INSPIRE

INSPECTING AND PRESERVING INFRASTRUCTURE THROUGH ROBOTIC EXPLORATION

Hyperspectral Image Analysis for Mechanical and Chemical Properties of Concrete and Steel Surfaces

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August 14, 2018

Outline of This Presentation

- Introduction
- Hyperspectral Imaging
- Dual VNIR-SWIR Camera
- Laboratory Tests
- Preliminary Tests of Three-span Bridge
- Experimental Plan for Future Tests
- Concluding Remarks

Introduction

- **Bridge Deterioration (2017 ASCE Report)**
  - ➢ **39% and 15% of 614,387 bridges in the U.S. are more than 50 years and 40 to 49 years, respectively.**
- **Main Cause of Deterioration**
  - ➢ **Steel corrosion**
  - ➢ **Monitoring and prevention**
    - ✓ ***Half-cell potential measures the potential difference between steel and reference electrode.***
    - ✓ ***Corrosion can be prevented by introducing cathodic protection.***

https://www.pressherald.com/2016/10/11/bath-viaduct-project-begins-to-divert-traffic-for-months/

https://metallisation.com/applications/ cathodic-protection-of-steel-in-concrete/

Introduction

- **The current practice of visual inspection is time-consuming, traffic disruptive, and subjective, leading to inconsistent reporting.**
- **A hyperspectral camera can potentially supplement visual inspection with quantifiable and reliable imagery.**
  It can be used to characterize physical and chemical features (e.g., concrete crack and steel corrosion).

Introduction

- **Applications of hyperspectral imaging in construction materials and structures are limited.**
- **Most researches focused on recycled concrete aggregate control, concrete drilling core, concrete compressive strength.**
- **Corrosion and carbonation induced concrete degradation has never been systematically studied before.**

INTRODUCTION

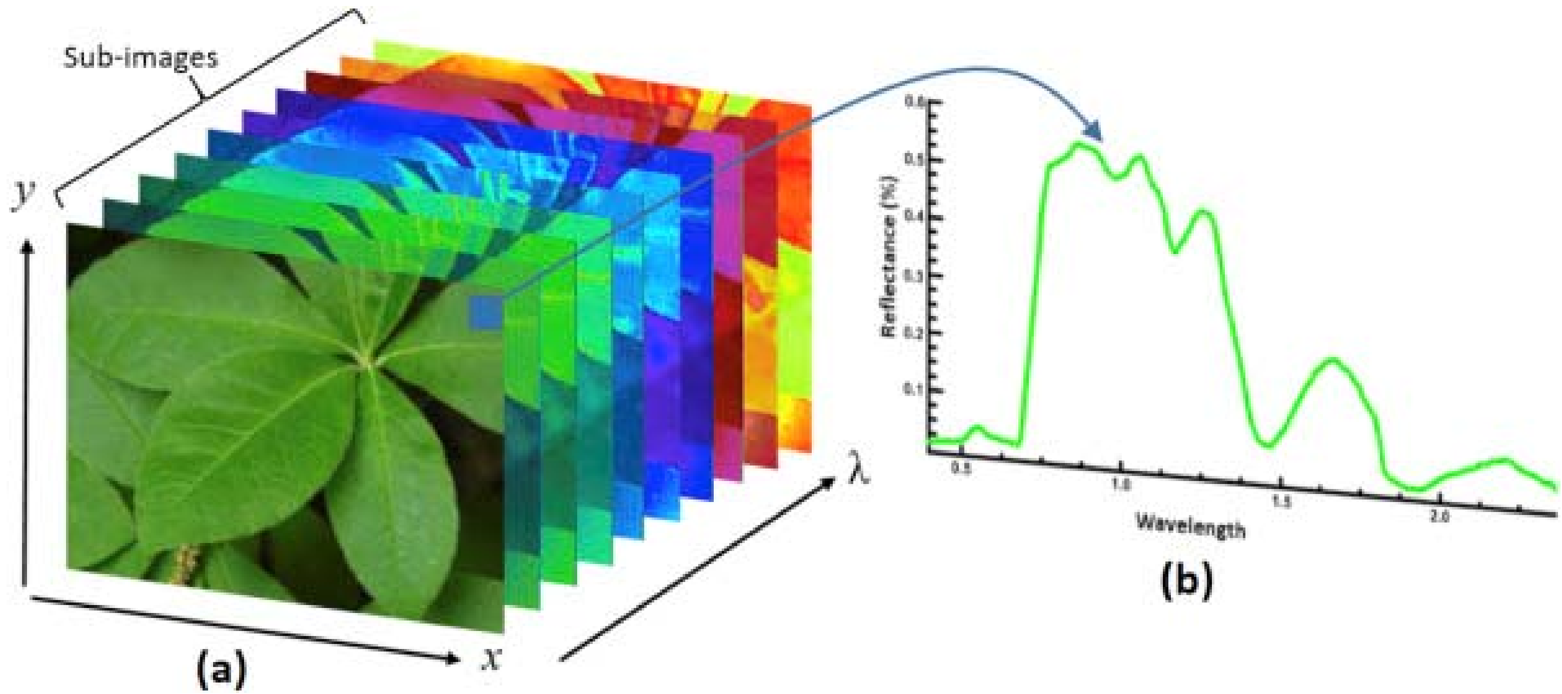
- This project aims to
  - Develop an open-source catalogue of concrete and steel surfaces and their spectral/spatial features through hyperspectral imaging.
  - Develop/train a multi-class classification or regression classifier through machine learning.
  - Validate the classifier as a decision-making tool for the assessment of concrete crack and degradation processes, in-situ concrete properties, and corrosion process in steel bridge.

