# Bridge Condition Assessment Using Remote Sensors


**Michigan Technological University**

**Colin Brooks – Co-Principal Investigator**
cnbrooks@mtu.edu
Dr. Tess Ahlborn, P.E., Principal Investigator
tess@mtu.edu


***Michigan Bridge Conference, March 23, 2011***


USDOT/RITA Commercial Remote Sensing and Spatial Information Technologies Program
Program Manager: Caesar Singh



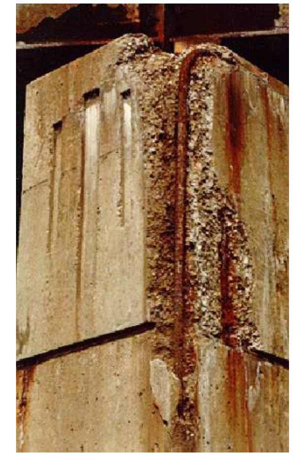



## Bridge Condition in the U.S. - $150B to repair today


Settlement


Deteriorated Bearing

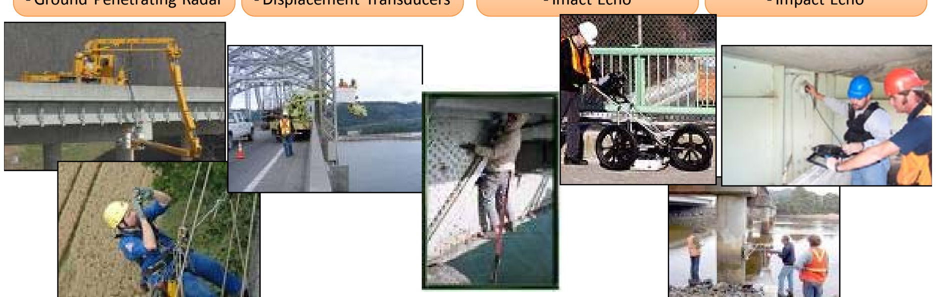

Deck Section Loss


Deteriorated Concrete Element





| **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 |







## 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."*

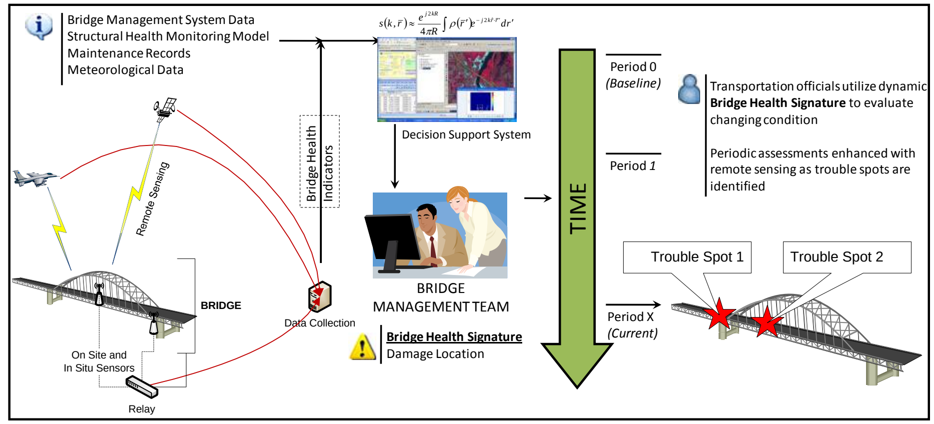
## Structural Health Monitoring

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





## Project Concept








## 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


An Evaluation of Commercially Available Remote Sensors for Assessing Highway Bridge Condition

T. M. Ahlborn, Ph.D., P.E.[1], R. Shuchman Ph.D[2], L. L. Sutter Ph.D.[1], C. N. Brooks[2], D. K. Harris, Ph.D.[1], J. W. Burns Ph.D[2], K. A. Endsley[2], D. C. Evans[1], K. Vaghefi[1], R. C. Oats[1]

October 2010

Michigan Tech

Written for bridge engineers – Available on website





## Top Priorities / Challenges

| Location | "Top 10" Priorities/Challenges |
|---|---|
| Deck Surface | Map cracking, Scaling, Spalling, Delaminations (through 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 |

