MichiganTech Transportation Institute

Memo

To: L. Sutter, D. Harris, D. Evans, R. Oats, K. Vaghefi

From: T. Ahlborn

CC: R. Shuchman, J. Burns, C. Brooks, K.A. Endsley, C. Roussi, B. Hart, P. Hannon

Date: July 14, 2010

Technical Memo Number: 05

Re: Laboratory Work Plans and Specimen Fabrication

Attached are four laboratory work plans as proposed by our MTRI team members.

1. Experimental Plan for Field Spectra Data Collection to support Bridge Surface Condition Assessment

2. Experimental Plan for High-Resolution Digital Image Analysis to support Bridge Surface Condition Assessment

3. Experimental Plan for Preliminary Investigation of Radar Applications for Bridge Deck Sensing

4. Experimental Plan for Digital Image Correlation and Tracking for Measuring Displacement of a Structural Element

It is necessary to review these plans for completeness and provide feedback to MTRI. The review will be completed on two levels. First, a review and discussion will be conducted to ensure that these plans fulfill and encompass the overall objectives of the project and second, that the details (specification size, quantity, etc.) are adequate to address the individual plan goals.

Discussion of these plans will continue during our next bi-weekly conference call such that feedback can be incorporated. These sample work plans are to be considered as living documents, and will continue to be revised as we progress.

Also attached are the specimen fabrication details of the thin-slab specimens that were cast in our structures and materials laboratory in April, 2010.

Experimental Plan for Field Spectra Data Collection to support Bridge Surface Condition Assessment

Rick Powell and Colin Brooks, MTRI
Version of 3/30/2010
Revised 7/14/10, Tess Ahlborn, MTTI

Overview and Objective

The current state of knowledge about the spectral characteristics of bridge surface condition, and the relationship of these characteristics to indicators of bridge condition, is inadequate. The availability of high spatial resolution multispectral and hyperspectral remote-sensing systems, with the potential to cost-effectively enhance current bridge inspection practices, drives the need to conduct a detailed study of spectral properties of a variety of bridge surface conditions. Surface defects such as spalling, scaling, cracking, and other observable defects that present themselves in the field are the primary focus of the study. We will focus on these indicators of bridge condition, while investigating other targets of opportunity within focused field data collections.

Our objective is to develop a library of the spectral characteristics of various bridge surface defects, conduct a quantitative assessment of spectral separability, and an evaluation of which wavelengths are most suitable for spectral separation of critical bridge condition features. The results are intended both to identify the specifications of an optimal sensor for bridge condition assessment, and to asses the potential for field spectral reflectance units (such as spectroradiometers) to become part of a future bridge inspection process.

The study will be conducted in both the field and in the lab. Bridges with known surface defects in Washtenaw and Oakland counties in Michigan will be used to collect measurements with the assistance of the respective Road Commissions. We propose that the Michigan Tech Structures and Materials Laboratories will develop concrete blocks of identical shapes, size, and composition to evaluate the spectral response of surface defects over time.

Spectroradiometer Measurements

Spectra will be acquired with an Analytical Spectral Devices (ASD) FieldSpec3 spectroradiometer (Analytical Spectral Devices, Boulder, CO). The spectroradiometer samples a spectral range of 350–2500 nm. The instrument uses three detectors spanning the visible and near-infrared (VNIR) and short-wave infrared (SWIR1 and SWIR2), with a spectral sampling interval of 1.4 nm for the VNIR detector and 2.0 nm for the SWIR detectors. Field-based bridge surface measurements will be taken within two hours of solar noon and bracketed by Spectralon (Labsphere, North Sutton, NH) 100% reflective standard. The unit is GPS-enabled and records the location of each sample in a format suitable for mapping and relating to remote sensing imagery.

Field spectra of relatively large bridge surface defects such as spalling (holes, roughness) and cracks will be captured at nadir from a height of 1 m using the bare fiber optic input, which provides a field of view of approximately 43 cm in diameter. Moderate and smaller sized surface defects will be acquired from the same height using the unit's 8° foreoptic, with a field of view of approximately 30cm. Select targets of opportunity will be acquired from nadir, 5°, 30°, 45°, and 60° using bare fiber and the 8° foreoptic mounted to a tripod to evaluate the Bidirectoral Reflectance Distribution Function (BRDF) of the surface defects and explore if better spectral separation of conditions can be achieved at off-nadir viewing geometries.

Preliminary Field Data Collection and Exploratory Analysis:

A preliminary set of spectroradiometer measurements, as described above, will be collected at three local bridges representing a variety of bridge deck surface conditions. These include a recently constructed bridge deck with no observable surface defects, a bridge deck surface with some moderate surface defects, and an older bridge deck with significant amounts of surface roughness. MDOT safety procedures will be used on any roadway or bridge data collections. Field data collection procedures will be implemented and evaluated for utility, and may be revised for future data collections. An exploratory data analysis of the preliminary data collection will be performed to evaluate the spectral response of the various levels of bridge surface deck deterioration. The results of the preliminary data analysis may be used to inform and revise future field data collections, including target selection, and analysis techniques. We anticipate a 2-week period to complete this exploratory analysis.

Lab Sampling Procedure:

To investigate the effect of chloride contamination on bridge surfaces, concrete samples would be artificially degraded and the spectrum measured periodically.

We propose that the Michigan Tech Structures and Materials Laboratories would develop 4 concrete blocks of identical shapes, size (30 x 30 x 6 cm^3), and composition (curing, cure temperature, and aggregate materials) identical to that used in bridge surfaces. One sample will be retained as control. The other 3 samples will be exposed to a 10% solution of chloride for 12 weeks. Spectral measurements will be collected every week for the 12 week period. Sampling the blocks during the exposure period will be collected as well when feasible.