Hyperspectral Imaging

- **The Method**
  - Hyperspectral imaging is based on light reflectance from an exposed surface (long and narrow like a 'line') of concrete or steel members. As a hyperspectral camera moves in a direction perpendicular to the 'line', the entire surface of a structural member can be scanned. For each pixel in the scanned area, spectral analysis is made to determine spectral signatures of the scanned surface, such as characteristic wavelength at absorption peaks. These features, uniquely associated with certain materials/chemical bonds, can be used to identify the chemicals generated during corrosion process.

Hyperspectral Imaging

- **Example Images in Agriculture Application**



https://www.google.com/search?q=hyperspectral+imaging+principle&client=firefox-b-1-ab&tbm=isch&source=iu&ictx=1&fir=YPRSxCEbscaj7M%253A%252C9FJ4kfE_mrjmRM%252C_&usg=AFrqEzd1XFXXtgMYq7hoTH_rVWInuIl71w&sa=X&ved=2ahUKEwiqrNqMoubcAhVSjqQKHfJSC7gQ9QEwBXoECAUQBg#imgrc=_UStnno6WrlxWM:

Hyperspectral Imaging

- **The Flowchart of Structural Condition Assessment with Hyperspectral Imaging**

Camera setup at optimal measurement distance

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Imaging as camera moves at constant speed

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Hyperspectral image processing with reflectance calibration

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Machine learning for interesting feature extraction

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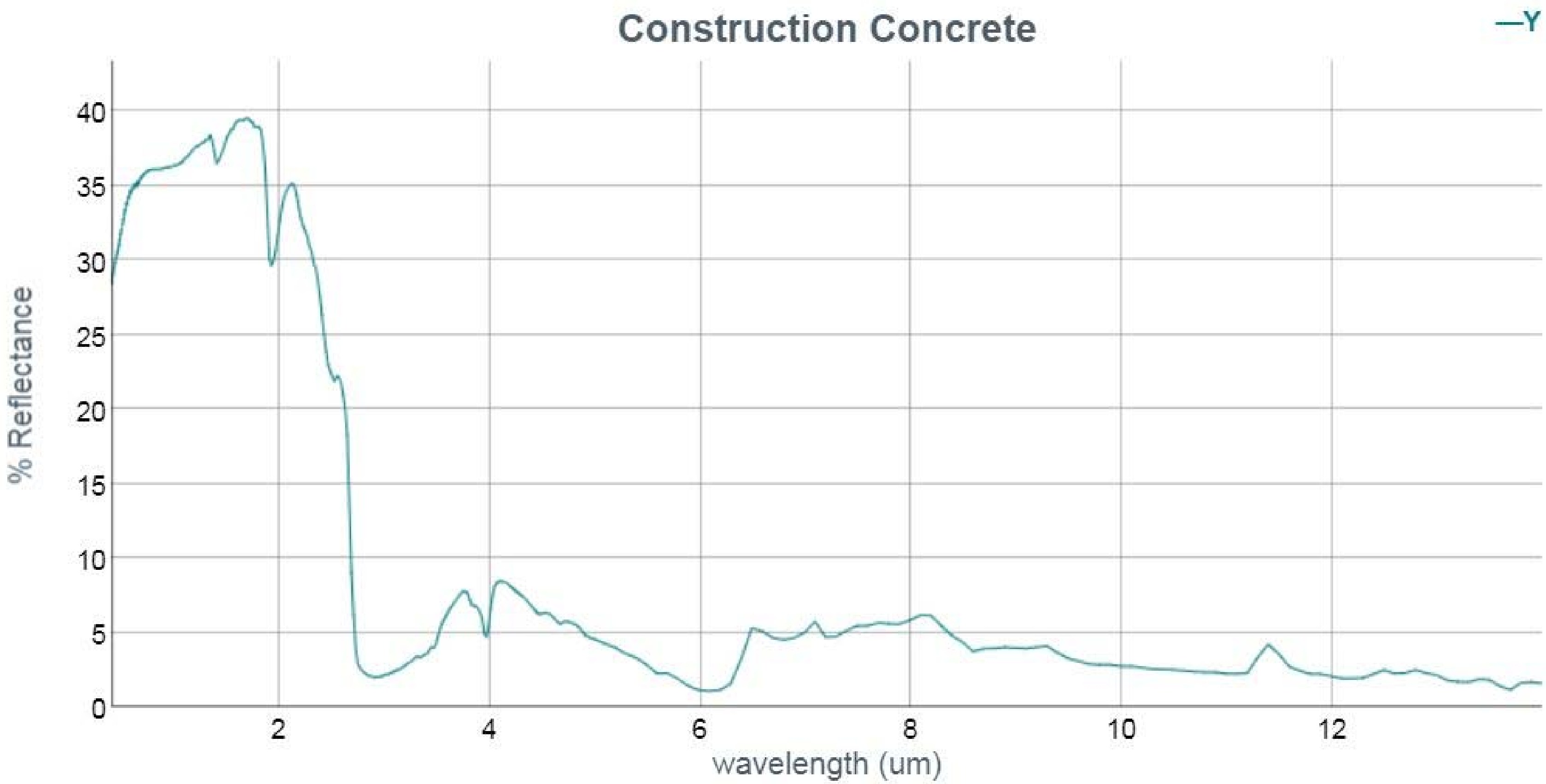
Classification of structural condition from reference imagery

