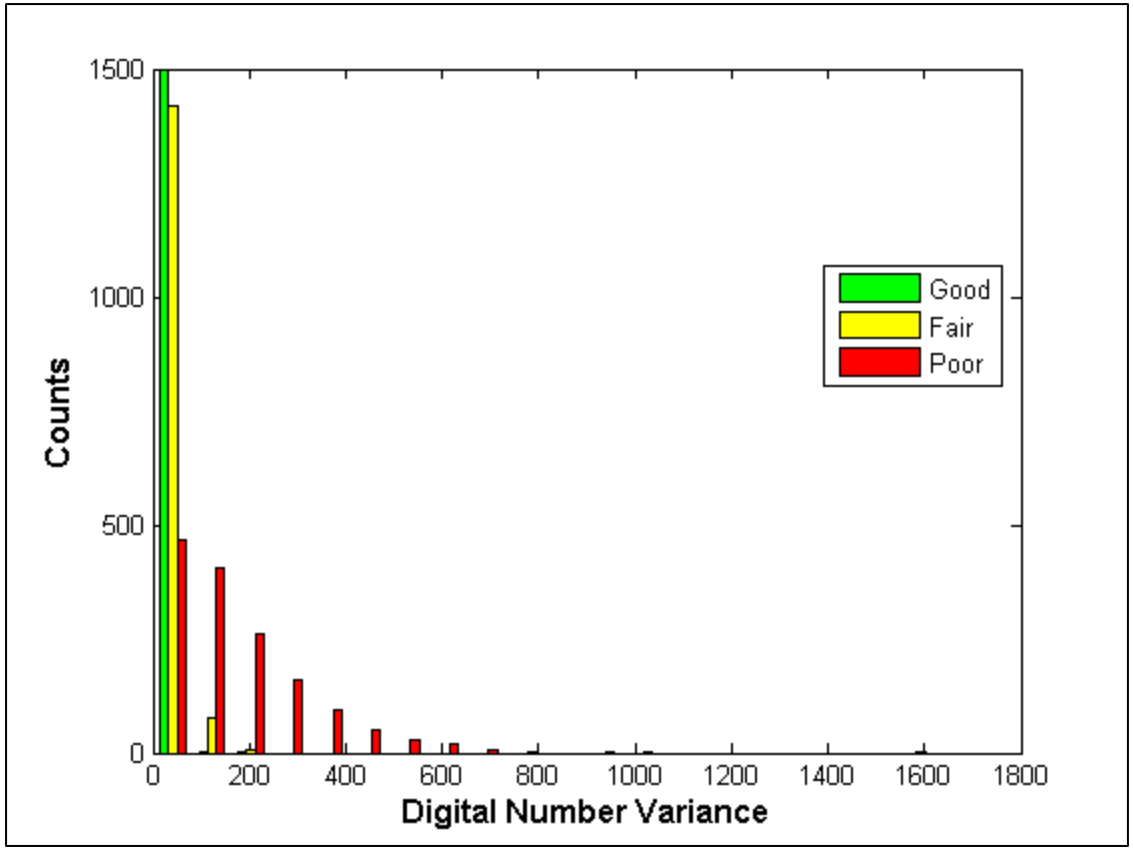


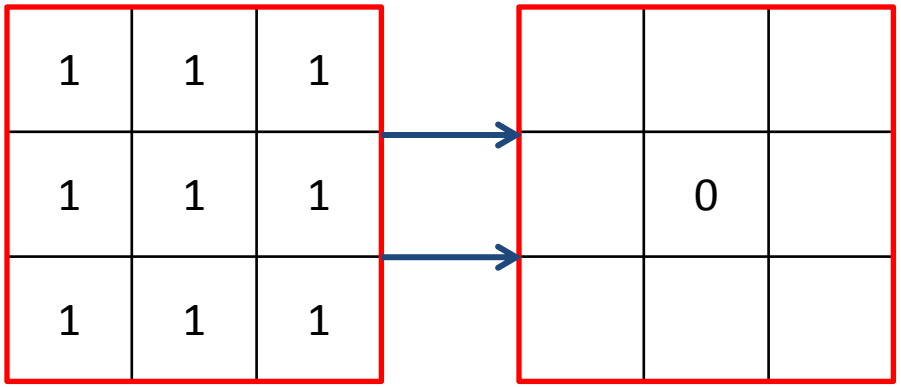
24A

Variance



	Good	Fair	Poor
Mean	18.7	31.5	174.0
STD	10.7	27.6	145.7

Entropy

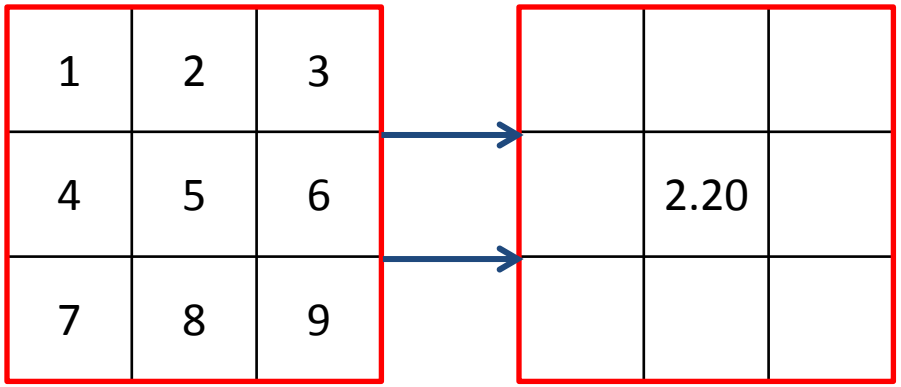