The Fieldspec3 spectroradiometer (ASD Inc.) with a spectral range of 350–2500 nm will be used to collect reflectance spectra of the concrete blocks in the laboratory with a quartz–tungsten–halogen (QTH) lamp as a light source. Diffused light from the 100 W light source will be used to illuminate the concrete block at 45° angles when spectra are collected in the laboratory. The foreoptic of the spectroradiometer will be aligned vertically, and the height of the foreoptics from the top of the concrete block will be adjusted so that reflected light only from the surface of the concrete block will fill the field of view (FOV) of the instrument. Spectra will be collected at a height of at 30 cm from the surface of each concrete block. The Spectralon (Labsphere, North Sutton, NH) 100% reflective standard will be used to calibrate before recording each concrete spectra.

Correlation between degradation level and spectral response:
We will analyze the statistical relationship between degradation (as known from lab samples, or as visible in the field) and the spectral response measured by the Fieldspec3. We will also perform an analysis to investigate the relationship between degradation depth (such as chloride penetration) and spectral response. This will include having samples analyzed in Houghton for degradation depth. We will calculate a first order derivative for change at each wavelength over time of degradation (estimates degradation), and compare estimates to actual degradation.

Time Period

Field data collection should occur during the spring and summer seasons (late April-August) when solar radiation and angle are optimal. Lab-based measurement may occur at any period, but we recommend starting in the Spring so that lab samples can be created. Field data collection, analysis, and reporting is estimated to be completed within 60 days, with primary labor support for Rick Powell (at ¼ time), Rick Dobson (at ¼ time), plus a ½ time intern, with limited coordination support (1 day per pay period) for Colin Brooks. Limited additional time would be needed to collect the spectral profiles of the concrete samples, in coordination with the Michigan Tech lab.

Sampling Procedure:

For each sampling point:

1. **Measure Reflectance Spectra.**

    For each sample site, the instrument will be optimized and calibrated to white reference.

    Spectral reflectance will be collected.

    Five samples will be collected for each measurement.

    Each sample will consist of the average of 25 scans.

    Field Spectra Sampling Form (Appendix A) will be completed for each location in the field and for each concrete sample block.

2. **Digital Photographs** Surface, weather conditions and context will be recorded with GPS attributed photographs at each sampling location.

3. **GPS Point:** Although the spectroradiometer instrument controller will be configured to record GPS location, the high-resolution Trimble GeoExplorer GPS unit will be used to record the point as backup.

Required Resources:

1. 100 W quartz–tungsten–halogen (QTH) lamp
2. 2- person crew
3. Map of study sites
4. ASD FieldSpec3 Spectroradiometer with Instrument Controller.
5. Two GPS units (WAAS enabled Garmin & differential correction-capable Trimble unit)
6. Data forms (FieldSpec)
7. Pencils, clipboard, black markers
8. Digital camera
9. Safety equipment (including orange blazer, steel-toed boots, car light, hard hat) for data collections on or near roadways and bridges; safe data collection procedures will be used for all data collections.

Michigan Tech Research Institute

Appendix A. Spectrometer Field Data Collection Form.

FIELD SPECTROMETER DATA			
PROJECT NAME:			
DATE/TIME:			
SITE:		OBSERVER:	
PHOTO REFERENCE:			
COORDINATES	X:	Y:	
INSTRUMENT ID:		# OF SCANS AVG:	
GEOMETRY OF OBSERVER'S POSITION RELATIVE TO INCIDENT RADIATION *sketch or description*			
HEIGHT OF INSTRUMENT ABOVE GROUND:		ABOVE TARGET:	

SCAN NO.	TARGET	TIME	SKY CONDITION		COMMENT

Experimental Plan for High-Resolution Digital Image Analysis to support Bridge Surface Condition Assessment

Colin Brooks, Rick Powell, Rick Dobson, MTRI
Version of 3/30/2010

Overview and Objective

Understanding the surface condition of bridge decks is a priority method of evaluating bridge condition for transportation departments. One measure used by MDOT, amongst others, is to assess the percentage of a bridge deck that has visible delamination. One example trigger level for indicating a significant problem described by MDOT at our February 5th, 2010 kickoff meeting was greater than 30% deck delamination. Greater than 10% delamination was described a trigger for an in-depth inspection. Major deck cracking is an additional problem described by MDOT.

To sense and analyze these problems, we propose to perform a high-resolution digital photograph collection taken from above the bridge deck at sufficient height to collect overlapping stereo-capable images. Our primary objective is to demonstrate the capability of using custom image processing algorithms developed by MTRI to rapidly estimate the frequency, size, depth, and distribution of delamination features on a bridge deck. Demonstrating capability for automatic recognition and characterization of major deck cracking, at resolutions higher than is capable with aerial photography or satellite imagery, is a secondary objective. Both of these objectives serve the larger project focus of demonstrating where remote sensing can effectively and efficiently be used to assess bridge condition.

The study will primarily be field-focused, using local and State bridges with visible surface defects in the southeast Michigan area. Lab-created control samples will be sensed on a representative basis. Based on available maps, proximity, and our relationships with local road commissions, we will focus on Washtenaw and Oakland counties in Michigan, with the assistance of the respective Road Commissions and MDOT.

