Augmenting Bridge Inspections through UAS-enabled Multi-Sensor Data Collections

Team lead:
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Project colleagues:
Michigan Technological University: Thomas Oommen, Tim Havens, Tess Ahlborn, Amlan Mukherjee, Kuilin Zhang, Rick Dobson, David Banach, Ben Hart, Sam Aden, Rudiger Escobar-Wolf, Nick Marion
SSI, Inc: Andrew Semenchuk, Jeff Bartlett

Project funding provided by:
Michigan Department of Transportation (2016-0067/Auth.1: OR15-139)
Program Manager: Steve Cook, Research Mgr: André Clover
UAV Platforms

- Multiple platforms have been tested
  - Focus on flexible, lower cost platforms

- Bergen Hexacopter & Quad-8
  - Price: $4,500 to $6,200
  - Flight time: 20 min
  - Payload: up to 4.5 kg (~10 lbs)
  - Hexacopter first tested on USDOT OST-R CRS&SI project on Unpaved Road Assessment project [http://www.mtri.org/unpaved/](http://www.mtri.org/unpaved/)

- Aerostat / Tethered Blimp
  - Test system: $1500 (higher winds version ~$4,500)

- Imaging small quadcopters (<$1600)
  - DJI Phantom 3 Advanced
  - 3D Robotics IRIS+
  - Mariner, Splash2 (waterproof)
  - DJI Mavic Pro

- Micro-UAS quadcopters
  - Confined space imaging
  - <$500
Optical Sensor for Structure-from-Motion (SfM) photogrammetry

- Nikon D800, D810 – full-sized (FX) sensor, 36.3 MP, 4 fps - $3,000
- 50mm prime lens - $700
- Collect stereo overlapping imagery to create cm-resolution 3D surfaces
  - Structure from Motion (SfM) photogrammetry
  - AgiSoft Photoscan
  - MTRI SfM software workflow
- Demonstrated on USDOT unpaved roads project (CRS&SI – C.Singh)

Creating 3D data from overlapping images

Taken from 25m / 82'
Optical sensor: small quadcopter cameras for basemap & corridor imaging, bridge components, & traffic video

- Small cameras on board DJI Mavic Pro & Phantom small quadcopters + Mariner series
- Provide 12-20 mp images & up to 4K video
- Useful for making basemaps of sites
- Imaging fascia & undersides of bridges
- Recording traffic video for analysis
Thermal Sensors

FLIR Tau 2 – 640 x 512 sensor

FLIR Vue Pro & Pro R -640 x 512 sensor (Pro R - Radiometric version, ~$5400)

FLIR Duo – 160x120, $999

Sensitive to 7.5 - 13.5 µm, within 5% of reading
LiDAR for 3D bridge & road models

Hokuyo UTM-30LX LiDAR

Velodyne LiDAR Puck (≈$8k – now $4k)
Example sensing data sets & results

- Focus on corridor & bridge data in s. Michigan
- Collected data from 5 bridges, 2 highway corridors in Phase II project; 2 bridges in Phase I
- Demonstrated both overhead (nadir) and offset (oblique) data collections
  - UAS deployment more practical with oblique data collections
  - Current FAA rules do not allow operation of UAS over moving traffic, people (Part 107)
  - Waiver process possible
Seven standard geospatial outputs for UAS sensing of bridge decks

Orthoimage  DEM  Hillshade  Thermal  Spalls  Delaminations  Point Cloud
Automated spall detection

- Automated spall detection algorithm (developed by Brooks, Dobson, Aden, Graham)
- Applied to high-resolution 3D elevation model (DEM) of bridges created from UAS images
- Merriman East: 4.4% spalled (150.0 ft²)
- US-31/White River: 79.2 ft² (1.1%) spalling in 2017 vs. 33.6 ft² (0.5%) in 2014
Thermal Algorithm for Delamination Detection

- Thermal delamination analysis tool
  - Developed an ArcPy tool based on the thermal-visible algorithm
  - User friendly (i.e., through standard ArcGIS Tool GUI)
Analyzing thermal results

Compare results to traditional hammer sounding & chain drag methods (NDT)

Beyer Road Bridge Delaminations

UAV Data
Uncle Henry Rd Bridge
STR#9298 Saginaw, MI
November-December, 2016

Total Area of Sounding
Survey Polygons = 188 sq ft

FLIR View Pro 640 and Thermal-Optical Algorithm Results

Nikon D800 Imagery - 11/14/16

Delaminations mapped from the combined thermal-optical algorithm shown on the FLIR View Pro 640 Thermal Data (11/14/16) on DJI Phantom Imagery (12/30/16)

Delaminations mapped from the combined thermal-optical algorithm compared to results from the sounding survey (likely delaminations) on DJI Phantom Imagery 12/30/16
Quantitative thermal analysis results

