A Summary of the 2nd Quarterly Report

for the Technical Activities Council

Bridge Condition Assessment Using Remote Sensors

Michigan Technological University

USDOT Cooperative Agreement No. DTOS59-10-H-00001

Principal Investigator:

Dr. Tess Ahlborn, P.E.
Associate Professor, Civil and Env. Engineering
Michigan Tech Transportation Institute
Michigan Technological University
1400 Townsend Drive
Houghton, MI 49931
(906) 487-2625; tess@mtu.edu

Program Manager:

Caesar Singh, P.E.
Lead Engineer/Program Manager
Research Development & Technology
RITA, U.S. Dept. of Transportation
1200 New Jersey Avenue, SE, E33-123
Washington, DC 20590
(202) 366-3252; Caesar.Singh@dot.gov

TABLE OF CONTENTS

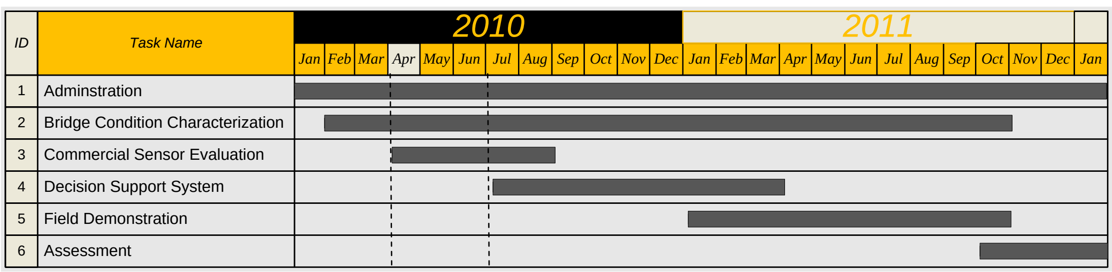
EXECUTIVE SUMMARY

This quarterly report documents progress for *"Bridge Condition Assessment Using Remote Sensors"* during the second quarter for the period of April 1, 2010 – June 30, 2010. Our Michigan Tech research team is investigating the use of remote sensing technologies to assess the structural health of bridges and provide additional inputs to bridge asset management systems. The project will explore correlations between commonly used inspection techniques and remote sensing systems, and develop a decision support system to combine various inputs to create a unique bridge signature that can be tracked over time.

The primary goals of this project are to:

1. Establish remotely sensed bridge health indicators.
2. Develop a baseline bridge performance metric, the "signature," for benchmarking overall bridge condition.
3. Provide a system that enhances the ability of state and local bridge engineers to prioritize critical repair and maintenance needs for the nation's bridges.

The project schedule is shown below with Quarter 2 activities bounded by dashed lines:



Accomplishments for this quarter are discussed below and include the first meeting of the Technical Advisory Council, completion of the State-of-the-Practice Synthesis, and progress on Tasks 1, 2, and 3. Also, according to the Revised Cost Proposal submitted June 26, 2009, and included as Attachment 2 of that cost proposal, the following deliverables were cited for Quarter 2. All technical memos are located at the end of this document and are discussed in the relevant tasks below.

- ✓ Technical Memorandum No. 2 (revised) which identifies outcomes of the first TAC meeting and review of the proposed work plan (Task 1.2).
- ✓ Technical Memorandum No. 4 documenting the State-of-the-Practice Synthesis (Task 2.1).
- ✓ Technical Memorandum No. 5 containing the information related to the laboratory work plan and specimen fabrication (Task 2.2).
- ✓ Technical Memorandum No. 6 that describes progress to date on the sensor evaluation (Task 3.0).

TECHNICAL STATUS

Progress of each of the six tasks is documented below and references Technical Memos and Appendices which are located at the end of this document.

Task 1: Administration

Several sub-tasks within the administration task have been initiated and completed.

A primary activity has been coordination of the teams and establishment of a Technical Advisory Council. Technical Memorandum No. 2 was cited as a deliverable for Quarter 1 to describe the outcomes of the first TAC meeting and comments from review of the proposed work plan. **Technical Memorandum No. 2 (revised)** provided information to the research team of the TAC meeting to be held June 16-17, 2010 in Ann Arbor, MI. **Appendix A** includes the meeting notes and supporting documentation for the TAC meeting.

