Evaluating Commercial Remote Sensors for Highway Bridge Condition Assessment

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


Settlement

Deck Section Loss


Deteriorated Concrete Element

Michigan Tech 2

MECHANICAL (Global Structural Integrity)		DURABILITY (Local Material Integrity)	
Deflection -Displacement Transducers -- Tiltmeters (rotation) - Seismic (accelerometers) - Laser	**Strain** -Electrical Resistance Gages -Fiber-Optic Gages - Vibrating Wire Gages	**Cracking** - Visual Inspection -Acoustic Emission - Ultrasonic Pulse Velocity - Thermography	**Corrosion** - Half-cell Potential - Acoustic Emission
Thickness - Caliper - Ground Penetrating Radar	**Stiffness** - Seismic (accelerometers) - Displacement Transducers	**Delamination** - Chain Drag - Imact Echo	**Thickness (Cover)** - Ground Penetrating Radar - Impact Echo

Michigan Tech 3

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.***"**

Michigan Tech 4

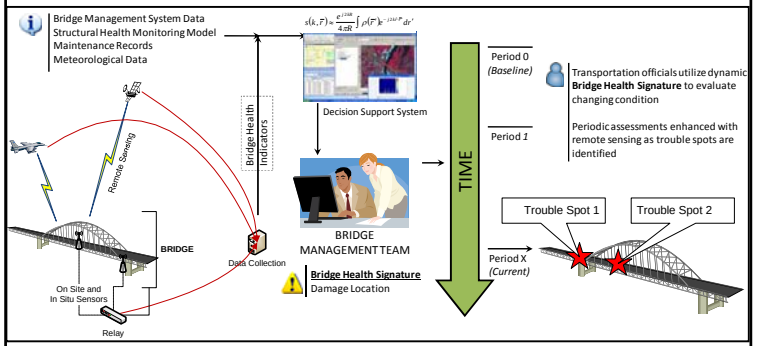
Structural Health Monitoring

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

Top Priorities / Challenges

Location	"Top 10" Priorities/Challenges
Deck Surface	Map cracking, Scaling, Spalling, Delaminations (thru surface cracks), Expansion Joint External Issues
Deck Subsurface	Scaling, Spalling, Delaminations , Expansion Joint Internal Issues, Corrosion, Chloride Ingress
Girder Surface	Structural Steel and Structural Concrete Cracking, Paint Condition, Steel or Concrete Section Loss
Girder Subsurface	Structural Concrete Cracking, Concrete Section Loss, Chloride Ingress, Prestress Strand Breakage
Global Metric	Bridge Length, Settlement, Transverse Movement, Vibration, Surface Roughness

Project Concept



Commercial Sensor Evaluation: Performance metrics

- ❑Commercial availability
- ❑Sensitivity of measurement: resolution

- ❑Cost: capital, operational
- ❑Ease of pre-collection prep: structure, equipment
- ❑Ease of data collection and operation
- ❑Complexity of analysis
- ❑Stand-off distance rating
- ❑Traffic Disruption

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 (UNCC)

3-D Optics

Definition: Any digital photography in the optical, thermal infrared, and near infrared parts of the spectrum collected from an aerial, satellite, or other platform

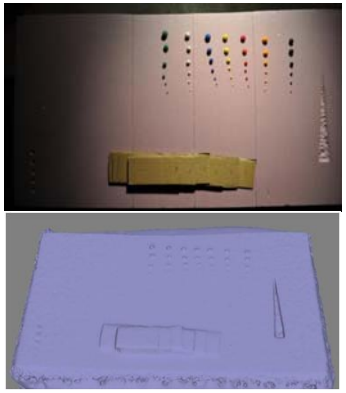
Proposed Application: Mapping bridge features; 3D models; characterizing deck surface (spalling, cracks)

Currently: using SLR cameras

Stereo overlapping of photos and 3-D modeling software creates a point cloud

3-D Optics – Initial Testing

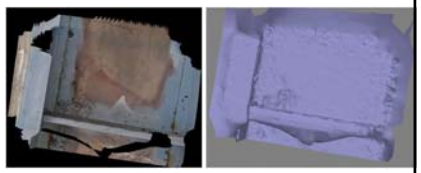
- Initial testing to gain an understanding of the capabilities of the technologies
- Preliminary lab tests determine resolution in the horizontal and vertical direction
- Contrast, lighting or camera angle affects the resolution of the image
- Initial experiments show the resolution to be about 4mm in both the horizontal and vertical directions



3-D Optics – Field Testing

- Preliminary work - what can be measured in the field
- System is being designed with low-cost components (Digital SLRs, commercial close- range) and photogrammetry software
- How to best transfer this information to the bridge inspector – visualizing results

Spalls located under the bridge deck.



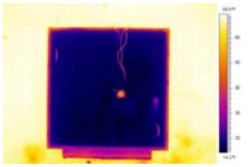
Models generated from the infield photos with textured model on the left and shaded model output from PhotoScan on the right.