Digital Imagery Collection

We will use a digital SLR (DSLR) camera to collect the high-resolution photographs needed for this study. The Spatial Analysis Lab currently has a Nikon D40 DSLR available for check-out; other high-resolution cameras could be used as purchased or loaned to the study. The Nikon D40 (http://www.nikonusa.com/Find-Your-Nikon/ProductDetail.page?pid=25420) is a recent and advanced DSLR appropriate for use in the study. Its relevant specifications are:

Focal Length: 18-135mm (we will use 18mm for the project)
Focal Length Multiplier: 1.5
Field-of-View (FOV) Horizontal: 67.4 Deg

FOV Vertical: 47.9 Deg
FOV Diagonal: 77.4 Deg
6.1 megapixels resolution (3008 x 2000 pixels)
DX-format CCD image sensor, 15.6 x 23.7 mm size

As we are proposing to do both image processing for feature analysis and stereo-pair analysis to characterize delamination depth, we will require collection from an appropriate height to capture these data. For a single-camera, single photo system, the horizontal field-of-view (FOV) of the camera can be used in a simple trigonometric equation to calculate the height at which photos need to be collected to capture a certain width of road area. Similarly, for a two-camera system set up to simultaneously acquire the 60% overlap normally used for stereo photography (Falkner, 1995), the camera height required for this overlap for certain widths can be calculated. Table 1 shows the camera height needed for a single-camera, single-photo system. Table 2 shows the height needed for the two-camera, 60% overlap system we propose to apply for this study, under the assumption we can implement one inexpensively. Note that typical lane widths are highlighted in the figures. We have also calculated the heights needed for a system where a single camera would take three photos across the roadway.

Table 1: Collection heights required for a single-camera system:

Nikon D40	
Focal Length	18mm
Focal Length Multiplier	1.5
FOV Horizontal	67.4 Deg
FOV Vertical	47.9 Deg
FOV Diagonal	77.4 Deg

FOV-H = Field of View - Horizontal
FOV-V = Field of View - Vertical
FOV-D = Field of View - Diagonal

These calculations are for a single camera.

FOV-H (ft)	Camera Height (ft)	Camera Height (m)	FOV-V (ft)	FOV-D (ft)	
1	0.75	0.23	0.89	1.60	
2	1.50	0.46	1.78	3.20	
3	2.25	0.69	2.67	4.81	
4	3.00	0.91	3.55	6.41	
5	3.75	1.14	4.44	8.01	
6	4.50	1.37	5.33	9.61	
7	5.25	1.60	6.22	11.22	
8	6.00	1.83	7.11	12.82	
9	6.75	2.06	8.00	14.42	
10	7.50	2.29	8.88	16.02	
11	8.25	2.51	9.77	17.63	
12	9.00	2.74	10.66	19.23	**Single Lane**
13	9.75	2.97	11.55	20.83	
14	10.50	3.20	12.44	22.43	
15	11.25	3.43	13.33	24.03	
16	12.00	3.66	14.21	25.64	
17	12.75	3.88	15.10	27.24	
18	13.49	4.11	15.99	28.84	**Single Lane with Shoulder**
19	14.24	4.34	16.88	30.44	
20	14.99	4.57	17.77	32.05	
21	15.74	4.80	18.66	33.65	
22	16.49	5.03	19.54	35.25	
23	17.24	5.26	20.43	36.85	
24	17.99	5.48	21.32	38.46	**Two Lanes**
25	18.74	5.71	22.21	40.06	
26	19.49	5.94	23.10	41.66	
27	20.24	6.17	23.99	43.26	
28	20.99	6.40	24.87	44.86	
29	21.74	6.63	25.76	46.47	
30	22.49	6.86	26.65	48.07	**Two Lanes with Shoulder**
31	23.24	7.08	27.54	49.67	
32	23.99	7.31	28.43	51.27	
33	24.74	7.54	29.32	52.88	
34	25.49	7.77	30.20	54.48	
35	26.24	8.00	31.09	56.08	
36	26.99	8.23	31.98	57.68	**Three Lanes or Two Lanes with two Shoulders**
37	27.74	8.46	32.87	59.29	
38	28.49	8.68	33.76	60.89	
39	29.24	8.91	34.65	62.49	
40	29.99	9.14	35.53	64.09	
41	30.74	9.37	36.42	65.69	
42	31.49	9.60	37.31	67.30	**Three Lanes with Shoulder**
43	32.24	9.83	38.20	68.90	
44	32.99	10.05	39.09	70.50	
45	33.74	10.28	39.98	72.10	
46	34.49	10.51	40.86	73.71	
47	35.24	10.74	41.75	75.31	
48	35.99	10.97	42.64	76.91	**Three Lanes with Two Shoulders**

Table 2: Collection heights required for a dual-camera system with 60% overlap.

Nikon D40

These calculations are for a 2 camera system.

Focal Length	18mm
Focal Length Multiplier	1.5
FOV Horizontal	67.4 Deg
FOV Vertical	47.9 Deg
FOV Diagonal	77.4 Deg

FOV-H = Field of View - Horizontal
FOV-V = Field of View - Vertical
FOV-D = Field of View - Diagonal

