A Sensor-Based and Spatially Enabled Roadway Asset Management System
(A Reliable, Cost-effective Performance Measurement Technology)

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Outline

• Introduction
  – Architecture of A Sensor-Based and Spatially Enabled Roadway Asset Management System
  – Research objective
  – Research focuses

• Georgia Tech Sensing Vehicle
• Pavement rutting/crack
• Traffic sign
• Summary
A Sensor-Based and Spatially Enabled Roadway Asset Management System

Phase 1

Sensing System

Data Processing and Collection
- Sign Detection
- Distress Detection
- Distress Classification
- Marking Assessment
- Cross Slope measurement
- Curvature Extraction
- Width Extraction

Data Integration and management

Common location reference system

GIS Platform

Decision Support
- Sign Management
- Roadway safety assessment
- Concrete pavement M&R analysis
- Pavement Marking Management
- Pavement Management
- HPMS; Road Characteristics
Research Objective

- To develop and validate an innovative and cost-effective means to inventory roadway assets and evaluate their condition (e.g. asphalt pavement surface conditions and traffic signs).

A Reliable and Cost-effective Measurement Technology
Research Roadmap and Focuses in Phase 1

**Integration of Sensing Devices**
- LCMS (for pavement asset)
- Imaging and mobile LiDAR (for traffic sign asset)

**Data Collection**
- Agencies’ data
- Sensing device collected data

**Application Validation (Seven Focuses)**
1. Network-level rutting measurement
2. Localized rutting identification
3. Performance evaluation of automatic crack detection algorithms
4. Validation of crack detection using 3D continuous transverse profiles
5. Develop and validate an enhanced sign inventory procedure using mobile-LiDAR and image processing technology
6. Validate the sign condition assessment using mobile LiDAR
7. Validate an integrated GIS-based sign asset management system

**Outreach Plan**
Georgia Tech Sensing Vehicle
(All-In-One Technology)
3D Line Laser Imaging Technology

1. Transverse dir : 1 mm

2. Elevation: 0.5 mm

3. Data points collected per second and width covered:

   $2 \text{ (lasers)} \times 2048 \text{ (points/profile/laser)} \times 5600 \text{ HZ} = 22,937,600 \text{ points}$

   $2 \text{ (lasers)} \times 2048 \text{ (points/profile/laser)} \times 1 \text{ (mm)} = 4.096 \text{ m}$
LiDAR and Imaging System

High resolution LiDAR
1. Rutting

- Rut depth measurement
- Localized rutting
Point-based Rut Bar

<table>
<thead>
<tr>
<th>Automated Survey System</th>
<th>3-point</th>
<th>5-point</th>
<th>7-point to 37 point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Highway Agencies</td>
<td>16</td>
<td>13</td>
<td>11</td>
</tr>
</tbody>
</table>