Hyperspectral Imaging

- **Characteristic Spectral Feature of Various Types of Materials (from Jet Propulsion)**



Co-aligned Dual VNIR-SWIR Camera

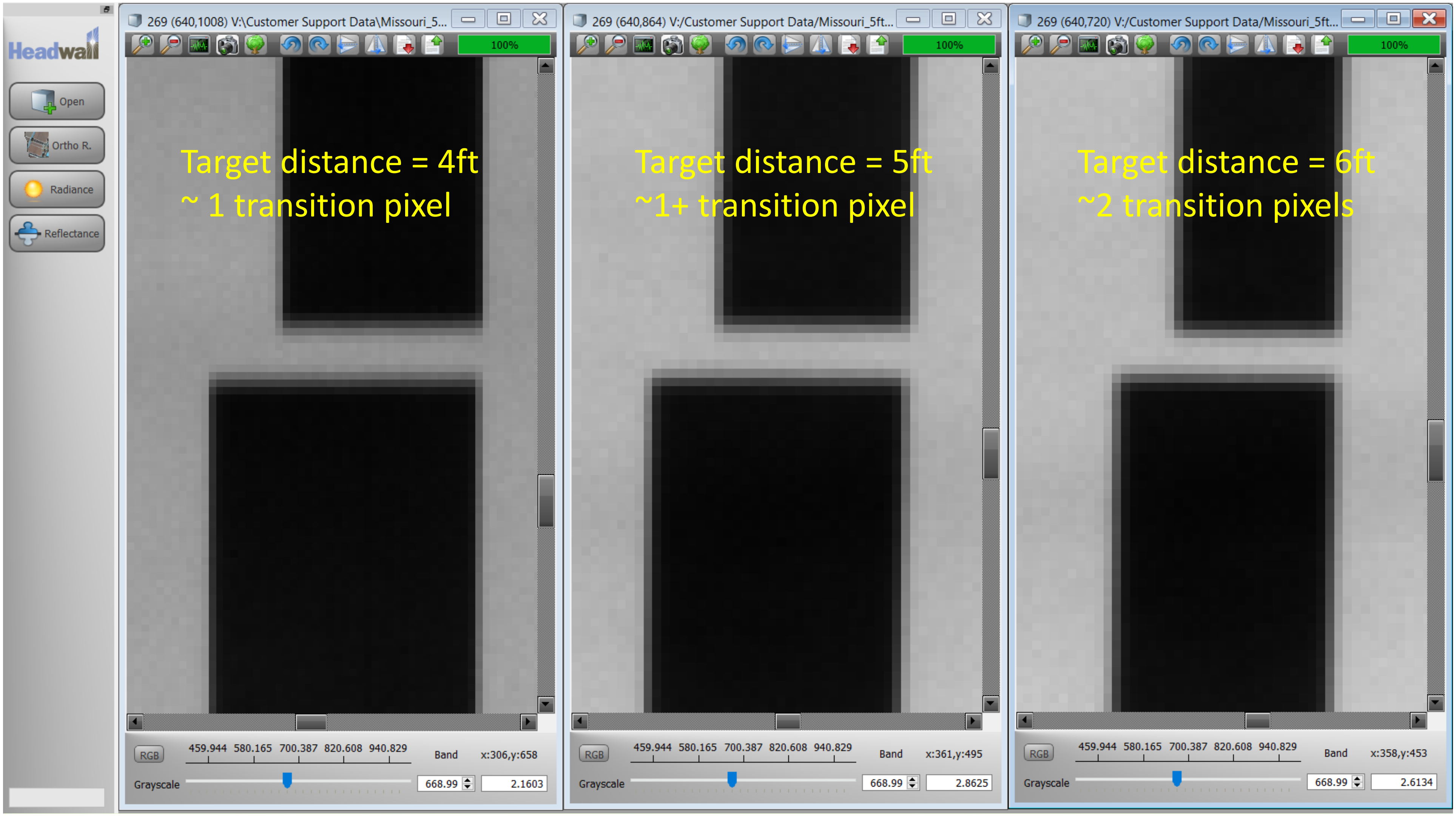
- **Specifications**
  - **The airborne sensor package measures approximately 10.7” x 8.2” x 6.5” in size and weighs approximately 6.25 lb.**
  - **Spectral range**
    - ✓ ***400-1000 nm (VNIR)***
    - ✓ ***900-2500 nm (SWIR)***
  - **Max frame rate**
    - ✓ ***330 Hz (VNIR)***
    - ✓ ***>100 Hz (SWIR)***