The project Website continues to be updated: www.mtti.mtu.edu/bridgecondition
This web site includes an overview of the project, taken from the original technical proposal. The site also includes information related to the project schedule, tasks and deliverables, the decision support system, project team partners, and key links for the project. The major deliverable items will be posted once approved by the program manager.

An internal project Wiki site has been established for internal correspondence related to the project and includes the state-of-practice report, project presentations, literature, and other documents that are shared within the research team. All team members have access to this project web site for updating information and keep members informed of progress.

Based on a RITA-approved news release, Michigan Tech published the information on its daily "Tech Today" announcements. The release was picked up by a number of additional sources, which we linked to from the project website. Several of these sources and their interpreted information are documented in **Appendix B**.

A technical paper (*"Evaluation of Remote Sensing Technologies for Detecting Bridge Deterioration and Condition Assessment"*) was submitted for consideration at the NDE/NDT for Highways and Bridges: Structural Materials Technology (SMT) 2010 Conference, to be held in New York City, NY, August 16-20, 2010. A final copy of the paper will be published in the conference proceedings and made available on the project website following the conference.

Task 2: Bridge Condition Characterization

This task consists of several sub-tasks: the State-of-the-Practice Synthesis, laboratory investigation and demonstration, and structural modeling. These sub-tasks are being accomplished through several activities.

Technical Memorandum No. 4 documents the posting of the State-of-the-Practice Synthesis to the internal project wiki site. The synthesis will be posted to the project web site <www.mtti.mtu.edu/bridgecondition> once approved by the project manager. **Appendix C** of this quarterly report includes a complete copy of the document.

A significant activity of this task is to assess performance of commercially available sensors and their potential application to bridge health monitoring. Using input provided from our TAC and other partners, we have developed a draft matrix listing the top 10 priorities and some specific remote sensing assessment techniques that are showing promise for applicability (see Table 1). This matrix has been revised several times since our first presentation of this information that listed more generic techniques. It is a working matrix and indicates our current thinking.

We have also worked to identify measurable criteria for several observable indicators, see Table 2. These quantitative measures are allowing the various specialty groups within our Michigan Tech team (e.g. sensor experts, bridge engineers, materials experts) to understand our respective areas of expertise.

Table 1 – Potential RS techniques for Top 10 Priorities

Priority	Possible Bridge Indicator	Proposed Technique
Scour / Settlement	Deflection of Structural Components, Increased Vibration	Digital Image Correlation, IfSAR
Corrosion damage	Deflection of Structural Components Increased	GPR, IfSAR, Digital Image Correlation, Spectra, HRD Image Analysis
Steel beam Section loss / loss of stiffness	Deflection of Structural Components	Digital Image Correlation, IfSAR
Vibration	Vibration	Digital Image Correlation, IfSAR
Large cracking	Surface discontinuity, Surface defect, Surface deflection, Vibration	GPR, IR, Spectra, HRD Image Analysis
Deck - Delamination/ Spalling	Subsurface Defect, Vibration, Defect in surface, Localized change in reflectivity	GPR, IR, Spectra, HRD Image Analysis
Deck - Map cracking and other material issues for decks	Surface discontinuity, Surface defect, Surface deflection, Vibration	GPR, IR, Spectra, HRD Image Analysis
Expansion Joint failure	Subsurface and surface defect	GPR, HRD Image Analysis
Chloride ingress, Contamination	Change in surface material composition, texture, or volume material composition	GPR
Length of Bridge	Measured length over time	HRD Image Analysis