(McGhee 2004)
Rut Depth Measurement

1. Lab Test

2. Field Test
### Accuracy of Rut Depth Measurement (1)

**Note:** **1. Lab Test** (Absolute error less than 1mm)

<table>
<thead>
<tr>
<th>Profile #</th>
<th>Severity Level</th>
<th>Ground Truth</th>
<th>LCMS Measured</th>
<th>Difference to Ground Truth</th>
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<td></td>
<td></td>
<td></td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Run</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Run</td>
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<tr>
<td>1</td>
<td>low</td>
<td>8.04</td>
<td>8.26</td>
<td>7.12</td>
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<td>2</td>
<td>low</td>
<td>7.92</td>
<td>8.16</td>
<td>7.99</td>
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<tr>
<td>3</td>
<td>low</td>
<td>7.94</td>
<td>6.79</td>
<td>7.57</td>
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<td>4</td>
<td>medium</td>
<td>13.22</td>
<td>13.22</td>
<td>13.05</td>
</tr>
<tr>
<td>5</td>
<td>low</td>
<td>12.34</td>
<td>12.27</td>
<td>11.47</td>
</tr>
<tr>
<td>6</td>
<td>medium</td>
<td>14.24</td>
<td>13.75</td>
<td>14.03</td>
</tr>
<tr>
<td>7</td>
<td>medium</td>
<td>15.54</td>
<td>15</td>
<td>14.8</td>
</tr>
<tr>
<td>8</td>
<td>medium</td>
<td>16.24</td>
<td>15.41</td>
<td>16.7</td>
</tr>
<tr>
<td>9</td>
<td>medium</td>
<td>17.46</td>
<td>17.57</td>
<td>17.13</td>
</tr>
<tr>
<td>10</td>
<td>medium</td>
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<td>9.68</td>
</tr>
<tr>
<td>11</td>
<td>high</td>
<td>43.38</td>
<td>43.24</td>
<td>--</td>
</tr>
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# Accuracy of Rut Depth Measurement (2)

Note: **2. Field Test** (Absolute error about 2mm)

<table>
<thead>
<tr>
<th>Profile #</th>
<th>Severity Level</th>
<th>Ground Truth</th>
<th>1st run</th>
<th>2nd run</th>
<th>3rd run</th>
<th>Average</th>
<th>Difference to Ground Truth (mm)</th>
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<td>1</td>
<td>Medium</td>
<td>14.5</td>
<td>12.1</td>
<td>14.0</td>
<td>13.5</td>
<td>13.2</td>
<td><strong>1.3</strong></td>
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<tr>
<td>2</td>
<td>Medium</td>
<td>15.8</td>
<td>13.4</td>
<td>14.6</td>
<td>12.8</td>
<td>13.6</td>
<td><strong>2.2</strong></td>
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<tr>
<td>3</td>
<td>Low</td>
<td>9.6</td>
<td>10.7</td>
<td>10.8</td>
<td>10.3</td>
<td>10.6</td>
<td><strong>-1.0</strong></td>
</tr>
<tr>
<td>4</td>
<td>Medium</td>
<td>14.2</td>
<td>12.9</td>
<td>12.1</td>
<td>11.3</td>
<td>12.1</td>
<td><strong>2.1</strong></td>
</tr>
<tr>
<td>5</td>
<td>Low</td>
<td>8.5</td>
<td>6.0</td>
<td>6.7</td>
<td>7.6</td>
<td>6.8</td>
<td><strong>1.7</strong></td>
</tr>
<tr>
<td>6</td>
<td>Low</td>
<td>9.5</td>
<td>7.3</td>
<td>7.2</td>
<td>7.1</td>
<td>7.2</td>
<td><strong>2.3</strong></td>
</tr>
<tr>
<td>7</td>
<td>Low</td>
<td>7.8</td>
<td>5.9</td>
<td>6.0</td>
<td>6.6</td>
<td>6.2</td>
<td><strong>1.6</strong></td>
</tr>
<tr>
<td>8</td>
<td>Low</td>
<td>9.4</td>
<td>7.2</td>
<td>7.1</td>
<td>7.2</td>
<td>7.2</td>
<td><strong>2.2</strong></td>
</tr>
<tr>
<td>9</td>
<td>Medium</td>
<td>21.1</td>
<td>19.8</td>
<td>20.8</td>
<td>20.3</td>
<td>20.3</td>
<td><strong>0.8</strong></td>
</tr>
<tr>
<td>10</td>
<td>Low</td>
<td>6.4</td>
<td>5.7</td>
<td>4.7</td>
<td>5.3</td>
<td>5.2</td>
<td><strong>1.2</strong></td>
</tr>
</tbody>
</table>
Assessment of Rut Bar System Errors

[Graph showing frequency distribution of relative errors for different rut bar systems, including 3-point rut bar, 5-point rut bar, 9-point rut bar, and 39-point rut bar. Each system is represented by a different color and line style, with a normal fit curve overlayed for comparison.]
Isolated Rut on I-95
Isolated Rut Identification and Measurement