Co-aligned Dual VNIR-SWIR Camera

- **Focus Distance Selection**
  - Focus of imagers set at 4 ft. NOTE: airborne lenses are designed for infinity focus.
  - Hyperspectral scans of high contrast targets taken at 4 ft, 5 ft and 6 ft
  - Images zoomed in to show the quality of focus at vertical edges
  - Metric: best focus = 1 transition pixel from white to dark
  - VNIR images show "good" focus for 4 ft, 5 ft and a little worse for 6 ft
  - SWIR images show a quicker loss of focus than VNIR. For sharp SWIR imagery, it is recommend to remain within 6" of optimal focus distance.

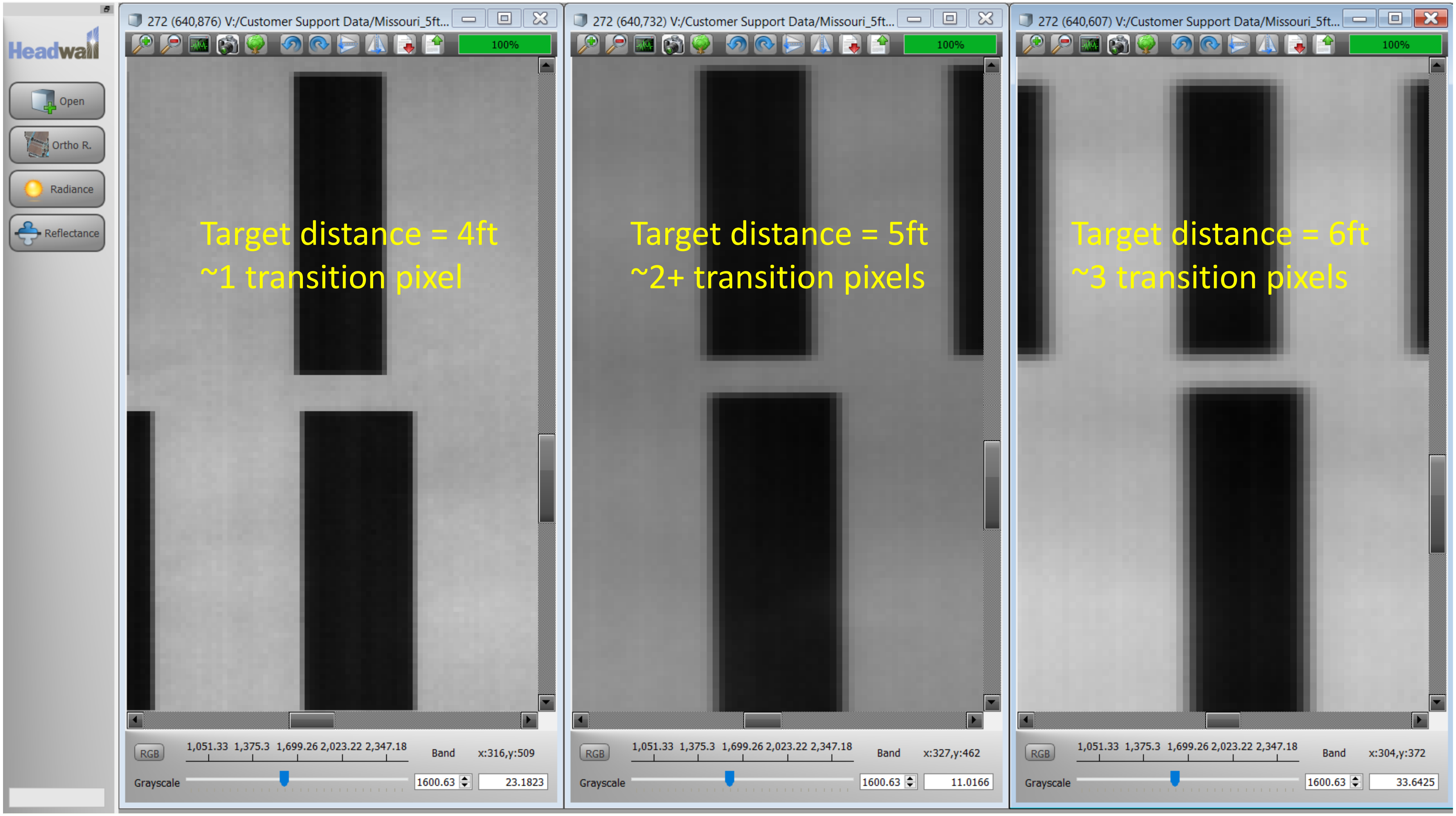
Co-aligned Dual VNIR-SWIR Camera