Thermal IR

Definition: Measuring the radiant temperature of the concrete deck by thermal infrared camera. Anomalies and subsurface delamination interrupt the heat transfer through the concrete. Surface delaminations will be appeared as hot spots on the thermal IR image.

Proposed Application: Locating delaminations and other subsurface defects.

Currently: Using thermal IR camera to locate subsurface defects and trying to identify their size/shape.



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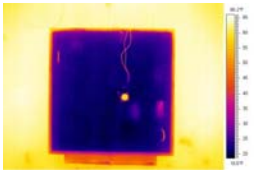

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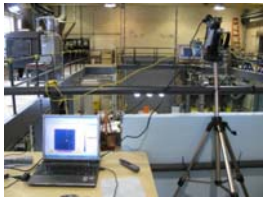
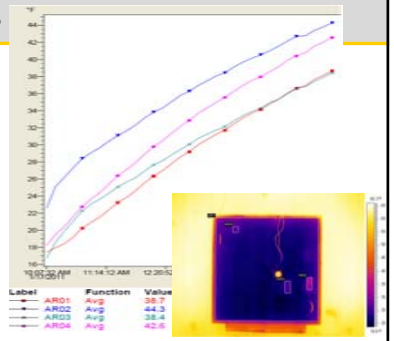
Thermal IR – Initial Testing

- To get better understanding of the thermal IR technology and how to employ the technology for detecting bridge challenges.
- 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.



Thermal IR - Future Works

- Determine the percentage of delamination
- Determine the maximum depth of delamination that can be detected
- Collect thermal IR information at highway speed
- Determine the effect of different environmental condition on the results
- Transfer data to DSS and find the best way to present the result



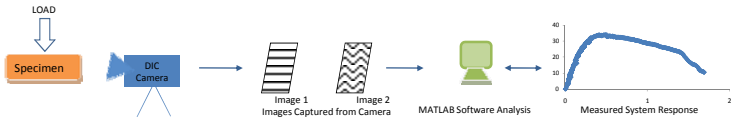
Variation of average temperature for each area during the experiment
Area 1: Concrete Slab 4'x4'x5.5"
Area 2: Styrofoam 2.5"x6"x1.5" @ 4" from the bottom
Area 3: Styrofoam 2.75"x6"x5/8" @ 4" from the bottom
Area 4: A piece of wood 3.5"x2.75"x1.5" @ 2" from the bottom

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;

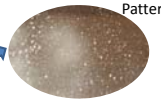
Currently: using SLR cameras on specimens and process images in computer software algorithms such as MATLAB



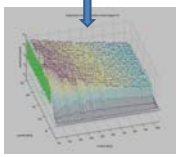
Digital Image Correlation (DIC) – Initial Testing

- 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

Loaded Steel Beam



Enhanced Tracking Pattern



Post-Processed Response

Digital Image Correlation (DIC) - Planned

- Comparison of experimental demonstrations using conventional measurement techniques and finite element analysis (FEA), to validate results
  - Bridge Pylons and W-Shape steel samples for testing
  - FEA modeling on testing frame and specimens for DIC process comparison

Structural Loading Frame and FEA Representation

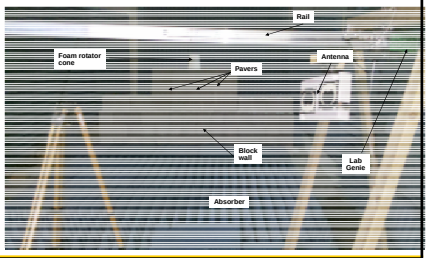
Bridge Pylon Sample Before Compression Tests

Imaging GPR

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 commerically-available radar to investigate detectability of subsurface structure and defects

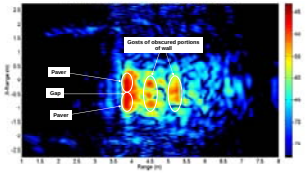
Proposed Application: Mapping bridge surface/sub-surface features; characterize/locate defects (spalling, cracks, delaminations, etc.)

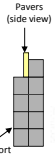


Imaging GPR – Thus Far

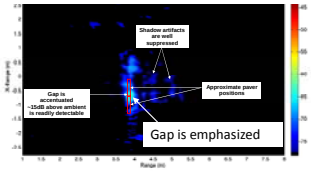
- Performed controlled laboratory experiments to assess and characterize detectability of defects as a function of radar parameters
- Indentified data processing techniques, such as coherent subtraction, to enhance the observability of subsurface features and defects
- Began planning of experiments to demonstrate concepts identified in lab on field data collections of bridges

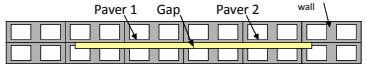
2 Pavers with 1 mm Gap – Background Subtracted