Homogeneous Window

Filtered Pixel

Example of a homogeneous surface typical of good pavement

$$\text{Entropy} = -\sum p \ln p$$

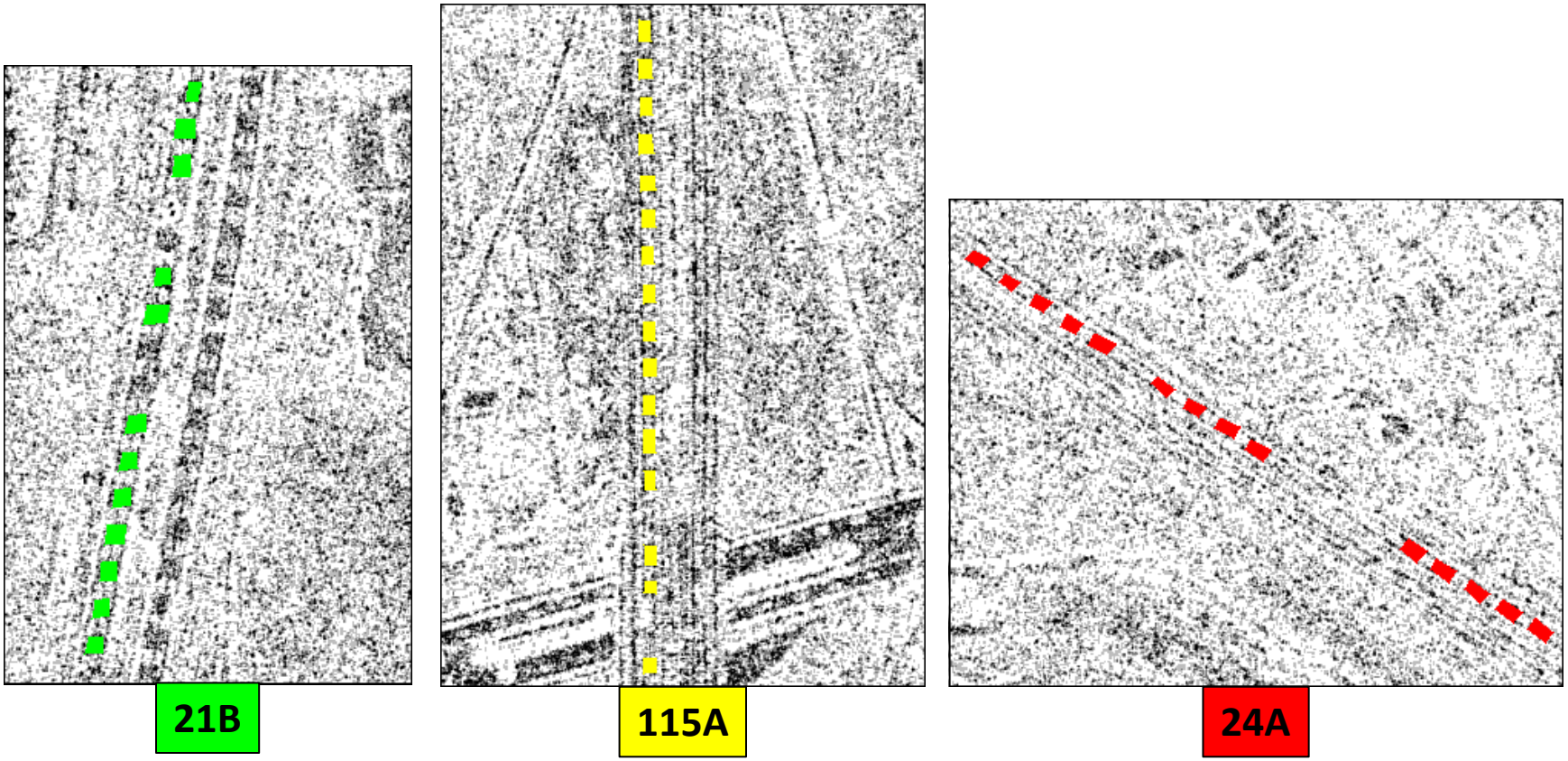


Heterogeneous Window

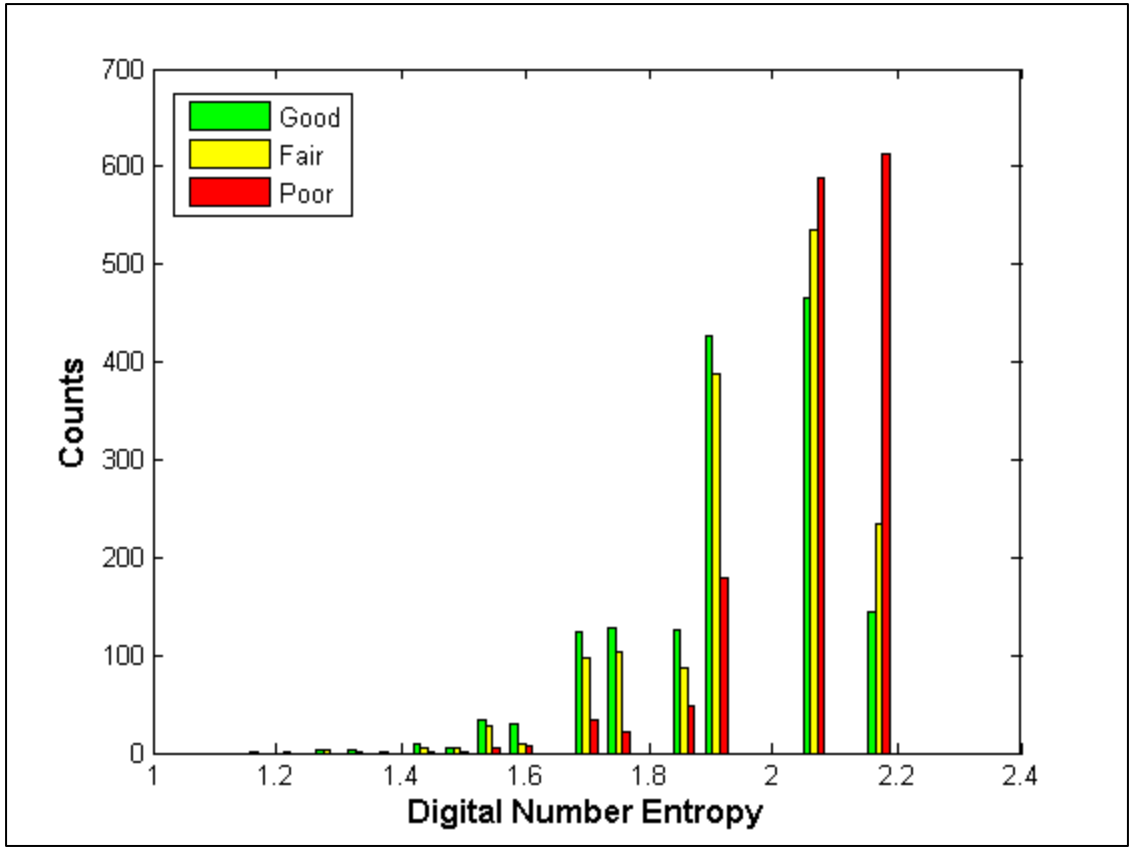
Filtered Pixel

Example of a homogeneous surface typical of poor pavement

Entropy



Entropy



	Good	Fair	Poor
Mean	1.9	2.0	2.1
STD	0.2	0.2	0.1

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