- **VNIR Lens Focused at ~4 Ft**



Co-aligned Dual VNIR-SWIR Camera

- **SWIR Lens Focused at ~4 Ft**

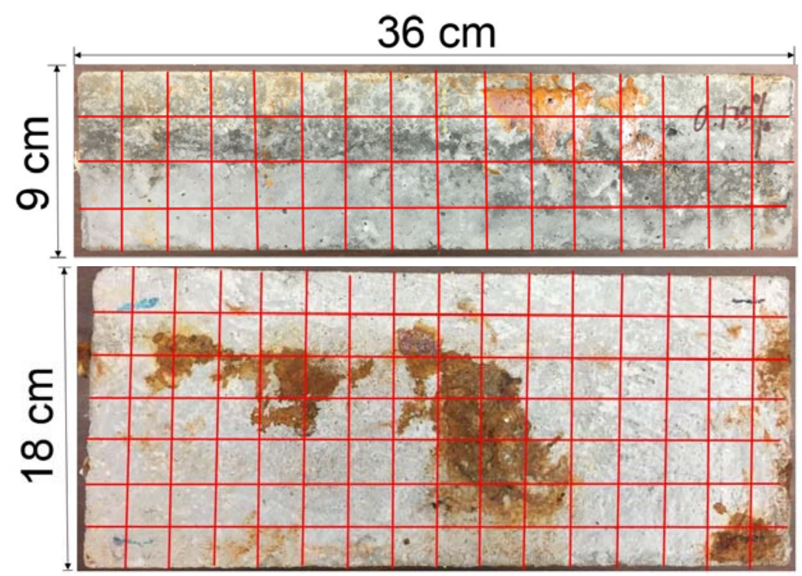


Laboratory Tests

- **Corrosion Test Setup**
  - The bottom ¼ height of each 36 cm × 18 cm × 9 cm specimen was immersed in salt solution.
  - Accelerated corrosion test was carried out by applying a constant current to steel bars with a current density of 500 μA/cm^2 until the mass loss of the steel bars reached 2%.
  - Steel bars with impressed current were corroded, resulting in concrete cracking and appearance of corrosion dust due to increasing volume of corrosion products.