60% Overlap Width (ft)	**Camera Height (ft)**	**Camera Height (m)**	**Total FOV-H (ft)**	**FOV-V (ft)**	**FOV-D (ft)**	
1	1.25	0.38	2.33	1.11	2.58	
2	2.50	0.76	4.67	2.22	5.17	
3	3.75	1.14	7.00	3.33	7.75	
4	5.00	1.52	9.33	4.44	10.34	
5	6.25	1.90	11.67	5.55	12.92	
6	7.50	2.29	14.00	6.66	15.50	
7	8.75	2.67	16.33	7.77	18.09	
8	10.00	3.05	18.67	8.88	20.67	
9	11.25	3.43	21.00	9.99	23.26	
10	12.50	3.81	23.33	11.10	25.84	
11	13.74	4.19	25.67	12.21	28.42	
12	14.99	4.57	28.00	13.32	31.01	**Single Lane**
13	16.24	4.95	30.33	14.43	33.59	
14	17.49	5.33	32.67	15.54	36.17	
15	18.74	5.71	35.00	16.65	38.76	
16	19.99	6.09	37.33	17.76	41.34	
17	21.24	6.47	39.67	18.87	43.93	
18	22.49	6.86	42.00	19.98	46.51	**Single Lane with Shoulder**
19	23.74	7.24	44.33	21.09	49.09	
20	24.99	7.62	46.67	22.20	51.68	
21	26.24	8.00	49.00	23.31	54.26	
22	27.49	8.38	51.33	24.42	56.85	
23	28.74	8.76	53.67	25.53	59.43	
24	29.99	9.14	56.00	26.64	62.01	**Two Lanes**
25	31.24	9.52	58.33	27.75	64.60	
26	32.49	9.90	60.67	28.86	67.18	
27	33.74	10.28	63.00	29.97	69.77	
28	34.99	10.66	65.33	31.08	72.35	
29	36.24	11.04	67.67	32.19	74.93	
30	37.49	11.43	70.00	33.30	77.52	**Two Lanes with Shoulder**
31	38.74	11.81	72.33	34.41	80.10	
32	39.98	12.19	74.67	35.52	82.69	
33	41.23	12.57	77.00	36.63	85.27	
34	42.48	12.95	79.33	37.74	87.85	
35	43.73	13.33	81.67	38.85	90.44	
36	44.98	13.71	84.00	39.96	93.02	**Three Lanes or Two Lanes with two Shoulders**
37	46.23	14.09	86.33	41.07	95.60	
38	47.48	14.47	88.67	42.18	98.19	
39	48.73	14.85	91.00	43.29	100.77	
40	49.98	15.23	93.33	44.40	103.36	
41	51.23	15.62	95.67	45.51	105.94	
42	52.48	16.00	98.00	46.62	108.52	**Three Lanes with Shoulder**
43	53.73	16.38	100.33	47.73	111.11	
44	54.98	16.76	102.67	48.84	113.69	
45	56.23	17.14	105.00	49.95	116.28	
46	57.48	17.52	107.33	51.06	118.86	
47	58.73	17.90	109.67	52.17	121.44	
48	59.98	18.28	112.00	53.28	124.03	**Three Lanes with Two Shoulders**

Using a two-lane roadway on a bridge with shoulder as our representative collection scenario, we would need a height of 11.43 meters (37.49 feet) for a dual-camera, 60%-overlap data collection for a system travelling down the roadway. For a single-camera system, taken from the side of the road with 60% overlap, with manual placing of the camera to get the next overlapping photo, the one-camera height of 6.86 meters (22.49 feet) would suffice. We are anticipating that this would require access to a “cherry picker” (boom lift), except in rare cases where a nearby overpass or building would provide the equivalent needed height and view of a bridge deck surface. It is our intention that this scenario would represent a future “real-world” data collection methodology for use by Departments of Transportation, which is a focus of the project sponsor.

To create the stereo photography and resulting high-resolution digital elevation model (DEM), we will use the advanced capabilities of the new ERDAS 2010 software now available in the MTRI Spatial Analysis Lab. While designed to produce DEMs from aerial photography with dedicated aerial cameras, it has also been used to generate DEMs from DSLRs. We will test this capability with an initial experiment using a height from a local building or other height (such as the top of a truck rented for another project data collection). We will also test feasibility on at least two samples created by the MTTI lab with controlled delamination and spalling issues. The custom DEM created through this process would also help in confirming that a feature is a delamination with a measurable depth of deck loss.

For analyzing the frequency, size, and distribution of delaminations, we propose to develop and apply a combination of custom algorithms in MATLAB, ENVI+IDL, and Definiens. It is noteworthy that even with the application of commercial image processing software, we will still be developing a custom algorithm for delamination characterization. We will not be applying just "out-of-the-box" software for our analysis. These algorithms should form part of the input for the Bridge Condition Assessment Decision Support System that will result from the larger project. MATLAB's image processing capabilities, the pixel-based strengths of ENVI that are customizable with IDL, and Definiens' capability to enable custom algorithm development will all be used, as appropriate, for our algorithm creation.

For automatic recognition and characterization of major deck cracking, we propose to develop a custom algorithm using the advanced object-based capabilities of our image processing software. We will use this opportunity to assess if our recent reliance on the object-based image classification capabilities of Definiens are still the best tool for algorithm development, given other new software developments. ENVI now has the "Feature Extraction Module" while ERDAS has the "IMAGINE Objective" tool that appears appropriate for this study based on our review of its capabilities. In particular, the capability to encode custom algorithms in the Feature Models capability of IMAGINE Objective makes that tool appropriate.

Time Period

We are proposing a 3-month project for this experiment plan. Month 1 would be focused on field data collection and collectionsystem design. Month 2 would be focused on algorithm development and testing. Month 3 would be for algorithm adjustment and any final data collections needed to fine-tune the final algorithms. To keep costs reasonable, we propose to take advantage of the presence of 1-2 summer interns to assist with the field data collection, under appropriate supervision.

Preliminary Field Data Collection and Exploratory Analysis:

To test the feasibility of our proposed method, we will rapidly gather a set of high-resolution digital photographs taken from above a bridge using another overpass, from the top of a local building, or from the top of a truck rented by MTRI for other data collections, so we can gather the imagery needed for delamination characterization and depth characterization. MDOT safety procedures will be used on any roadway or bridge data collections. If sufficient time remains, we would take a first pass at high-resolution crack characterization as well. We estimate that this initial data collection would take two days of field collection and four days of analysis.

Sampling Procedure:

For each sampling point, with development of custom analysis algorithms:

In the field:
1. **Visit study sites to find optimal locations to collect data.**
2. **Obtain the help of MDOT or the local road commission for making the bridge available for data collection, and availability of a boom lift if needed.**
3. **Use safety equipment (including orange blazer, steel-toed boots, car light, hard hat) and safe data collection procedures for data collections on or near roadways and bridges.**
4. **Take digital photographs from appropriate height.**
5. **Record the GPS location of each photograph.**

In the Spatial Analysis Lab:

6. **Process photos into stereo pairs for DEM extraction.**
7. **Characterize depth of delamination areas.**
8. **Use custom image analysis algorithm for characterizing the frequency, size, and distribution of delamination areas.**

Required Resources:

1. 2- person crew for field data collection (MTRI researcher - Dobson + intern)
2. Image analyst (Powell with Brooks)
3. Map of study sites
4. Permission to collect at bridge locations
5. Available method of reaching needed height (cherry picker, above bridge structure)
6. Image analysis software (MATLAB, Definiens, ERDAS, ENVI, as determined through the study)
7. GPS unit (Trimble when available, Garmin 76 Csx WAAS-capable unit or equivalent)
8. Two DSLR cameras similar to available Nikon D40.
9. Safety equipment (including orange blazer, steel-toed boots, car light, hard hat) for data collections near roadways or bridges.
10. For lab testing: Two or more lab-controlled samples with spalling and/or delamination problems.