MP: 100.16 to 100.17
Length = 480 ft
Max Depth = ¾ in.
Area = 2600 ft²
Volume = 51 ft³
Cracking

- Automatic crack detection
- Performance evaluation
Problem on Region-based Performance Measurement

Algorithm 1 result (3ft), 100% detection

Algorithm 2 result (3ft), 100% detection

Ground truth (3ft)

5ft by 5ft pavement area sample
Linear Buffered Hausdorff Quantification Method

\[ BH(A, B) = \max(h(A, B), h(B, A)) \]

\[ h(A, B) = \frac{1}{m \sum_{a \in A, L} \min_{b \in B} \|a - b\|} \]

Scoring Measure (SM) = 100 - \frac{BH(A, B)}{L}
A Buffered Hausdorff Distance Scoring Method

(a) Original Image

(b) Ground Truth Image

(c) Dynamic Optimization Result
   Score: 92

(d) Canny Edge Detection Result
   Score: 14

(e) Crack Seed Verification Result
   Score: 3

(f) Iterated Clipping Result  Score: 64
Advantage of 3D data over 2D data on crack detection

With 3D continuous profile technology, it is a lot more clear to distinguish a crack from the surrounding pavements.
Laboratory Test for Crack Detection

(a) 1mm (daytime)

(b) 1mm (night)

(c) 2mm (daytime)

(d) 2mm (night)
Field Test for Crack Detection (1)

Daytime (no shadow)                   Shadow                                Night
Field Test for Crack Detection (2)

Daytime (score = 98.3)  Night (score = 98.0)
Crack Width Measurement (1)
Demo Video

Initial source point
Validation of Pavement Condition Assessment Using 3D Line Laser Imaging Technology (on-going tasks)

- Asphalt pavement crack classification
- Concrete pavement condition evaluation (faulting, spalling, crack, should joint drop, etc.)
3. Traffic Sign Inventory

- Using mobile LiDAR and image processing algorithms
- Sign retro-reflectivity condition assessment
Image-based Traffic Sign Detection

- MUTCD Shapes: circle, triangle, rectangle, pentagon, Octagon, etc.
Sign Recognition Using Image Pattern Recognition Algorithms

(a) Raw image containing speed limit sign
(b) Processed binary image after color segmentation
(c) Extracted speed limit digits

Incorporated other features, Harr features derived from the Adaboost Cascade algorithm, used effectively in face recognition
Sign Pattern Recognition

FIGURE 9 Sign recognition from multi-features.

(NCHRP IDEA Final Project Report, Tsai, 2009)
Sign Detection Demo
Sign Condition Change Detection
Sign Change Detection

Figure 11. Spatial searching with GPS coordinates: a) A tilted milepost sign taken in FY 2005; b) Two baseline candidate images taken in FY 2003 are selected through GIS spatial search.
Sign Change Detection (cont.)
Use of Mobile LiDAR for Sign Detection
Summary

- It is promising to use emerging sensor technology to develop a cost-effective measurement technology.
- 3D line laser imaging technology is capable of building a “All Purpose” device for assessing pavement surface conditions: rutting, cracking, potholes, macro-texture, etc.
- The accuracy and repeatability of rut depth measurement can be improved using 3D line laser technology. It can be applied for network-level rutting survey and isolated rut identification.
- The accuracy of crack detection and width measurement can be improved using 3D line laser imaging technology.
- It can be further applied to crack classification and concrete condition assessment (e.g. faulting, spalling, broken slabs).
- Mobile LiDAR and image processing algorithms can be used to improve the efficiency of sign data collection under a well-designed sign inventory procedure.
Outreach Plan

• Work with GDOT to initiate pilot studies to extend the research results to practical application: I-285 interstate highway pavement condition evaluation to demonstrate the practical use of the technology and how to generate the information, including report that can support pavement maintenance operation and decision-making.
Thanks