Laboratory Tests

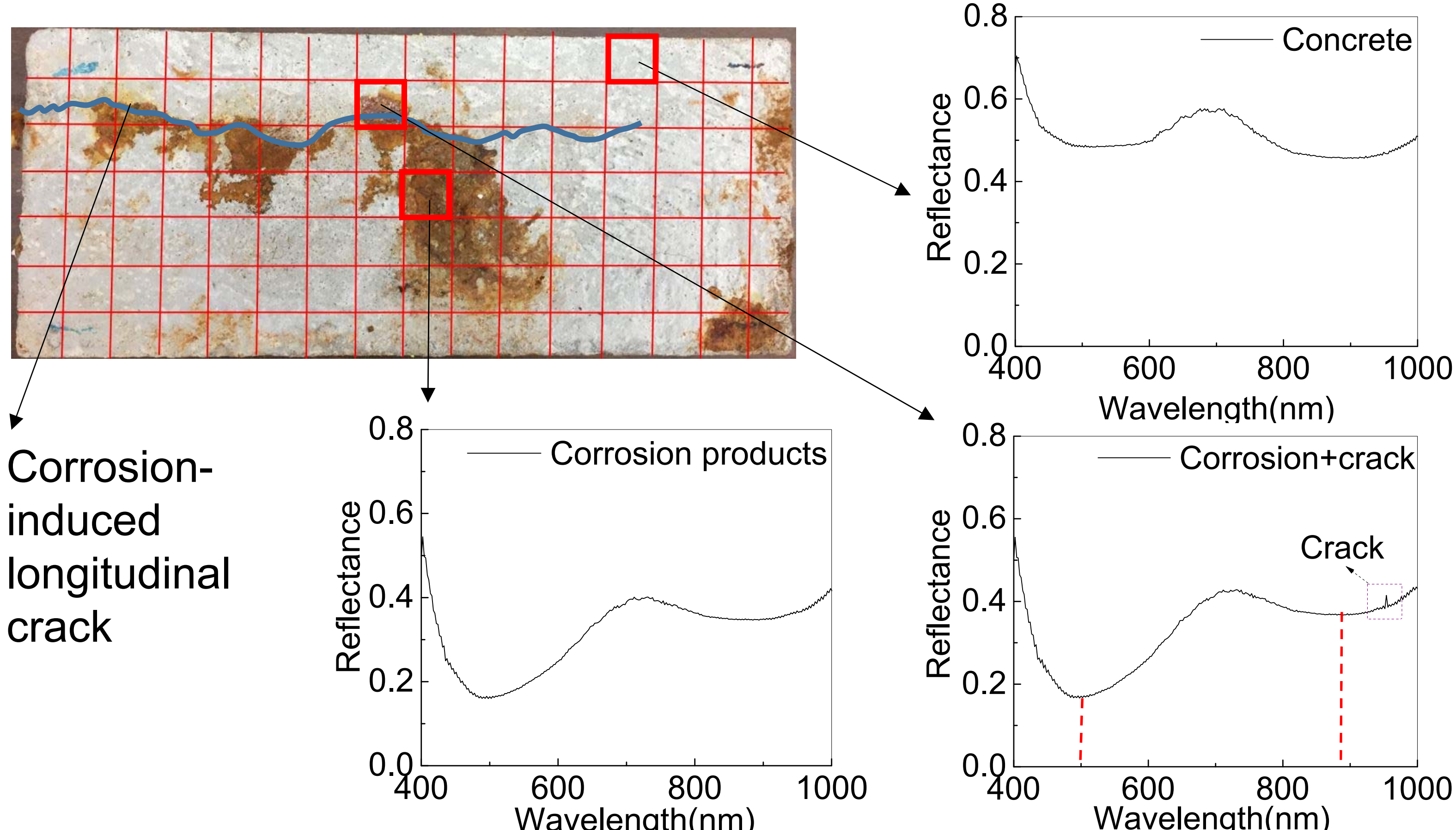
- **Hyperspectral Imaging Setup with a VNIR Camera**
  - **The camera was set up 2 m above the concrete specimens.**
  - **The camera scanned at a constant speed of 0.127 m/s.**
  - **For the VNIR camera, both the exposure time and the frame period are 0.167 s.**