Table 2 – Observable and Measureable Indicators

Observable Indicator	Quantitative change(s) to be measured	Amount that indicates problem / issue (e.g., in cm - for good/bad/in-between)
Vibration	Amount of vibration (and direction)	0.5 - 20 hz, most bridges 2-5 hz; precision: 0.5 hz? Vertical waves; 2" amplitude
Deflection	Amount of deflection	Precision 1/8", range 1-6"; up to 120' span
Surface defect	Size of defect (e.g., width, length of crack)	
- voids		presence of delamination at rebar interface - how is this differently affecting 4" of concrete above it; presence of void (pothole), fine scale as possible (rate sensor capabilities)
- cracks		mm level (0.2 - 2.0 mm) - width, density, pattern, location, change over time (progressivity); 6mm really bad!
Subsurface defect	Size, depth of defect	*see void discussion*
Change in surface material (e.g. composition, texture, volume)	Amount of spectral reflectance for different wavelengths under different conditions	Create a spectral profile of concrete in various conditions
Subsurface chloride %	% chloride levels by depth (profile)	example: 1.5% Cl at 5 mm of interest (varies by concrete type)
Change in surface roughness	Amount of spectral reflectance for different wavelengths under different conditions	Pitting - metal - care at 10% of thickness (1" thick - 1/10" you have a problem); deck surface - see Devin's papers for example values
Dielectric constant value	Change in dielectric constant over time	Will be determined based on lab samples (related to void discussion)

Technical Memorandum No. 5 addresses the laboratory work plan and specimen fabrication progress. We consider this memo a "living document" that will experience revisions as we receive more feedback from the TAC and as we develop more detailed plans. The memo includes four specific examples (draft experimental plans) that have been developed to date and are being reviewed at two levels. The first level is a comprehensive review considering how each plan fits into the overall framework of the project objectives, such as described in Table 1 above. This comprehensive review will also address additional techniques not specifically stated here, as well as components of modeling not addressed as of yet. The second level of review will address the details of each example; ensuring specimen fabrication details (e.g. size, quantity) are met. The technologies for consideration by these four examples are also described under Task 3 (below).

<u>Additional Task 2 activities:</u> Beginning with last quarter and seeking to establish solid project connections with a local road agency to augment the team's existing relationships with the Michigan DOT, the team met on March 1, 2010 with representatives of the Road Commission for Oakland County (RCOC). This meeting was documented in the first quarter report. The RCOC team was agreeable to providing

technical guidance and access to Oakland Country bridges for testing as best as they could. Furthermore, later in the month, the project team formally invited RCOC to join its Technical Advisory Committee, and RCOC Executive Director Brent Bair assigned Dennis Kolar to that role.

Since our initial March 2010 meeting, the Road Commission for Oakland County (RCOC) has provided regular access to its bridges for collection of reference data, such as the spectral reflectance data we gathered at their Silverbell Bridge, a bridge which is undergoing enhanced 6-month inspections, and has lane closures and weight restrictions. We appreciate this access and help.

In addition, the Michigan Tech team has been coordinating with TAC member Amy Trahey, Great Lakes Engineering Group, to shadow one of her inspection crews on a field inspection. This occasion will afford Michigan Tech team members an opportunity for inspection field experience and offer insights for future implementation.

Task 3: Commercial Sensor Evaluation

For the commercial sensor evaluation, we have been concentrating on the demonstration, development, and testing of remote sensing technologies that have the capability to be implemented on a practical basis. Based on our evaluation so far, three remote sensing technologies appear very promising to significantly help with bridge condition assessment and the generation of bridge condition signatures. They are: Synthetic Aperture Radar (and related radar technologies), digital image correlation and tracking, and 3-dimensional photogrammetric bridge deck model generation. A fourth technology, using spectral reflectance measurements to create distinct measurements of the condition of surficial bridge elements, is undergoing further testing before we recommend it as a practical, valuable technology for bridge condition remote sensing. **Technical Memorandum No. 6** provides similar information to the project team during this quarter.