Existing thermal method: ASTM D4788 - 03(2013)
Standard Test Method for Detecting Delaminations in Bridge Decks Using Infrared Thermography
Beyer Rd Bridge quantitative results

UAV Data - Beyer Rd Bridge
Sounding Survey 12/30/16
Algorithmic Delaminations
Thermal Data 11/14/16
Str#9293 Saginaw, MI

Area of Bridge = 1,756.13 sq ft
Total Area of Sounding Survey
Polygons = 313.28 sq ft
Total Area of Delamination
Polygons = 92.73 sq ft

- Sounding Survey Polygon
- Detected Delamination
- Exclusion Zone

Delamination Polygon Area

<table>
<thead>
<tr>
<th>ID</th>
<th>Area (sq ft)</th>
<th>Area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.28</td>
<td>0.67</td>
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<tr>
<td>4</td>
<td>4.63</td>
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<td>36</td>
<td>4.51</td>
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<td>5</td>
<td>3.91</td>
<td>0.36</td>
</tr>
<tr>
<td>3</td>
<td>2.86</td>
<td>0.28</td>
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<tr>
<td>10</td>
<td>2.67</td>
<td>0.27</td>
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<tr>
<td>40</td>
<td>2.37</td>
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<td>72</td>
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<td>74</td>
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<td>20</td>
<td>2.05</td>
<td>0.19</td>
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<tr>
<td>Sum of 60</td>
<td>63.29</td>
<td>5.82</td>
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</table>

Sounding Survey Polygon Area

<table>
<thead>
<tr>
<th>ID</th>
<th>Area (sq ft)</th>
<th>Area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>211.2</td>
<td>19.62</td>
</tr>
<tr>
<td>B</td>
<td>51.06</td>
<td>4.74</td>
</tr>
<tr>
<td>C</td>
<td>14.21</td>
<td>1.32</td>
</tr>
<tr>
<td>D</td>
<td>6.93</td>
<td>0.64</td>
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<tr>
<td>E</td>
<td>19.01</td>
<td>1.77</td>
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<tr>
<td>F</td>
<td>6.52</td>
<td>0.61</td>
</tr>
<tr>
<td>G</td>
<td>4.39</td>
<td>0.41</td>
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</table>
US-31 White River Bridge & corridor - Nikon D810 DEM + Hillshade

US 31 White River Bridge
June 15 2017
Digital Elevation Model
+ Hillshade

STR 7587
Built 1965

Length = 169.0 ft
Width = 42.9 ft
Spans = 3
US 31 Bridge Deck
Time Comparison

2014

2017

Bridge Area - 7,250 ft²
Spall Areas
2014 - 33.6 ft² (0.5% of the bridge deck)
2017 - 79.2 ft² (1.1% of the bridge deck)
US-31 – crack comparisons (Nikon D810 imagery)

US 31 Surface Cracking
Nikon D810
Underside of US-31/White River bridge – Splash2 drone

- Application worked, but Splash2 needs further development
Cost-Benefit Analysis results

- Calculated Net Present Value (NPV) of treatment costs
- UAV-enabled thermal analysis techniques are finding smaller areas of delamination distress than NDT techniques (chain dragging-CD/hammer sounding-HS)
- Better estimation of amounts of distress using UAVs can help lower maintenance costs
  - Repair smaller, more precise areas

### Distress: Delamination (sq ft) vs. NDT Technique

<table>
<thead>
<tr>
<th>Distress: Delamination (sq ft)</th>
<th>NDT Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridge</td>
<td>UAV CD and HS</td>
</tr>
<tr>
<td>Uncle Henry Road</td>
<td>53.59 ft², 188.0</td>
</tr>
<tr>
<td>Beyer Road</td>
<td>92.73, 313.28</td>
</tr>
</tbody>
</table>

### Net Present Value

<table>
<thead>
<tr>
<th>NDT Technique</th>
<th>Bridge</th>
<th>Uncle Henry Road</th>
<th>Beyer Road</th>
</tr>
</thead>
<tbody>
<tr>
<td>UAV CD HS</td>
<td>Fair</td>
<td>Poor</td>
<td>Fair Poor</td>
</tr>
<tr>
<td>Treatments</td>
<td>$10,438</td>
<td>$35,614</td>
<td>$18,061 $61,016</td>
</tr>
</tbody>
</table>

- Cement Overlay
  - $1,184 | $4,152 | $2,048 | $6,919

- Asphaltic concrete overlay without membrane
  - $447 | $1,569 | $774 | $2,615

- Asphaltic concrete overlay with membrane
  - $723 | $3,364 | $1,250 | $4,224

- Deck replacement (new deck with epoxy-coated bars)
  - $1,337 | $4,688 | $2,313 | $7,813