Pixel size ≈ 2.25 cm

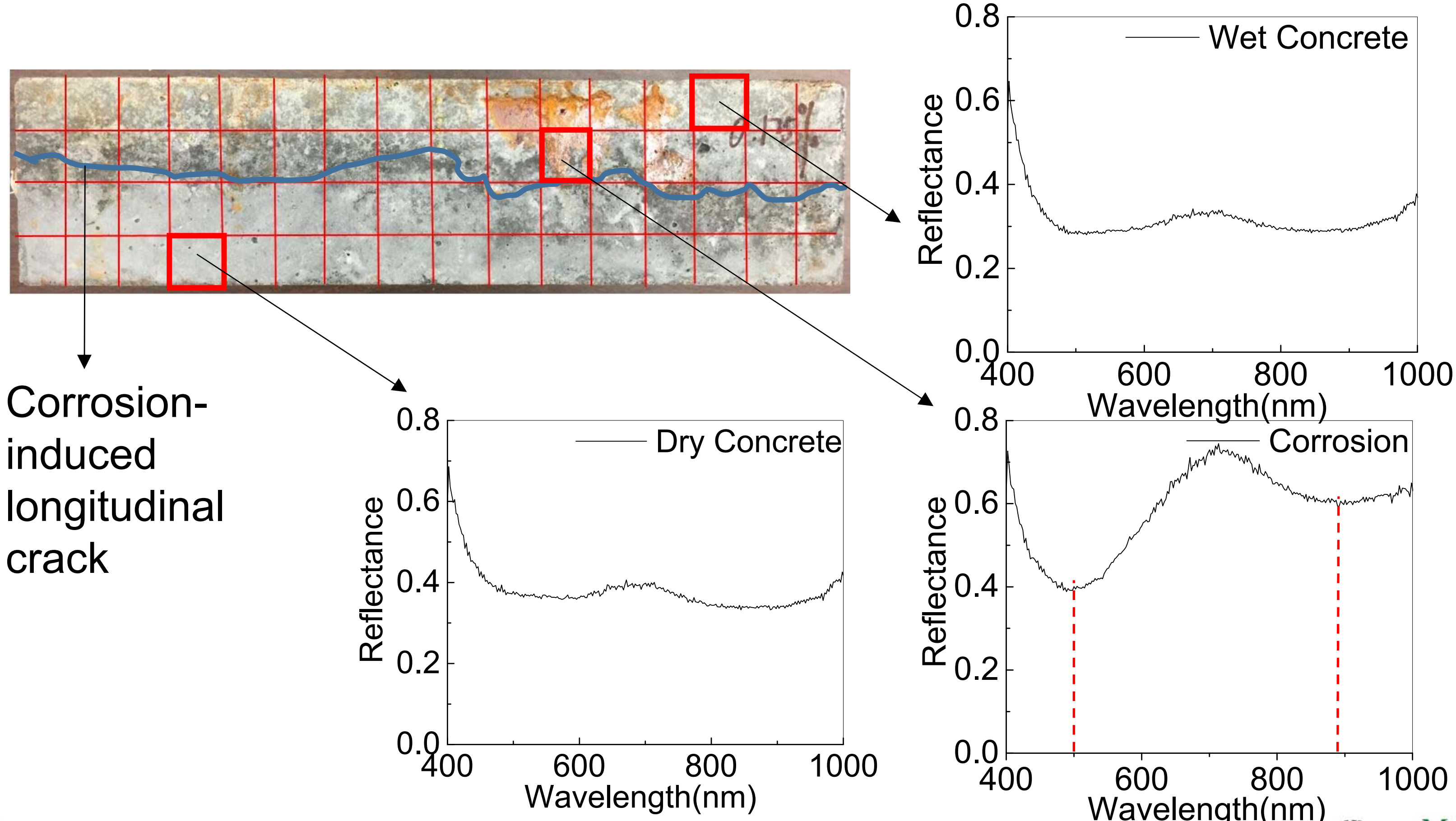
Laboratory Tests

- **Reflectance Spectra of Representative Pixels on the Top Surface of Specimen**



Laboratory Tests

- **Reflectance Spectra of Representative Pixels on the Side Surface of Specimen**



Laboratory Tests

- **Reflectance Summary at Characteristic Wavelengths**
  - **Top surface**

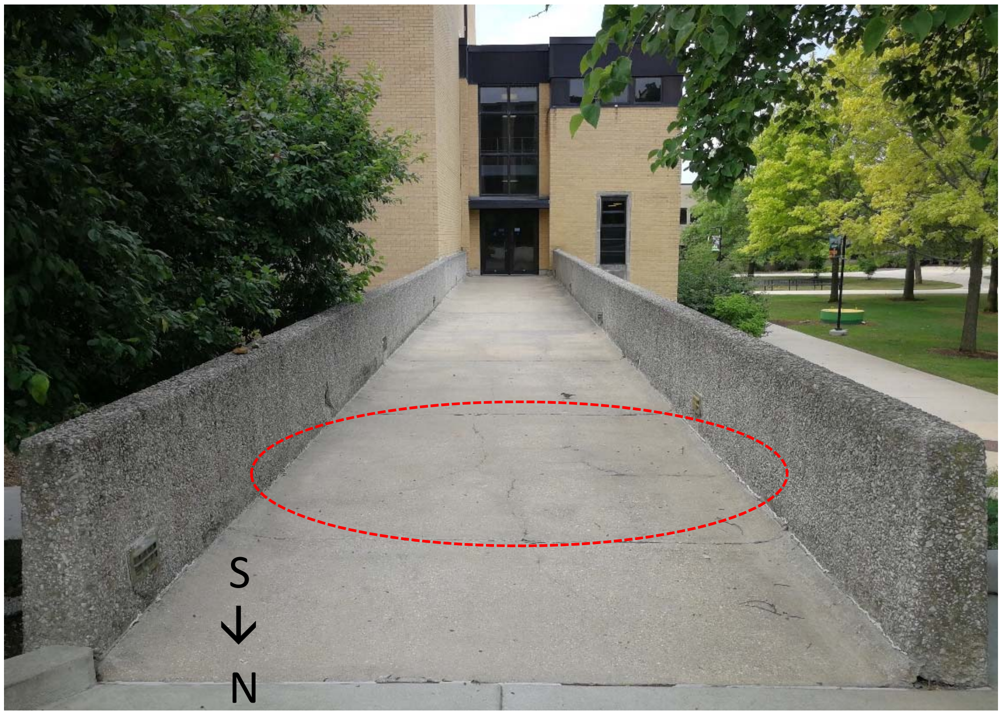
Reflectance / Wavelength	Concrete	Corrosion Products
510 nm	0.48	0.16
890 nm	0.46	0.35

