Bridge Condition Assessment Using Remote Sensors

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USDOT/RITA Commercial Remote Sensing and Spatial Information Technologies Program
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Motivation
National Need

Bridge Condition in the U.S. - $150B to repair today

Deteriorated Bearing
Settlement
Deck Section Loss
Deteriorated Concrete Element

Structural Health Monitoring

- Traditional Inspection Techniques
  - Visual, chain drag, half-cell potential, accelerometers
- Advanced Monitoring Techniques
  - GPR, impact echo, fiber optics, thermal IR, ultrasonic
  - Wireless remote monitoring
- Remote Sensing: Non-contact data collection
  - “the collection of data about an object, area, or phenomenon from a distance with a device that is not in contact with the object.”
Structural Health Monitoring

- Remote Sensing for Bridges
  - Consider commercially available technologies
  - Monitor and assess condition, enhance inspection
  - At a distance
  - Without stopping traffic or closing lanes

Commercial Sensor Evaluation Report

Evaluated twelve RS technologies for Bridge Condition Assessment – based on top priorities

Performance metric ranking

- Commercial availability
- Sensitivity of measurement: resolution
- Cost: capital, operational
- Ease of pre-collection prep: structure, equip
- Ease of data collection and operation
- Complexity of analysis
- Stand-off distance rating
- Traffic Disruption

Written for bridge engineers – Available on website

Top Priorities / Challenges

<table>
<thead>
<tr>
<th>Location</th>
<th>“Top 10” Priorities/Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck Surface</td>
<td>Map cracking, Scaling, Spalling, Delaminations (through surface cracks), Expansion Joint External Issues</td>
</tr>
<tr>
<td>Deck Subsurface</td>
<td>Scaling, Spalling, Delaminations , Expansion Joint Internal Issues, Corrosion, Chloride Ingress</td>
</tr>
<tr>
<td>Girder Surface</td>
<td>Structural Steel and Structural Concrete Cracking, Paint Condition, Steel or Concrete Section Loss</td>
</tr>
<tr>
<td>Girder Subsurface</td>
<td>Structural Concrete Cracking, Concrete Section Loss, Chloride Ingress, Prestress Strand Breakage</td>
</tr>
<tr>
<td>Global Metric</td>
<td>Bridge Length, Settlement, Transverse Movement, Vibration, Surface Roughness</td>
</tr>
</tbody>
</table>
Commercial Sensor Evaluation Report: Promising Technologies

- 3-D Optics including Photogrammetry
- Thermal Infrared
- Digital Image Correlation
- Radar including SAR and InSAR
- Street-view Style Photography
- Satellite Imagery and Aerial Photography
- LiDAR

Field Inspection of Bridges – shadowed bridge inspectors for various bridge types to better understand how these technologies can be practically implemented for enhancing inspections
3-D Optics – Field Testing

- Calculating volume of spall (dev. algorithm)
- Able to calculate volume for difficult to reach (tall) locations

Thermal IR

**Definition:** Measure radiant temperature of concrete by thermal infrared camera (anomalies interrupt the heat transfer through the concrete). Delaminations appear as hot spots.

**Current Practice:**
- ASTM D 4788: thermal IR test method, equipments and environmental conditions for detecting delamination in concrete bridge decks (80-90% efficient)
- Thermal IR training for bridge inspectors in some state DOTs

**Factors that can influence the Thermal IR image:**

- Different materials on the surface:
  - Dirt
  - Moisture
  - Staining
- Environmental effects:
  - Ambient temperature (ASTM D 4788 – 32°F)
  - Humidity
  - Solar Loading (consistent)
  - Wind speed (ASTM D 4788 – 10mph)
- Deck Overlay type:
  - Low slump concrete overlay
  - Asphalt concrete overlay
  - HPC overlay
- Location of delaminated area:
  - Deck (1-3 in depth)
  - Soffit
  - Girder

**Progress:** Laboratory demonstrations to investigate surface and subsurface defects

- Cold slabs were brought in the lab which has significantly higher temperature than outside and thermal IR images were taken inside the lab which had almost steady environmental condition.