## Rating Based, in Part, on Theoretical Sensitivity for Measurement Technologies

| Location | Challenges | Indicator | Desired Measurement Sensitivity | MTTI: Thermal IR | MTTI: 3D Photo-grammetry | MTTI: DIC | RADAR: GPR | RADAR: Backscatter Speckle | RADAR: InSAR |
|---|---|---|---|---|---|---|---|---|---|
| Deck Surface | Expansion Joint | Torn/Missing Seal | | 11 | 14 | 0 | 0 | 9 | 0 |
| | | Armored Plated Damage | | 11 | 14 | 0 | 0 | 0 | 0 |
| | | Cracks within 2 Feet | 0.8 mm to 4.8 mm (1/32" to 3/16") width | 11 | 14 | 0 | 0 | 9 | 0 |
| | | Spalls within 2 Feet | 6.0 mm to 25.0 mm (1/4" to 1") depth | 11 | 14 | 0 | 0 | 9 | 0 |
| | | Chemical Leaching on Bottom | | 0 | 0 | 0 | 0 | 0 | 0 |
| | Map Cracking | Surface Cracks | 0.8 mm to 4.8 mm (1/32" to 3/16") width | 11 | 14 | 0 | 0 | 9 | 0 |
| | Scaling | Depression in Surface | 6.0 mm to 25.0 mm (1/4" to 1") depth | 11 | 14 | 0 | 0 | 9 | 0 |
| | Spalling | Depression with Parallel Fracture | 6.0 mm to 25.0 mm (1/4" to 1") depth | 11 | 14 | 0 | 0 | 9 | 0 |
| | Delamination | Surface Cracks | 0.8 mm to 4.8 mm (1/32" to 3/16") width | 11 | 14 | 0 | 0 | 0 | 0 |
| Girder Surface | Steel Structural Cracking | Surface Cracks | < 0.1 mm (0.004"), hairline | 11 | 11 | 0 | 0 | 0 | 0 |
| | Concr. Structural Cracking | Surface Cracks | 0.1 mm (0.004") | 11 | 11 | 0 | 0 | 0 | 0 |
| | Steel Section Loss | Loss/Change in Cross-Sectional Area | Percent thickness of web or flange | 11 | 11 | 0 | 0 | 11 | 0 |
| | Paint | Paint Condition | Amount of missing paint ( X % ) | 11 | 0 | 0 | 0 | 0 | 0 |
| | Concrete Section Loss | Loss/Change in Cross-Sectional Area | Percent volume per foot | 11 | 11 | 0 | 0 | 11 | 0 |
| Deck Subsurface | Expansion Joint | Material in Joint | | 0 | 0 | 0 | 0 | 0 | 0 |
| | Delamination | Moisture in Cracks | Change in moisture content | 11 | 0 | 0 | 11 | 0 | 0 |
| | | Internal Horizontal Crack | Approximately 0.1 mm (0.004") level | 11 | 0 | 0 | 0 | 0 | 0 |
| | | Hollow Sound | | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Fracture Planes / Open Spaces | Change in signal from integrated volume | 0 | 0 | 0 | 12 | 12 | 0 |
| | Scaling | Depression in Surface | 6.0 mm to 25.0 mm (1/4" to 1") depth | 11 | 0 | 0 | 12 | 0 | 0 |
| | Spalling | Depression with Parallel Fracture | 6.0 mm to 25.0 mm (1/4" to 1") depth | 11 | 0 | 0 | 12 | 0 | 0 |
| | Corrosion | Corrosion Rate (Resistivity) | 5 to 20 kΩ-cm | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Loss/Change in Cross-Sectional Area | Amplitude of signal from rebar | 0 | 0 | 0 | 13 | 13 | 0 |
| | Choride Ingress | Choride Content through the Depth | 0.4 to 1.0 % chloride by mass of cement | 0 | 0 | 0 | 12 | 12 | 0 |
| Girder Subsurface | Concr. Structural Cracking | Internal Cracks (e.g. Box Beam) | Approx 0.8 mm (1/32") | 11 | 0 | 0 | 0 | 0 | 0 |
| | Concrete Section Loss | Loss/Change in Cross-Sectional Area | Percent volume per foot | 0 | 0 | 0 | 0 | 11 | 0 |
| | Prestress Strand Breakage | Loss/Change in Cross-Sectional Area | Wire 2 mm (0.08") or strand 9.5 mm (3/8") diameter | 0 | 0 | 0 | 9 | 9 | 0 |
| | Corrosion | Corrosion Rate (Resistivity) | 5 to 20 kΩ-cm | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Loss/Change in Cross-Sectional Area | Amplitude of signal from rebar | 0 | 0 | 0 | 8 | 13 | 0 |
| | Choride Ingress | Choride Content through the Depth | 0.4 to 1.0 % Chloride by mass of cement | 0 | 0 | 0 | 10 | 11 | 0 |
| Global Metrics | Bridge Length | Change in Bridge Length | Accuracy to 30 mm (0.1ft) (smaller) | 0 | 15 | 11 | 0 | 0 | 12 |
| | Bridge Settlement | Vertical Movement of Bridge | Approximately 6 mm to 12 mm (1/4" to 1/2") | 0 | 12 | 11 | 0 | 0 | 12 |
| | Bridge Movement | Transverse Directions | Approximately 6 mm to 12 mm (1/4" to 1/2") | 0 | 12 | 11 | 0 | 0 | 12 |
| | Surface Roughness | Surface Roughness | Change over time | 0 | 14 | 0 | 0 | 11 | 13 |
| | Vibration | Vibration | 0.5 -20 Hz, amplitude? | 0 | 0 | 10 | 0 | 12 | 12 |