We propose to use Powell at 1/5 time, Brooks at 1/5 time, Dobson at ¼ time, and an intern at ½ time during the 3-month duration of the experiment. This will provide a focused time period and set of hours to complete the experiment design in a timely manner.

References:

Falkner, E. 1995. Aerial Mapping: Methods and Applications. CRC Press – Lewis Publishers, Boca Raton, FL. 322 pp.

Experimental Plan for Preliminary Investigation of Radar Applications for Bridge Deck Sensing

K. Arthur Endsley and Ben Hart, MTRI
Version of 7/14/2010

Overview and Objective

Radio detection and ranging (radar) is a technology in broad-use for measuring the distance to and direction and speed of targets. Radar involves the use of electromagnetic (EM) waves, either pulsed or continuously transmitted, for measurement. In through-transmission techniques the signal changes as it propagates from source to receiver. In most applications, however, a single antenna is used as both source and receiver, and it is the reflected signal that is measured. Changes in the radar signal consist of phase, frequency, or amplitude shifts which might be caused by the target's motion or the dielectric properties of both the target's material and the medium of transmission. Radar emissions vary in these parameters as well depending on the application. By adjusting the emission frequency, the technology has the potential to provide information on a target's composition and internal structure.

There are a variety of techniques applying radar signals to different ends, and several of these have viable transportation applications. Ground-penetrating radar (GPR) is a well-established technique for sensing subsurface features and defects in concrete structures. Some state DOTs even have the equipment and the expertise to perform GPR surveys in-house. Generalized microwave and millimeter-wave radar techniques have become popular in structural health monitoring (SHM) because they offer more compact and less expensive equipment than commercial GPR equipment. Synthetic aperture radar (SAR) is a process that generally involves a scanning or moving radar take multiple measurements along a transect line. By applying range migration processing to these measurements it is possible to derive a 2D projection of 3D reflectivity in the scene. SAR makes it possible to achieve spatial resolution not only in the range direction but also along the transect line. Furthermore, in range compression, a long EM pulse with encoded phase information can be used for enhanced resolution. GPR typically does not involve coherent processing; only time-delay information is used and so real target dimensions cannot be known.

We are interested in determining whether or not we can detect subsurface defects such as delamination, inclusions, or changes in a concrete deck's composition such as increasing chloride and/or water content. These measurements cannot be made directly without penetrating and thereby destroying the concrete deck. Optical methods that are limited to what can be sense in the visible spectrum have no way of detecting embedded features. In this report we describe an experiment in which we investigated the use of SAR collection and processing techniques to image concrete slabs. The preliminary results describe how deep we can penetrate concrete slabs in the laboratory and, consequently, whether or not we can image re-bar embedded in the slabs.

Radar Measurements

The AKELA radar is a fairly sophisticated radar system with innovative features such as range-gating, a low-noise amplifier, and position encoder. This system has a frequency range of 300-3000 MHz. Any values in that range can be chosen as the first and last frequencies of the radar scan. The number of evenly spaced samples over the selected range can also be chosen, 512 is what we choose. The sampling rate can also be adjusted. This parameter affects the signal-to-noise ratio, and, when the antenna is in motion, the spatial sampling distance. We chose 45 kHz as the sample rate for these measurements.

The antennas for the radar are chosen to have a radiation pattern such that only the target is being illuminated by the radar. We use two antennas mounted together, one for transmission and the other for receiving the reflected signal. To create a two dimensional radar image, these antennas must be moved and radar measurements made at evenly spaced intervals along the direction of motion. To achieve this motion a garage door opener was modified and the antennas mounted to the carriage on the rail. This solution provides a stable direction of motion and constant speed. A position encoder has been mounted to the motor and connected to the AKELA radar unit to record the position of the antennas for each measurement sweep.

Laboratory Sampling Procedure

The most basic determination necessary to assess the feasibility of using radar in the detection of subsurface flaws is to determine the effective resolution that can be achieved. Another objective is to determine whether or not we can resolve specific features or flaws based on their position (depth) within the concrete slab. In our facility, we used concrete pavers as “slabs” of a concrete deck and thin metal rods inserted in between two slabs to simulate re-bar. A reflective plate was placed at the bottom of the stack to provide a definite “bottom” for deepest reflections. Data have also been collected on actual concrete samples provided by MTTI in Houghton. These samples were representative of actual bridge surfaces with and without defects.

To make a measurement, the antenna translation system is mounted above, or to the side of the sample, depending on the desired look angle. The cables between the antenna, radar, and computer are routed out of the antenna beam so that they will not be included in the measurement. The software is then set up for a 20 second collection. Once the radar is running, the garage door button is pushed and the antennas move along the rail while the radar is running. At the end of the collection the data file is saved, manually or automatically depending on settings. The antennas are brought back to their starting position and the process may be repeated.

Time Period

This whole process is relatively quick. It takes two people 30 minutes to set up the system for measurement. Each data collection takes about a minute from beginning to end. The data processing is automated as well. Software takes the radar data files and processes them into MATLAB-friendly formats. A MATLAB script reads these files and creates the images for visual interpretation.