**Specimen with simulated defects**

**Thermal IR Laboratory Setup**

**Thermal IR Image**
Digital Image Correlation (DIC)

**Definition:** technique consisting of correlating pixels on optical images to determine variations

**Proposed Application:** Global response (movement, settlement, vibration); 3D models; Exploring for non-contact use

**Currently:** using SLR cameras on specimens and process images in computer software algorithms such as MATLAB

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Digital Image Correlation (DIC) – Initial Testing

- Used for measuring displacements on a steel beam with fiducial marks (pattern)
- Images from Digital SLR camera are processed through MATLAB
- From translation of fiducial marks, the beam deflection is measured
  - Potential measurement of beam vibrations (dynamic measurement)
- Can be presented easily graphically

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Digital Image Correlation (DIC) - Planned

- Compare experimental demonstrations using conventional measurement techniques and finite element analysis (FEA)
  - Bridge Pylons and W-Shape steel samples for testing
  - FEA modeling on testing frame and specimens for DIC comparison
- Field demo for global behavior

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Imaging GPR - Synthetic Aperture Radar (SAR)

**Definition:** Synthetic Aperture Radar (SAR): Coherently process RF backscattering measurements from a moving radar to produce a 2-D (or 3-D) spatial image of scene reflectivity. Low frequency radar is used to penetrate surfaces. Subsurface reflections correspond to layer and/or defects

**Currently:** using wideband, low frequency commercially-available radar to investigate detectability of subsurface structure and defects
Imaging GPR - Synthetic Aperture Radar (SAR)

**Current Practice:** Ground Penetrating Radar like PERES (Precision Electromagnetic Roadway Evaluation System)
- Short pulse
- Slow (3D scan)
- Expensive
- Calibration
- Antenna/Ground Impedance matching
- First Surface cancellation

**MTRI Approach:** using wideband, low frequency commercially-available radar to investigate detectability of subsurface structure and defects
- Fast (2D scan)
- SAR Processing
- Advanced Signal/Image Processing Techniques
- Low Cost

**Proposed Application:** Mapping bridge surface/sub-surface features; characterize/locate defects (spalling, cracks, delaminations, etc.)

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Interferometric SAR (InSAR)

**Definition:** InSAR exploits phase differences between 2 or more SAR images to estimate height of features. Comparison from two time periods can detect changes in geometry and/or position

**Current Practice:** Aerial InSAR frequently used to create 3-D surfaces (Digital Elevation Models); land settlement for large areas (InterMap data)

**Proposed Application:** Bridge dynamics, vibration, and strain; bridge stiffness; elevation surfaces (DEM); bridge settlement; global changes in position.

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Imaging GPR – Next Steps

- Perform controlled field tests
  - Box beams: interior defects
  - Quantify subsurface spall
- Develop algorithms to enhance the detectability of and characterize defects in radar imagery in context of DSS
- Advanced Signal/Image Processing Techniques
  - Translate “Blobology” into end user products in DSS
  - Use data from existing GPR systems

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StreetView-Style Photography

**Definition:** Contiguous collection of geo-located photographs taken from the ground, especially where the photographs have been projected into a continuous 360-degree viewing environment (like Google StreetView).

**Current Practice:** StreetView used by public for viewing areas of interest; private firms doing similar high-res 3-D scans of cities for inventory

**Proposed Application:** Damaged or missing expansion joint seals or plating, cracks and spalls near expansion joints, map cracking, scaling, spalling, and delaminations – testing use for bridges

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StreetView-Style Photography

- Low-cost way of creating GPS-tagged photos of top, underside of bridge usable in GIS, Google Earth
- Could be deployable by MDOT as needed as part of photo logging
- “Gigapan” ultra-high res bridge inventory photos as well

Satellite Imagery and Aerial Photography

**Definition:** Any satellite imagery and aerial photography in the visible and infrared ranges with sufficient resolution that can be used to remotely assess deck surface conditions

**Current Practice:** Some applications for assessment of larger crack density (>1/4”); general views of areas along & near transportation infrastructures

**Proposed Application:** Use high-resolution imagery to calculate indices of deck surface condition, esp. cracking and spalling. We will build from TARUT Study index of road sufficiency calculations via satellite imagery.