## 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: Photogrammetry

**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)

**Current Practice**: Most commonly used to create digital elevation models, measure features on aerial photographs; close range photogrammetry is expanding

**Currently in Study**: using DSLR cameras - Stereo overlapping of photos + 3-D modeling software creates a surface point cloud

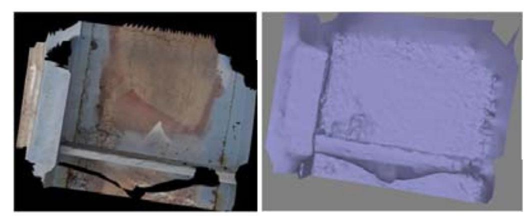




## 3-D Optics – Field Testing

- Preliminary work - showed the resolution to be about 4mm in both the horizontal and vertical directions
- System is being designed with low-cost components (Digital SLRs, commercial close-range photogrammetry software) - Low cost alternative for 3-D data (alt. LiDAR)
- How to best transfer this information to the bridge inspector – visualizing results

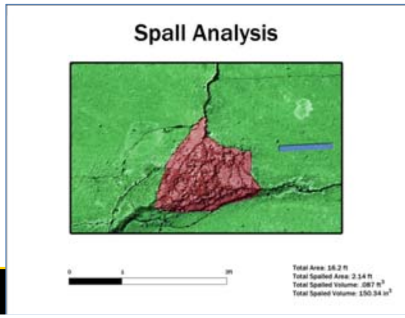
Spalls located under the bridge deck.



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

# 3-D Optics – Field Testing

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





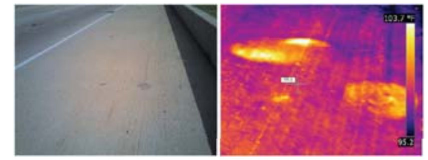



# Thermal IR

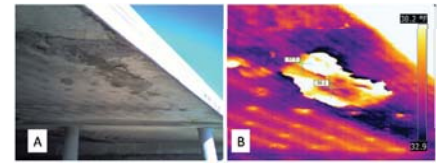
**Definition:** Measure radiant temperature of concrete by thermal infrared camera (anomalies interrupt the heat transfer through the concrete). Delaminations appear as hot spots.