Required Resources

1. AKELA Radar System
2. Garage door opener translation system
3. Laptop running AKELA APRD software
4. Two antennas with adequate cabling and connectors
5. Calibration targets
6. Miscellaneous tools

Experimental Plan for Digital Image Correlation and Tracking for Measuring Displacement of a Structural Element

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Version of 7/14/2010

Overview and Objective

Digital image correlation and tracking is a straightforward approach to measuring structural condition and dynamic character using recognizable features on a target surface. In this technique, deflection and vibration are sensed optically from structured-light photographs. Fiducial marks projected or applied to the target surface are correlated between multiple photographs. Their motion from frame to frame can be tracked to calculate the direction and speed of an object's motion. For structural health monitoring applications, a reference photograph can be used for comparison with subsequent still images or a series of photographs can be taken at regular intervals to characterize structural dynamics.

Displacement of the target is calculated at the pixel scale based on the displacement of individual fiducial marks. A wide size distribution in these marks is required in order to prevent aliasing; to ensure that a wide range of rigid displacements can be detected. The technique is capable of measuring both in-plane and out-of-plane displacement for an effectively 3D measurement of displacement and/or vibration. Most bridge dynamics can be optically sensed and this technique, in particular, allows for very fine accuracy. The resolution is dependent on the distance to the target, but dynamics such as displacement and strain can be measured at sub-pixel accuracy.

This document describes an early attempt to measure the deflection and vibration of a steel I-beam using digital image correlation and tracking. We planned to determine the resolution that can be achieved using this method to measure displacement and to ultimately determine whether or not the technique is useful for monitoring real-world bridge deflection.

Pattern Application

Our implementation of this technique consisted of spray-painting a pattern of white dots on the structural I-beam to be measured. Through experimentation, we found that the appropriate size distribution can be achieved by obstructing the direct flow of paint from the nozzle by using one's finger placed 0.5-1 inch in front of the nozzle opening.

Loading the Structural Element

The structural I-beam was stressed by dual hydraulic rams, operated synchronously, capable of generating a fixed displacement per input volt (for this model, 1 volt resulted in 0.5 inches of piston displacement). Based on the output results, it seems clear that the steel beam from which the rams are suspended was being pushed upwards as the ram was in operation. This is not surprising, as the steel I-beam is almost identical to the steel beams that support the rams; the steel I-beam is just as rigid as the steel beams supporting the rams. In addition to static loading, dynamic tests were also conducted in which a sinusoidal signal was used to induce alternating motion of the pistons.

Digital Image Collection

A series of digital images were taken at fixed intervals using a Nikon D300s, 12-megapixel, digital SLR camera with a 150 mm lens attached. The camera was placed 2 m from the target surface on a rigid tripod. The area of the beam in the camera's field of view was 5 by 5 inches. The maximum optical resolution that can be achieved with this setup is 0.0014 inches/pixel; We achieved an effective resolution of 0.0058 inches/pixel. The images are numbered automatically by the camera's firmware, and each of the images was correlated with the known load applied to the I-beam at that time. Table 1 shows the static load conditions when each frame was taken.

Digital Image(s)	Load Condition	Displacement Sensed
033	No load	
040	0.85 kips	0.08 in
104	5 kips	
129	10 kips	
140	15 kips	0.50 in
146	17 kips	0.50 in
158		0.60 in
183		0.70 in
198	22.8 kips	0.75 in
199-225	Unloading	
226-232	No load	

Digital Image Processing

Camera images were processed in MATLAB using software created by Christoph Eberl from Johns Hopkins University. This software subdivides each image into a grid of grids. Cross-correlation of each subgrid with the corresponding subgrid in the next image in succession is then performed. A displacement vector is calculated for each subgrid, effectively producing a displacement field for the entire image. The amplitudes of these vectors were extracted and plotted by the x and y positions for each image, rendering a plot of displacement over the 2D image surface for different loading conditions. At one point during loading the hydraulic rams reported a displacement of 0.2 inches, yet we calculated a displacement of 0.104 inches from the imagery. This most likely indicates the hydrualic rams' support beams were being displaced as they pushed down on the steel I-beam.

Time Period

The experiment required 2 hours of work in the laboratory stressing the steel I-beam and collecting the images. Processing in MATLAB required 10-15 minutes for about 150 images and the total job of processing and interpreting the results required one engineer at full time for half a day.

Required Resources

1. High-resolution digital SLR camera
2. Stable tripod with swivel head
3. Can of white spraypaint
4. Dual hydraulic ram
5. Computer capable of running MATLAB software
6. MATLAB software

Memorandum

To: Dr. Tess Ahlborn, P.E

CC:

From: Darrin Evans

Date: 6/8/2010

Re: Thin Slab Specimens

Test Slab AB

This test specimen consists of a 4'x4'x5 ½" slab of concrete with different "defects" placed inside the concrete. The concrete used is a MDOT Grade D deck mix design. Tests on the concrete determined the following properties 2.75" slump, 5% air content and a 5500 psi compressive strength. The relative humidity was measured to be 88.8% with a temperature of 20.1 degrees Celsius. This was measured with a HM44 at 12 days after casting.

Several "defects" are placed in the concrete slab at variable locations. Attached is a document showing the location and depths at which the different items are placed in slab AB. Along the A side of the slab different sized rebar are located at two different depths. Several rebar are stacked on top of one another to see if the bottom layer can be located or if just the top layer is visible.

In order to simulate delamination in the concrete slab, a plastic bag is situated along the B side of the slab as well as card boards which are located at different depths inside the slab. A plastic bottle is included to simulate a void in the concrete, but as the concrete was leveled managed to make its way to the surface. This leaves the bottle not in the original location that it was placed in but just under the surface. Ping pong balls are also used to simulate voids, but had the same situation as the plastic bottle with the locations changing after they were placed.