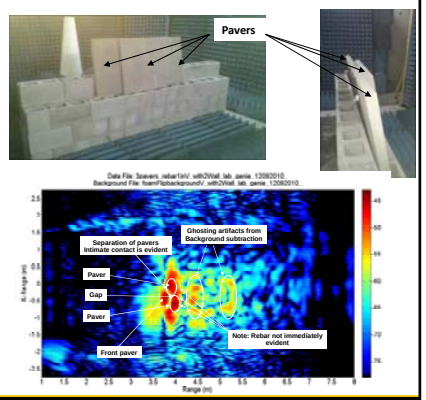
2 Pavers with 1 mm Gap – Change Detection





Imaging GPR – Next Steps

- Perform controlled field experiments
  - Detect defects in interior of box beams
  - Quantify utility for assessing subsurface spall
- Develop algorithms to enhance the detectability and characterization of deck defects in radar imagery in context of DSS
  - Provide output in DSS readily useable by bridge inspector
  - General enough to work with a variety of commercial radar sensors

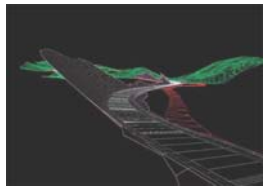


Interferometric SAR (InSAR)

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

Proposed Application: Bridge dynamics, vibration, and strain; bridge stiffness; **bridge settlement** and/or global changes in position.

Currently: Identified algorithms in literature for change detection processing of InSAR data, i.e. PSInSAR techniques. Evaluating applicability to bridge sensing application. Select bridge to assess if settlement can be measured using imagery separated in time (e.g., did a bridge settle between 2006 vs. 2011?)



Street-view 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).

Proposed Application: Damaged or missing expansion joint seals or plating, cracks and spalls near expansion joints, map cracking, scaling, spalling, and delaminations.

Example image from Google's StreetView showing the underside of a box-beam bridge in Michigan. With higher-resolution panoramas, such an interface could be extremely valuable to bridge inspectors and managers.

Our team's BridgeViewer setup is designed to demonstrate a low-cost, practical example implementable by DOTs.

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

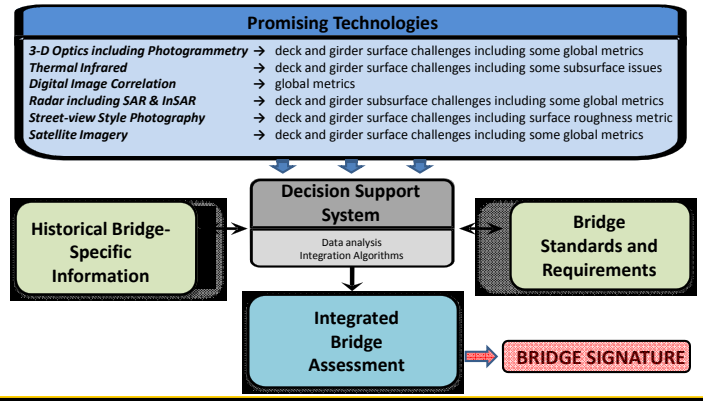
Proposed Application: Use high-resolution imagery to calculate **indices** of deck surface condition, esp. cracking and spalling. We will build from TARUT Study index of road sufficiency calculations via satellite imagery.

Currently: We will be assessing this technology as part of the field demonstrations – ensure careful use of funds if purchasing commercial satellite imagery.

SHM
Project Concept
Remote Sensing
In-Progress

Decision Support System
Field Demo

Decision Support System Integration



SHM
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Remote Sensing
In-Progress

Decision Support System
Field Demo

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
- 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 for mission planning and repair prioritization
- Will use example data to produce most usable, practical DSS that meets needs of bridge community

SHM
Project Concept
Remote Sensing
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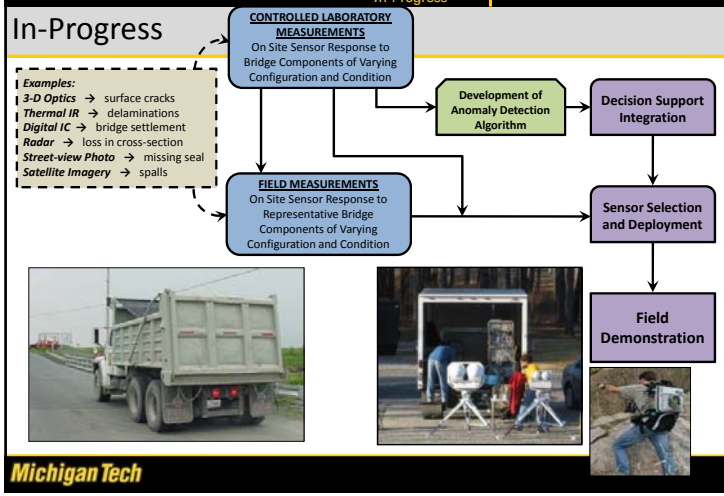

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Project Team / Disclaimer

- Project Team Members: MTTI + MTRI + CAR

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Thank You

www.mtti.mtu.edu/bridgecondition/

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