**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



Optical and thermal images of concrete overlay with delaminations




Optical and thermal images of delaminations in the soffit of a bridge
[G. Washer et al., Development of hand-held thermographic inspection technologies, Technical report, Missouri Department of Transportation, Sep 2009]





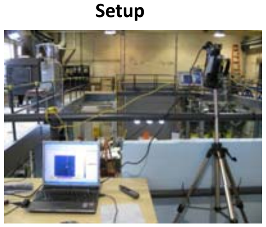
# Thermal IR – Initial Testing

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

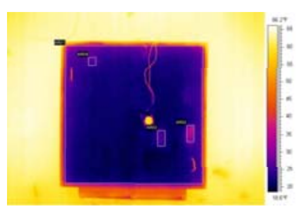
- Cold slabs were brought in the lab which has significantly higher temperature than outside and thermal IR images were taken inside the lab which had almost steady environmental condition.

**Specimen with simulated defects**

**Thermal IR Laboratory Setup**



**Thermal IR Image**







# Factors that can influence the Thermal IR image:

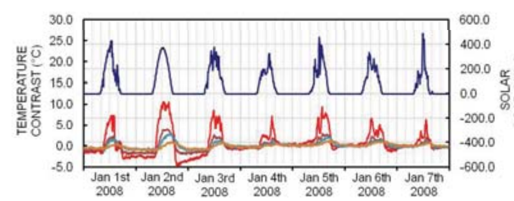
- Different materials on the surface:
  - Dirt
  - Moisture
  - Staining

  → **Edit the data according to the optical (normal) image.**

- Environmental effects:
  - Ambient temperature (ASTM D 4788 – 32F)
  - Humidity
  - Solar Loading (consistent)
  - Wind speed (ASTM D 4788 – 30mph)

  → **Use ambient temperature and humidity as input values on TIR camera.**

- Deck Overlay type
  - Low slump concrete overlay
  - Asphalt concrete overlay
  - HPC overlay
- Location of delaminated area
  - Deck (1-3 in depth)
  - Soffit
  - Girder




**Effects of solar loading on thermal contrast (solar loading vs. 1-,2-,3-, 5 in. simulated delaminations)** [G. Washer et al., Thermal Imaging for Bridge Inspection and Maintenance, *Tenth International Conference on Bridge and Structure Management*, 2008]

# Digital Image Correlation (DIC)

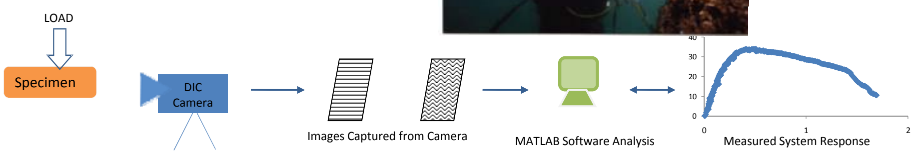
**Definition:** technique consisting of correlating pixels on optical images to determine variations

**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

Camera device used in underwater inspections Fig. 11.3.47 *Bridge Inspection Reference Manual (2005).*



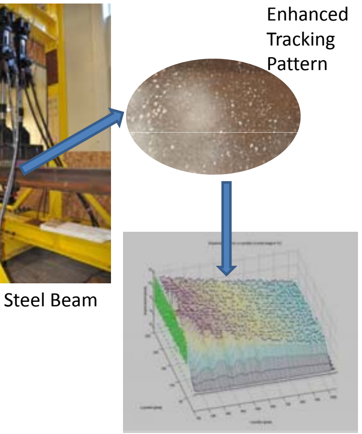





# Digital Image Correlation (DIC) – Initial Testing

- 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



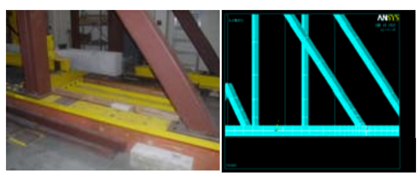

Post-Processed Response





# 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



Structural Loading Frame and FEA Representation

Bridge Pylon Sample Before Compression Tests



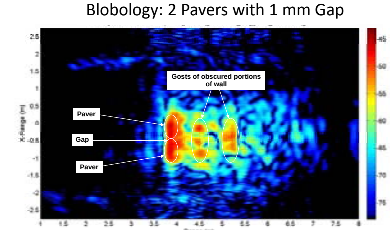


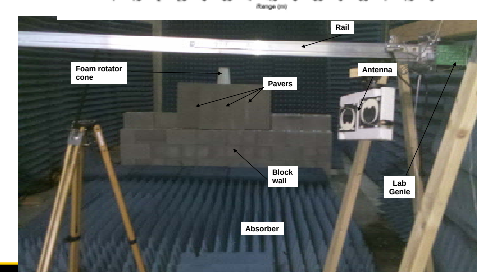
# Imaging GPR - Synthetic Aperture Radar (SAR)