*Patching - $10,438 vs. $35,614 – 70% less*
# Managing Processed Datasets: Collected vs. final sizes

<table>
<thead>
<tr>
<th>Site</th>
<th>Optical</th>
<th>Thermal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beyer Rd.</td>
<td>8 GB (total data collected)</td>
<td>285 MB (total data collected)</td>
</tr>
<tr>
<td></td>
<td>37 MB (merged scene)</td>
<td>120 KB (merged scene)</td>
</tr>
<tr>
<td>Uncle Henry</td>
<td>1.72 GB (total data collected)</td>
<td>220 MB (total data collected)</td>
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<tr>
<td></td>
<td>54 MB (merged scene)</td>
<td>120 KB (merged scene)</td>
</tr>
<tr>
<td>Holton Road</td>
<td>25 GB (total data collected)</td>
<td><strong>Vue Pro</strong> 600 MB (total data collected)</td>
</tr>
<tr>
<td></td>
<td>6 GB (merged scene)</td>
<td><strong>Vue Pro R</strong> 540 MB (total data collected)</td>
</tr>
<tr>
<td>US31 / White River</td>
<td>17 GB (total data collected)</td>
<td><strong>Vue Pro R – AM</strong> 1 GB (total data collection)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.5 MB (merged scene – corridor)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 KB (merged scene – bridge)</td>
</tr>
<tr>
<td>Gordonville</td>
<td>5.8 GB (total data collected)</td>
<td><strong>Vue Pro R – PM</strong> 500 MB (total data collection)</td>
</tr>
<tr>
<td></td>
<td>64 MB (merged scene)</td>
<td>4.5 MB (merged scene – corridor)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25 KB (merged scene – bridge)</td>
</tr>
</tbody>
</table>
Datasets are documented using both ASPRS and NCHRP accuracy standards.

New ASPRS Positional Accuracy Standards for Digital Geospatial Data

- Replaces:
  - ASPRS Accuracy Standards for Large-Scale Maps (1990)

- Developed by:
  - ASPRS Map Accuracy Standards Working Group, PAD, PDAD and LIDAR joint committee for map accuracy standard update

In Final Approved Version

- REVISION 7, VERSION 1, Nov. 14, 2014
- Approved and adopted by ASPRS during the board meeting on Monday Nov. 17, 2014 in Denver during ASPRS 2014 PECORA conference

### Table 7.1 Horizontal Accuracy Standards for Geospatial Data

<table>
<thead>
<tr>
<th>Horizontal Accuracy Class</th>
<th>Absolute Accuracy</th>
<th>Orthophotography Mosaic Seawall Mismatch (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-cm</td>
<td>( \pm X )</td>
<td>( \pm 0.44 ) X</td>
</tr>
</tbody>
</table>

### Table 7.2 Vertical Accuracy Standards for Digital Elevation Data

<table>
<thead>
<tr>
<th>Vertical Accuracy Class</th>
<th>Absolute Accuracy</th>
<th>Relative Accuracy (where applicable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-cm</td>
<td>( \pm X )</td>
<td>( \pm 1.36 ) X</td>
</tr>
</tbody>
</table>

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**Notes:**
- **RMSE**: Root Mean Square Error
- **NVA**: Normal Variance Assumption
- **VVA**: Vertical Variance Assumption
- **RMSD**: Root Mean Square Deviation
- **Max Diff**: Maximum Difference
Written to match Federal Geographic Data Committee - Content Standard for Digital Geospatial Metadata (FGDC CSDGM) standards. ISO 19115 compatible. XML format

Includes all necessary information; summary, description, accuracy measurements, contact information, etc.

Summary
This dataset shows the elevation of a section of the Holton Road corridor through optical imagery collected by an unmanned aerial vehicle.

Description
This orthomage shows the elevation of a portion of the Holton Road (M-120) corridor (near Twin Lakes, Michigan). The imagery that makes up this image was collected onboard of the Bergen Hexacopter, an unmanned aerial vehical (UAV) with a Nikon D810 optical camera and 50mm prime lens. All of the images collected were processed through Agisoft Photoscan, which reconstructed the imagery into a three-dimensional model. This DEM (with 9 mm (0.03 ft) resolution) is an export from Agisoft Photoscan, which has been assigned a Michigan State Plane coordinate system and georeferenced.

Credits
C. Brooks and J. Graham - Michigan Tech Research Institute
• Developed a Research Problem Statement: “Evaluating and implementing unmanned aerial systems (UAS) into bridge inspection and management methods” with AHD35 Bridge Management Committee members Basak Aldemir-Bektas (Iowa State), Ehsan Minaie (CDM Smith), & Derek Constable (FHWA), and Dr. Tess Ahlborn (Michigan Tech).

• Help & advice sought on moving this forward

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