Test Slab CD

This test specimen is constructed the same as the previous slab with the only changes being what material is added to simulate "defects." The properties for this slab were not tested, but the same mix design was ordered. This specimen has several sensors including thermo wire to detect the temperature at several different depths. These depths should be just under the surface and two and four inches from the surface at the center of the slab. This specimen also has two imbedded humidity sensors. One is placed near the center and the other is near the edge. The relative humidity was measure to be 93.5% with a temperature of 19.2 degrees Celsius. The relative humidity was measured with a HM44 at 4 days after casting.

Attached document shows where the different items are located in the concrete slab. Along the C side of the slab a piece of scrap wood is located. A corroded steel plate was also included to simulate distressed steel as well as an uncorroded steel plate for reference. Finally a couple of odd pieces of metal are placed in the slab.

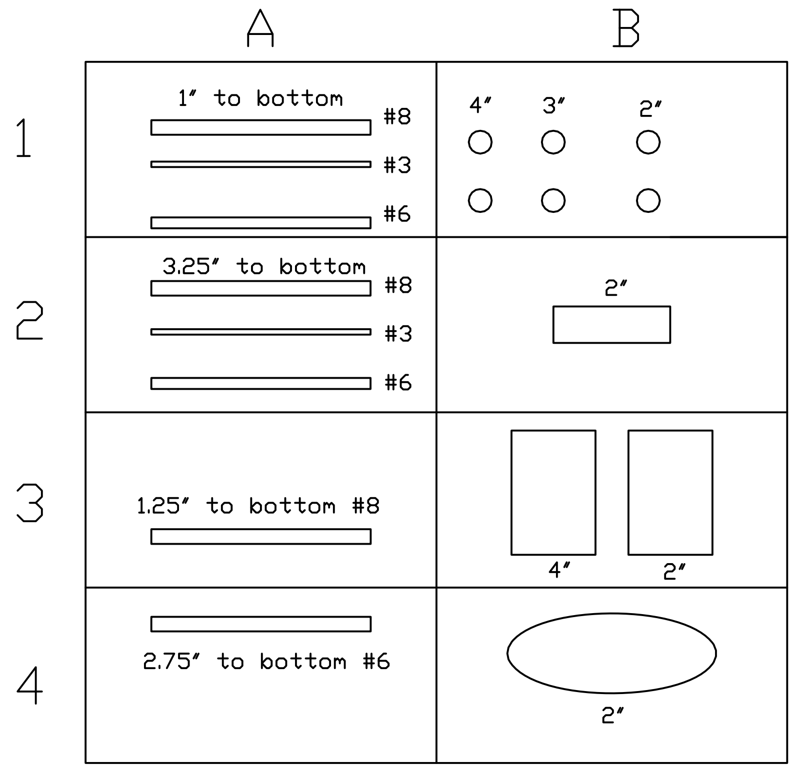
On the D side of the slab are a segment of epoxy coated #3 rebar along with a segment of regular #3 rebar for comparison. Two different sized pieces of Styrofoam are placed at two different depths. The Styrofoam was used to simulate a void in the concrete. A piece of plastic is placed about an inch below the surface to simulate a delamination in the concrete. This likely moved once more concrete was placed in the slab to finish the surface.

Attached:

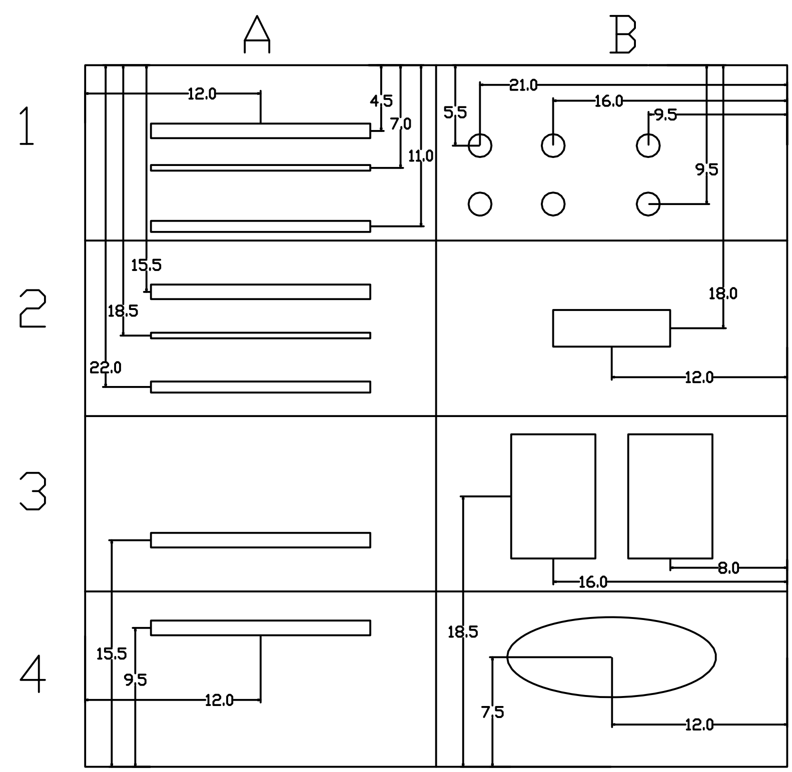
Final Concrete Slab AB Layout

Final Concrete Slab CD Layout

Final Concrete Slab Layout for AB



Vertical measurements from the bottom of the slab



Horizontal measurements in inches

The slab was made into a grid pattern like the one shown. Each grid space is approximately 1 ft by 2 ft. The labeling of the grid was done as shown so locations can be referred to as A2 or B4 for easy reference. The top slab shows the depths of the items in the slab while the bottom one shows the horizontal location from the outside of the slab.

A1: Three rebar which were #3, #6 and #8 were placed at the same level. Rebar were 15" in length.

A2:Three rebar which were #3, #6 and #8 were placed at the same level.

A3 and A4: A #6 bar was placed directly above a #8 bar.