**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

Blobology: 2 Pavers with 1 mm Gap



# 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

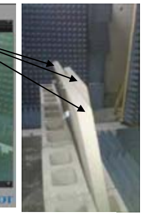
**Proposed Application:** Mapping bridge surface/sub-surface features; characterize/locate defects (spalling, cracks, delaminations, etc.)

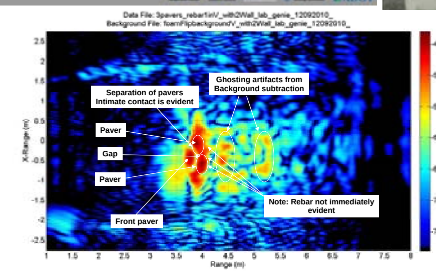




# Imaging GPR – Next Steps

- 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








# 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.

**Our Project:** **Selecting bridge to assess** if settlement can be measured using imagery separated in time


Example SAR data for Blue Water Bridge showing "bright" returns for man-made features – track their heights over time





# 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

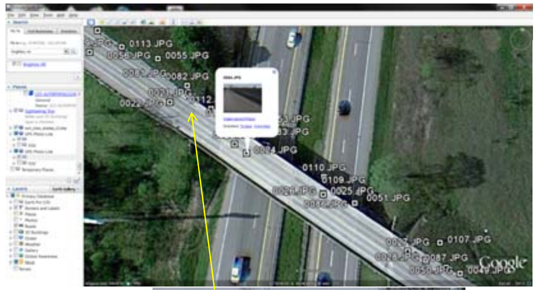
**Proposed Application:** Damaged or missing expansion joint seals or plating, cracks and spalls near expansion joints, map cracking, scaling, spalling, and delaminations – testing use for bridges

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

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

# 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







# 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)






# 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.

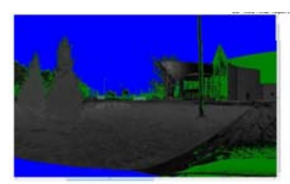
**Currently in Study:** We will be assessing this technology as part of the field demonstrations – ensure careful use of funds if purchasing commercial satellite imagery.





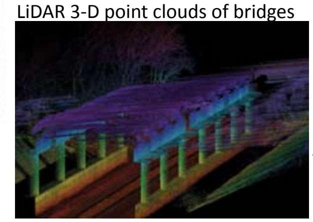
# LiDAR

- **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



Michigan Tech's LiDAR mobile mapping system & Rozsa building point cloud


LiDAR 3-D point clouds of bridges



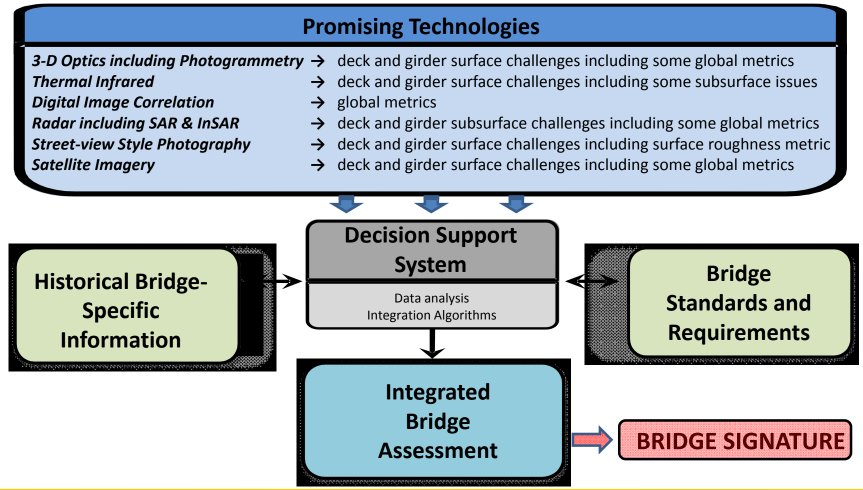
# Remote Sensing: Promising Technologies