StreetView-Style Photography

- Can use high-res photography to automate assessment of spalling amounts
- Calculating % spalled by area:
  - Ex: 6.4% spalled, 2.68 sq. ft (dev. algorithm)

LiDAR

- **Current practice example:** UNCC team funded by USDOT-RITA – LiDAR lead – bridge clearance assessment
- **Current Study:** Assessing methods of integrating bridge clearance data into Decision Support System
- Michigan Tech’s deployable “LiDAR car”
- Gathering 3-D LiDAR point cloud of example bridges in March/April – 3-D inventory of bridge + photos
Remote Sensing: Promising Technologies

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- Satellite Imagery and Aerial Photography
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Decision Support System – key attributes

- DSS needs to be able to integrate, interpret, and present data that is usable by non-experts
- Extract features of interest and indicators of bridge condition from remote sensing and other data
- Compare remote sensing results to expected / normal results and detect anomalous results, especially change (based on previously-collected data or modeled results)
- Should be accessible in the field (durable tablet) and available for mission planning and repair prioritization beforehand
- Needs example data to produce most usable, practical DSS that meets needs of bridge condition community
- Building from lessons learned, interface inspiration from Phase I/II UNCC team – wide survey of DOTs and DSS needs

Decision Support System – under development

Current design:
- Access to Bridge Operations tools (in the field)
- Access to Bridge Condition data in GIS format
- Access to remote sensing results – mission planning & in the field
- Access to existing mapping tools
- Accessible via ruggedized tablets
Decision Support System – under development

- New remote sensing data, geotagged photos, existing mapping tools, algorithm analysis results, & integration with existing bridge condition data – will be made available through a GIS web mapping interface part of the DSS

Field Demo on 2 Bridges – Summer 2011

- Criteria
  - Similar type bridges, condition: bad and ugly
  - Representative of high interest problems
  - Decks – condition, repairs, no overlays
  - Bridge with significant existing info. (e.g. inspections reports, historical data for good ground truthing)
  - Accessibility (highway over highway) preferred; distance to AA
  - Concurrent MDOT inspection data collection (scoping)

  - Special set of bridges for particular challenges (e.g. settlement)

Decision Support System – ruggedized field tablet

- Access to bridge operations data in the field would be useful
- Data & DSS access tools
- Rugged, internet-capable, relatively inexpensive tablets now available
- Ex: iPad, Galaxy Tab
- Interest from USDOT as practical tools

Field Activity Planning:

- Anticipated Outcomes
  - Technology/sensor performance vs. expected measures and limitations
  - Specific sensor observations to feed the DSS
  - Lessons learned with respect to all field demos, practical considerations for implementation
  - Identification of redundancies
Goal of Assessment Task

- Assess the potential for commercially available remote sensors to enhance condition monitoring of critical infrastructure (i.e., bridges) cost effectively
  - Compare marginal costs of employing sensor technologies investigated to the marginal enhancements that they provide

Effectiveness

Low Cost

High Cost

SHM - Overview
Remote Sensing
In-Progress
Wrap-up

Summary

Examples:
- 3-D Optics → spalls
- Thermal IR → delaminations
- Digital IC → bridge settlement
- Radar → loss in cross-section
- StreetView Photo → missing seal
- Satellite Imagery → deck condition

Development of Anomaly Detection Algorithm
Decision Support Integration
Sensor Selection and Deployment
Field Demonstration

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Project Team / Disclaimer

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