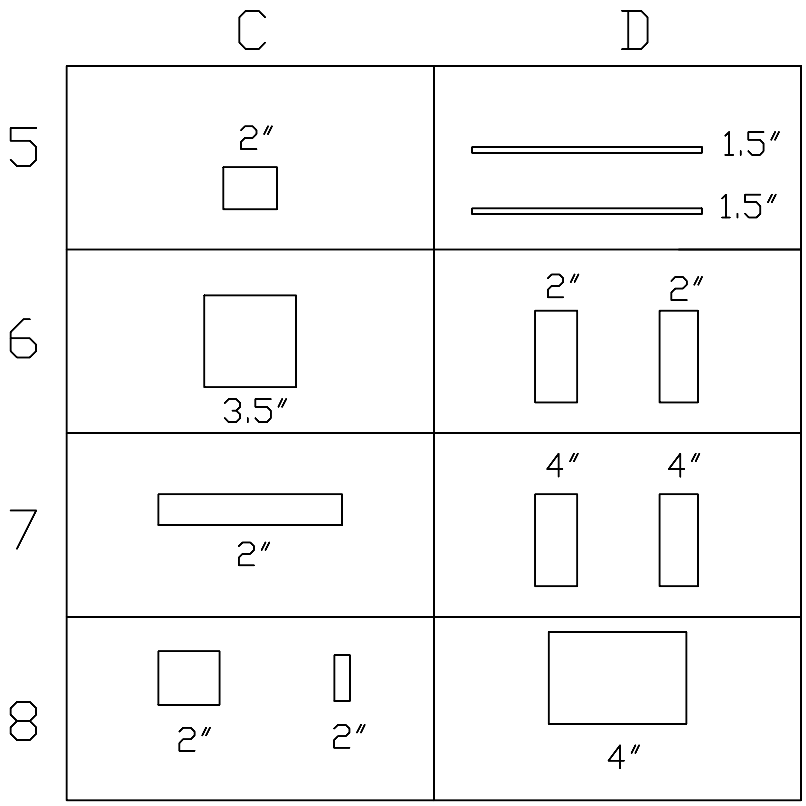
B1: 6 Ping pong balls were placed at different locations which probably don't correlate with the actual position. Diameter was 1.57".

B2: Plastic 16 fluid once bottle that floated to just under the surface. Diameter 2.5" x 8" in length.

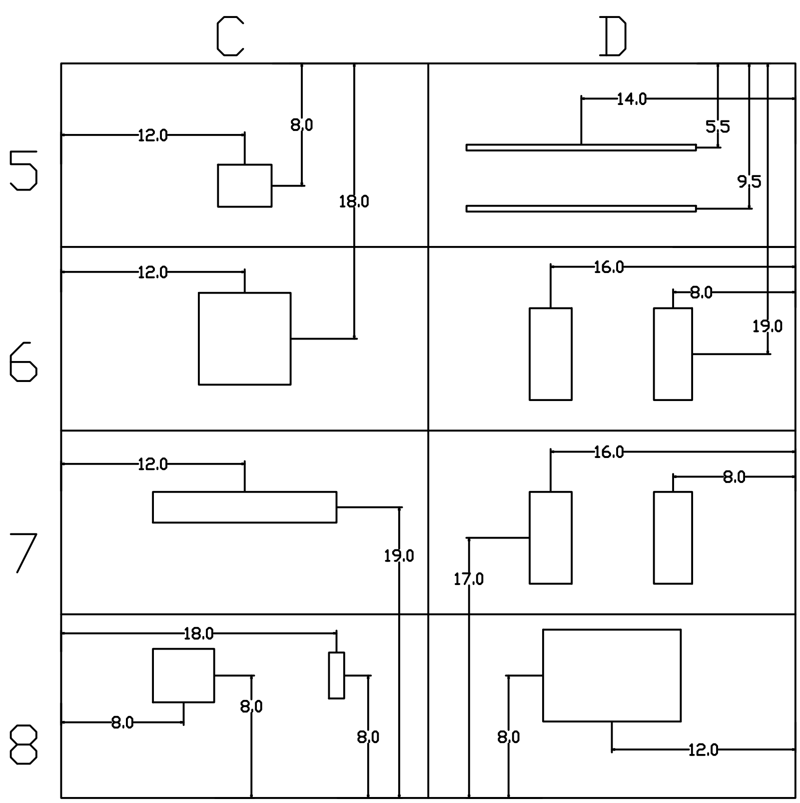
B3: Cardboard placed at two different depths. Dimensions are 5.75" x 8.5" and 0.05" thick.

B4: Plastic shopping bag approximately 7"x 15" and 0.003" thick.

Final Concrete Slab Layout for CD



Vertical measurements from the bottom of the slab



Horizontal measurements in inches

The slab was made into a grid pattern like the one shown. Each grid space is approximately 1 ft by 2 ft. The labeling of the grid was done as shown so locations can be referred to as C5 or D7 for easy reference. The top drawing shows the depths of the items in the slab while the bottom one shows the horizontal location from the outside of the slab.

C5: A piece of wood 3.5" x 2.75" and 1.5" thickness.

C6: A corroded plate 6" x 6" and .25" thickness. This plate also has a piece that extended to the bottom directly underneath of it.

C7: Contains a metal bar 2" x 12" and 1/8" thick. It has several holes along its length.

C8: Galvanized scrap metal 4" x 3.5" with 1.5" sides sticking up along two sides. The other piece of scrap metal was 1" x 3" and 0.5" thick with a hollow area in the center.

D5: This included 2 # 3 rebar one which was epoxy coated and the other one wasn't. The epoxy coated one was closest to the edge.

D6 and D7: Two different size pieces of Styrofoam with the larger one being closest to the outside edge. The smallest is 2.75" x 6" and 5/8" thickness. The larger one is 2.5" x 6" and 1.5" thick.

D8: Plastic bag shopping bag. With dimensions approximately 6" by 9" and 0.003" thick.