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





# Decision Support System Integration








# 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

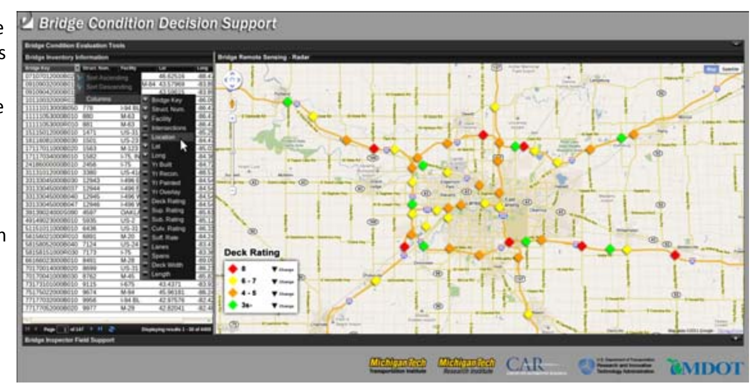




# Decision Support System – under development

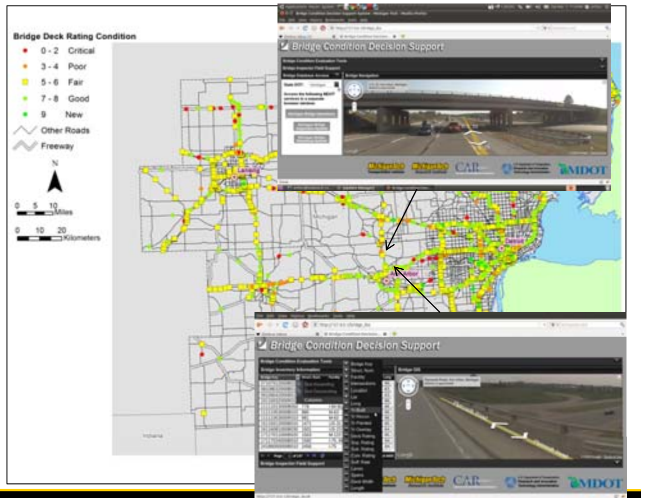
Current design:

- 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**








## 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

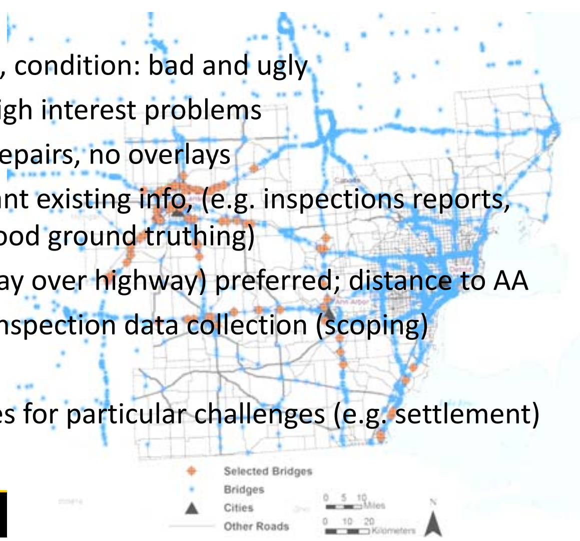




## Field Demo on 2 Bridges – Summer 2011

- 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)





