DIGITAL IMAGE PROCESSING
TECHNIQUES FOR PAVEMENT
MACRO-TEXTURE ANALYSIS

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Outline

- Significance of measuring road surface texture (macro-texture)?
- Texture from the visual and tactile viewpoints
- Digital image processing techniques
- Experimental Setup
- Results
- Discussions
Surface characteristics (WRC 1987)
Definition of texture

- **Visual texture:**
  - Image processing viewpoint (2D analysis)
  - Properties: Coarseness, directionality, regularity, blob-likeness, line-likeness etc
  - Tools: Fourier magnitude spectra, Autocorrelation, Wavelets etc

- **Tactile texture:**
  - 3D analysis - Depth sensors (e.g. road surfaces)
  - Properties: depth, roughness etc
  - Tools (for depth): Sand Patch test, Laser profilometer etc
The question

Could the tools of visual texture analysis be used to characterize texture depth?
The following algorithms were tested on road surfaces to determine their efficacy in capturing macrotexture.

1. **Fourier Magnitude spectrum (FFT – Fast Fourier Transform)** (Pidwerbesky et.al 2006)
2. **Autocorrelation function** (Kaizer 1955, Rubin 2004)
3. **Wavelets** (Unser 1992)
Imaging techniques: Mathematical definitions

- **Discrete Fourier Transform of an image:**
  \[
  F(u, v) = \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} I(i, j) e^{-j \frac{2\pi}{M} (ui + vj / N)}
  \]

- **The Autocorrelation function:**
  \[
  A[k,l] = \frac{1}{(M-k)(N-l)} \sum_{i=1}^{M} \sum_{j=1}^{N} I[i,j] I[i+k,j+l]
  \]
  \[
  = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} I[i,j]^2 
  \]
  \[
  0 \leq k \leq M-1, 0 \leq l \leq N-1
  \]

- **Wavelets:**
  \[
  \phi_{r,t}(x) = \phi(2^r x - t) = \sum_{n} \phi_{r,n} \sqrt(2) \psi(2^r x - t - n)
  \]
  \[
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  \]
  \[
  \psi_{r,n} = (-1)^n \sqrt(2) \phi(2^{r+1} x - n)
  \]
Imaging techniques

- Example of fine and coarse surface

(a) Fine surface
(b) Coarse surface
Imaging techniques

- **FFT magnitude spectrum**

- **Autocorrelation**

  - Fig. 1a
  - Fig. 1b

Direction of increasing coarseness
Imaging techniques: Wavelets

The diagram illustrates the decomposition of an image using wavelets. The process involves a series of transformations that break down the image into different frequency components. The diagram shows the flow from the original image $I(m,n)$ to the subbands $LL$, $LH$, $HL$, and $HH$.

- $I(m,n)$ is the original image.
- $L(n)$ and $H(n)$ represent the decomposition along columns.
- $L(m)$ and $H(m)$ represent the decomposition along rows.
- The subbands $LL$, $LH$, $HL$, and $HH$ are obtained as follows:
  - $LL$: Low-pass along columns and rows.
  - $LH$: Low-pass along columns, high-pass along rows.
  - $HL$: High-pass along columns, low-pass along rows.
  - $HH$: High-pass along columns and rows.

The subbands $LL$, $LH$, $HL$, and $HH$ represent different frequency components of the original image, each capturing different characteristics of the image.
Experiment set-up

- About 250 Images acquired from a section of Nudgee Road – Brisbane (2.26 km).
- SMTD (Sensor measured texture depth) values for comparison.
- Camera set-up
Fourier magnitude spectrum - results
ACF - results

- ACCOR method
- SMTD

- $y = 0.36x - 0.34$
- $R^2 = 0.64$
Wavelets (DWT) - results
Results combined for comparison

<table>
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<th>% outliers removed</th>
<th>FFT method</th>
<th>Autocorrelation</th>
<th>DWT</th>
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<td></td>
<td>Band-4</td>
<td>(1/slope) vs. SMTD</td>
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<td>10</td>
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Factors influencing imaging techniques

- **Image resolution**: must be adequate to capture macrotexture fluctuations.
- **Viewing angle**: Experiment show 60 degrees preferable to 90.
- **Shadowing**: direction of light source and impact on resulting image, requires modeling.
- **Illuminance**: Darker images appear to be coarser.
Effects of Illuminance
Effects of Illuminance

![Graph showing the effects of illuminance on autocorrelation over lag. The graph compares different illuminance levels including 100 lux, 300 lux, 2 klux, 7 klux, 20 klux, and 30 klux. The graph demonstrates how higher illuminance levels result in a coarser autocorrelation pattern.]
Conclusions

- Imaging techniques show promise for quantification of road surface macrotexture.
- Factors influencing the methods need to be either controlled or mitigated for improved results.
- Further research to investigate if the techniques can be calibrated once the various factors are mitigated/controlled.
- Further research required to investigate image acquisition from a high speed vehicle (whether motion blur could be contained).
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