Real-time 3D Scanning System for Pavement Distortion Inspection

Bugao Xu, Ph.D. & Professor

University of Texas at Austin
Center for Transportation Research
Austin, Texas 78712
Pavement distress categories

- Fracture (cracking, spalling and fatiguing)
- Distortion (rutting, corrugation and shoving)
- Disintegration (stripping, raveling)
Rutting and Shoving

- Rutting: surface depression in the wheel path.

- Shoving: longitudinal or transverse displacement

- Pothole: bowl-shaped holes of various sizes in the pavement surface
System principle

- Dynamic generation and characterization of 3D pavement profiles.
- Structured light.
System principle

- System Items
  - An infrared laser line projector
  - A GigE digital camera

- Laser line transversely covers pavement lane

- Camera captures consecutive laser line images while the vehicle moves forward

- Structured-light triangulation

- 3-D transverse profiles for distress detections
Elevation calculation

\[
\begin{align*}
\alpha &= \arctan \left( \frac{y_a}{f} \right) \\
 h &= l \cdot \tan(\theta) \\
 m &= l \cdot \tan(\theta - \alpha) \\
 \Delta h &= h - m = l \cdot (\tan(\theta) - \tan(\theta - \alpha))
\end{align*}
\]

The unknown parameters \((f, l\) and \(\theta)\) can be obtained through a calibration procedure.
# System specifications

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum scan rate</td>
<td>200 lines/sec</td>
</tr>
<tr>
<td>Sample Points</td>
<td>1024 points/line /1 unit</td>
</tr>
<tr>
<td>Scan width</td>
<td>1830 mm/ 1 unit</td>
</tr>
<tr>
<td>Vertical resolution</td>
<td>2 mm</td>
</tr>
<tr>
<td>Horizontal resolution</td>
<td>1.79 mm</td>
</tr>
<tr>
<td>Profile spacing</td>
<td>76.3 mm @55km/h</td>
</tr>
<tr>
<td>Maximum vehicle speed</td>
<td>112 km/h</td>
</tr>
</tbody>
</table>
Calibration

- An infrared filter eliminates the effect of the ambient lighting
- Only the points in the laser stripe are available
- The surface points are all located in the laser plane
- Tsai model is adopted to satisfy the coplanar calibration constrain
Calibration pattern and feature points
Multi-view scheme
Laser stripe location

- The processing time < 5 ms
- Image frame rate up to 200 frames per second.
- Insensitive to lighting conditions and pavement textures.
Sub-pixel laser stripe location

- Median filtering
- Coarse edge detection
- Stripe curve interpolation by cubic splines
- Fine profile adjusting (sub-pixel)
Laser line locating procedure
Edge detection

\[
\begin{cases}
\text{if } (\text{avgGray} \leq \text{threshold}_1) \& \& (\text{ratioAvg2Bkg} \leq \text{threshold}_2), \\
\qquad \quad \left(
\begin{array}{ccc}
-5 & -35 & -5 \\
0 & 0 & 0 \\
5 & 35 & 5
\end{array}
\right) \\
\quad \text{else, Canny}
\end{cases}
\]

avgGray: average grey value of image

ratioAvg2Bkg: the ratio between average grey value and background of image

Canny operator: with dynamic thresholds (which change depending on the image average grey value) is applied.
Fine profile adjusting

\[ Y = Y_r - k + \sum_{Y_r - k}^{Y_r + k} F(i)(i - Y_r + k) / \sum_{Y_r - k}^{Y_r + k} F(i) \]

*Y*: final profile precise location.

*Y_r*: coarse position of the stripe obtained from last step.

*F(i)*: the image grey value at pixel *i*.

Adjust the profile in each image column.
### 3D scans of a target

![3D scan diagram](image)

<table>
<thead>
<tr>
<th>Triangular target</th>
<th>Actual (mm)</th>
<th>Scanned (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (H)</td>
<td>200.6</td>
<td>200.475</td>
</tr>
<tr>
<td>Width (W)</td>
<td>706.0</td>
<td>706.873</td>
</tr>
</tbody>
</table>

#### Mean and S.D.
- Height (H): Mean = 200.475, S.D. = 0.319
- Width (W): Mean = 706.873, S.D. = 0.290
Pavement rutting measurement

Pavement rutting refers to surface depression in the wheel path.

- Median filtering
- Approximating profile
- Calculating the 1st and 2nd order derivatives of the endpoints
- Searching the rut support point pair
- Calculating the rut parameters
Rut depth measurement

Left wheel path
rut depth

Right wheel path
rut depth

A B C D E F G H
Approximating profile

Searching rut support points
Calculating rut parameters

- Rut depth: The maximal distance between the line AG and the road profile

- Rut area: The area between the line AG and the road profile

- Rut level: According to the rut depth, rut level is classified into 4 levels:
  - depth <6 mm 1
  - 6<=depth<12 2
  - 12<=depth<19 3
  - depth>=19 4
## Rutting Measurements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Scanned</th>
<th>Manual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Run 1</td>
<td>Run 2</td>
</tr>
<tr>
<td>Max rut depth (mm)</td>
<td>58.67</td>
<td>57.27</td>
</tr>
<tr>
<td>Rut depth (mm)</td>
<td>36.54</td>
<td>38.07</td>
</tr>
<tr>
<td>Rut area (mm$^2$)</td>
<td>37514.56</td>
<td>38053.42</td>
</tr>
</tbody>
</table>
**Shoving Measurements**

- Locate support points of shoving profile (points B&E)
- Search bump root points A&C, and points D&H
- Calculate the heights of the bumps ($h_0$ and $h_1$)
- Calculate the shoving width and depth
# Shoving Measurements

![Image of road condition]

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<th>Manual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Run 1</td>
<td>Run 2</td>
</tr>
<tr>
<td>Max depth (mm)</td>
<td>71.30</td>
<td>72.64</td>
</tr>
<tr>
<td>Max width (mm)</td>
<td>675.57</td>
<td>704.01</td>
</tr>
</tbody>
</table>
# Pothole detection

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Scanned</th>
<th>Manual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pothole depth (mm)</td>
<td>67.53</td>
<td>71</td>
</tr>
<tr>
<td>Pothole width (mm)</td>
<td>477.93</td>
<td>472</td>
</tr>
</tbody>
</table>
Summary

- 3D pavement profiles: real-time
- Structured light: reliable and inexpensive
- Multi-view coplanar calibration:
- Laser stripe locating method: sub-pixel accuracy
- Preliminary experiments: accurate rutting and shoving measurements.