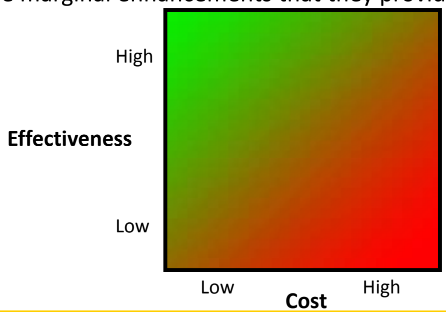



## Field Activity Planning:

- 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

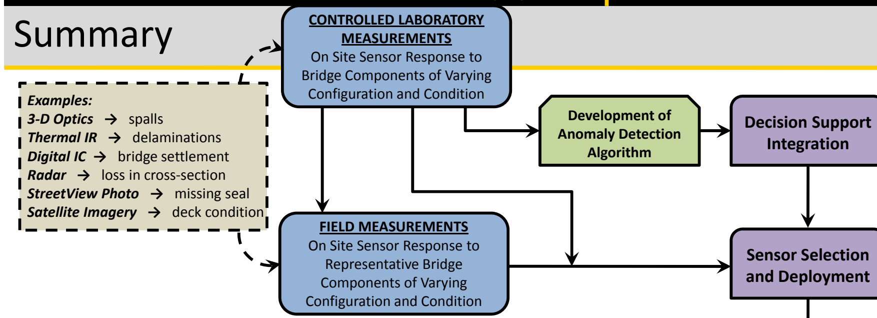
- Assess the potential for commercially available remote sensors to enhance condition monitoring of critical infrastructure (i.e., bridges) cost effectively
  - Compare marginal costs of employing sensor technologies investigated to the marginal enhancements that they provide

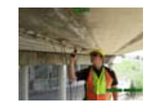







## Summary







## Acknowledgements

- USDOT – Research and Innovative Technology Administration
  - Commercial Remote Sensing and Spatial Information Program Manager: Caesar Singh
  - Cooperative Agreement #DTOS59-10-H-00001
- Project Partners
  - Michigan Department of Transportation
  - Michigan Tech Transportation Institute
  - Michigan Tech Research Institute
  - Center for Automotive Research
- Technical Advisory Council





## Project Team / Disclaimer

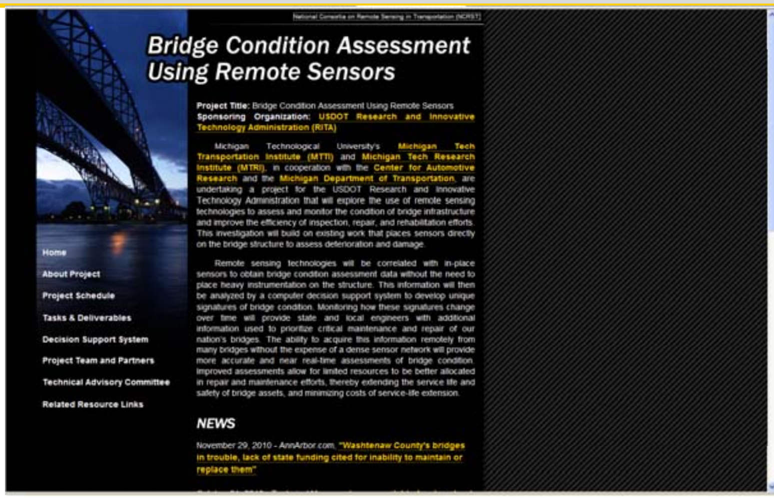
- Project Team Members: MTTI + MTRI + CAR

Tess Ahlborn
Devin Harris
Larry Sutter
Bob Shuchman
Colin Brooks
Joe Burns
Chris Roussi
Arthur Endsley
Khatereh Vaghefi
Ben Hart
Renee Oats
Rick Dobson
Darrin Evans
Jim Ebling
Richard Wallace
Mike Forster
Ryan Hoensheid
Kiko de Melo e Silva
John Valenzuela
Joel LeBlanc
Andrew Leonard
Shazeb Quadir
Christina Nolte
Pam Hannon
Michelle Wienert
Kirk Scarbrough

**DISCLAIMER:** The views, opinions, findings and conclusions reflected in this presentation are the responsibility of the authors only and do not represent the official policy or position of the USDOT/RITA, or any State or other entity.

# Thank you

## Website: www.mtti.mtu.edu/bridgecondition/






## Contact Information

**Tess Ahlborn, Ph.D., P.E. – Principal Investigator**

Director, Center for Structural Durability

Michigan Tech Transportation Institute

Associate Professor, Civil and Environmental Eng.

Michigan Technological University

1400 Townsend Drive Houghton, MI 49931

906-487-2625; tess@mtu.edu

www.mtti.mtu.edu/bridgecondition/