Synthetic Aperture Radar (SAR) is a technique that combines multiple radar returns to generate a 2D projection of the 3D radar reflections in the scene. With coherent processing, preserving phase information, this projection has real dimensions and spatial resolution in two directions (range and cross-range). This presents a tremendous advantage over unprocessed radar data, such as what is usually collected in commercial GPR surveys. In such cases, the phase information is discarded—only time-domain range returns are collected and, consequently, subsurface features appear as singular reflections. By preserving phase information and using range compression, we are able to achieve enhanced resolution using less power. These techniques have already been demonstrated in laboratory testing and field collects. We have used a commercial Akela radar system to measure the dimensions of subsurface features such as rebar when looking for corrosion, or subsurface defects such as delamination. We have taken the Akela radar and constructed our own cross-track, range-compressed radar system capable of measuring bridge slabs in three dimensions. This system was demonstrated before the TAC group in the MTRI radar lab during our June meeting. Our feasbility tests have shown we can achieve a resolution of 10 cm, and we are expecting an improvement to 6 cm with a new Akela radar we are bringing online in summer 2010 (which has become available for the project since it was acquired for other research).

Digital image correlation and tracking is another technology that appears very promising for practical use based on our background investigation and testing so far. In digital image correlation, multiple, frequent digital photographs of fine-grained marks on a target surface are taken at discrete intervals. Displacement of the target, such as a bridge beam, is calculated based on the 3-dimensional displacement of the individual marks. Tracking is handled by processing the imagery using MATLAB software we have acquired for the study. In on our testing thus far, we have measured displacements as small as 2.5 mm (1/10 inch) of a steel I-beam undergoing controlled stress loading at the MTTI labs on the Michigan Tech campus. With appropriate optics, we are planning testing at long standoff distances for more practical implementation. We also expect to be able to increase the effective resolution so as to measure displacement to 1/1000 of an inch. We expect to rigorously document the relationship between sensor-target geometry and effective resolution to demonstrate the technique's flexibility for Phase III field deployments.

We have also been working on a practical system for calculating the extent and depth of bridge deck surface problems, such as spalls, using photogrammetry and 3D modeling. We expect that our current design, exploiting well-established methods of 3-D measurement and the commercial software Leica Photogrammetry Suite (LPS, Version 2010), is capable of measuring the size and depth of spalling features with a maximum resolution of 2 mm horizontal and 3.75 mm in depth. We have designed a demonstration system to measure real-world effective resolutions of a vehicle-mounted, dual-camera system that would enable us to image and measure an entire road lane at one time without having to close lanes. Creating a 3-D bridge deck surface model without lane closures has been identified as a priority by our Michigan DOT partners. We are also demonstrating how the commercial LPS software can be used to extract information from the stereo pairs we are collecting.

For all remote sensing technologies we are evaluating, we are focusing on understanding the measurement requirements for indicators of bridge condition important to DOTs. This enables us to select the remote sensing technologies that can meet those requirements, if they exist, and can be reasonably implemented. This requirements definition process will continue to be a high priority for our team.

Task 4: Decision Support System

No progress was planned for this task in Quarter 2. However, we received input from our June TAC meeting on what a DSS should focus on. For the technologies applicable to the monitoring of a larger number of bridges, TAC members said that our project's DSS should provide the ability to show "red light / green light" indicators of bridge problems, where a map-based visualization system of bridge locations and conditions would show a "green light" if a combination of remote sensing and traditional technologies showed that a bridge was in acceptable condition, a "red light" if the bridge needed priority maintenance or enhanced inspection; a "yellow light" for a bridge could show a bridge that has changed significantly but not yet reached a critical status. The TAC also clearly described how any remote sensing-based technology assessments made available through our DSS and its normalcy algorithms should be compatible with existing tools, assessment methods, and data sources, such as the standards and data used to inform the National Bridge Inventory (NBI) rating system, in use by state DOTs and local transportation agencies. We will use this input to guide our Task 4 work in creating a demonstration DSS.

Task 5: Field Demonstration

No progress was planned for this task in Quarter 2.

Task 6: Assessment

No progress was planned for this task in Quarter 2.

PROBLEMS ENCOUNTERED

Based on the need to more fully work with TAC members to obtain their input, and more fully assess technologies, we anticipate that completing a detailed Commercial Sensor Evaluation will take longer than the initial 5 months planned for Deliverable 3-A (currently due September 2010). We would like to request a reasonable extension of that task to produce a more detailed evaluation. We would still produce an overview evaluation based on our work completed by September 2010, but would produce a more detailed supplement at a date mutually agreed on with the program manager. We suggest a date of March 2011 for the supplement.

We recognize that the laboratory work plan and specimen fabrication is slightly behind schedule, due in part to our delay in getting the TAC established. We have received valuable input from our partners and are working on realistic work plans to demonstrate the feasibility of implementing several remote sensing techniques for bridge condition assessment. We do not believe that this slight set-back will negatively affect the long-term completion of this project. And we do believe that a focused well-thought laboratory work plan will only enhance the overall ability to implement our results.

Following the submittal of our Quarter 1 report, it was noted that the chart presented under the "Business Status" section did not match the invoice sent to USDOT because our internally accounting procedures were not documenting external cost-share contributions to the PI's expectations. Consequently, several meetings were held with the research accounting department and a standardized form was developed for such documentation. The process now includes monthly reporting from the external cost-share contributors to the PI, then to the research accounting department. As such, the chart presented herein under "Business Status" matches the invoices that are sent to USDOT.

FUTURE PLANS

Quarter 3 activities will continue to follow the general schedule outlined within the technical project proposal. Task 1 administrative activities are progressing well. From a technical perspective, the primary focus of the activities in Quarter 3 will continue on the bridge condition characterization (Task 2) and the evaluation of commercial sensor technologies (Task 3). In addition, activities related to the decision support system described in Task 4 will commence.

Anticipated Activities and Deliverables for Quarter 3 include:

- Refinement of the laboratory work plan as activities commence (based on Technical Memo No. 5 and progress to date reported) (Task 2.2).
- Structural modeling development (Task 2.3) and coordination with the sensor evaluation process.
- Progress on the commercial sensor evaluation (Task 3.0) including describing which sensors can perform most effectively on measuring high priority bridge conditions characteristics. We intend to continue performing focused testing of promising remote sensing technologies, such as additional methods of 3-dimensional bridge deck sensing, that meet the priorities of the transportation community, based on our TAC and MDOT input.
- Initial software development for the decision support system (DSS), including designing code for integrating sensor data and normalcy models for sensor response (Tasks 4.1, 4.2, 4.3).
- Presentation of the technical paper (*"Evaluation of Remote Sensing Technologies for Detecting Bridge Deterioration and Condition Assessment"*) for NDE/NDT for Highways and Bridges: Structural Materials Technology (SMT) 2010 Conference.

ADVISORY/STEERING COMMITTEE MEETING

Members of the Technical Advisory Committee include:

Steve Cook – Michigan Department of Transportation
Roger Surdahl – Federal Highway Administration
Krishna Verma – Federal Highway Administration
Amy Trahey – Great Lakes Engineering Group
Carin Roberts-Wollmann – Virginia Tech
Keith Ramsey – Texas Department of Transportation
Michael Johnson – CalTrans
Duane Otter – Transportation Technology Center, Inc.
C. Douglas Couto – Transportation Research Board
Peter Sweatman – University of Michigan Transportation Research Institute
Dennis Kolar – The Road Commission for Oakland County
Dan Johnston – Independent Materials Consultant
Charles Ishee – Florida Department of Transportation

The first meeting was held June 16-17, 2010. The objective of the meeting was to introduce the TAC membership to the project and to receive feedback on the project proposed activities and expectations. Several presentation were given, including a general overview of the project, and an introduction to remote sensing, and presentations covering specific topics such as photographic methods, radar applications, spectral reflectance, and 3-D bridge deck modeling.

TAC members were asked to provide input on the list of priorities concerning bridge condition, a vision for an ideal decision support system for monitoring and understanding changes in bridge condition, and the level of bridge sensing technologies (remote or direct) that is currently being used in their state or region. For remote attendees, we set up real-time presentation sharing (using Adobe Connect Pro and a teleconference number (through www.freeconference.com) so that their input could be effectively gathered. **Appendix A** includes the meeting notes and supporting documentation for the TAC meeting. The meeting was very successful in that team members received valuable guidance for this project. A significant outcome of our first TAC meeting was the support and approval of our project objectives and approach as indicated by the TAC members. TAC members will be provided with project updates and asked for continued guidance.