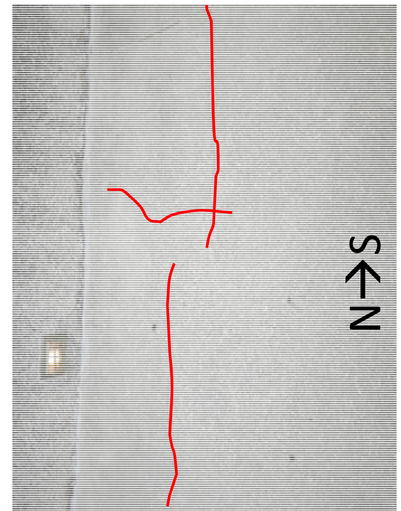
  - **Side surface**

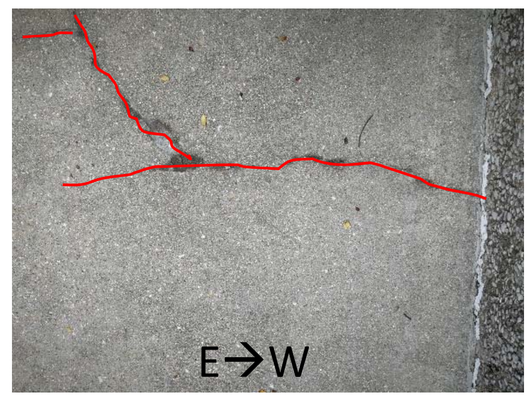
Reflectance / Wavelength	Dry Concrete	Wet Concrete	Corrosion Products
510 nm	0.37	0.28	0.39
890 nm	0.33	0.29	0.59

Three-span Pedestrian Bridge

- **Visual Inspection on Top Deck Surface**
  - ➢ **Cracks observed**

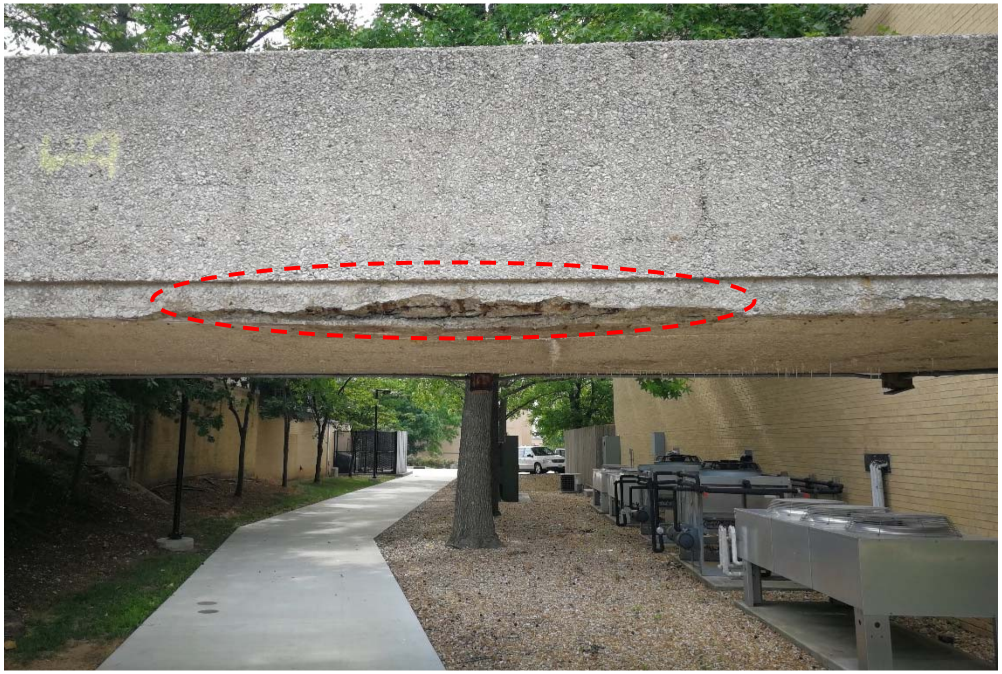


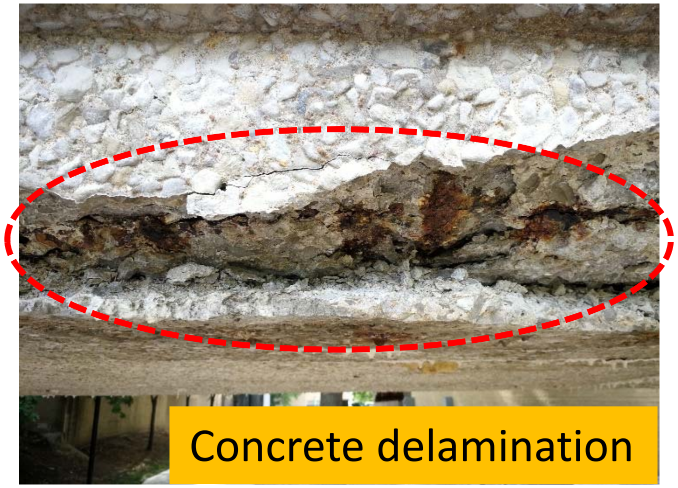




Three-span Pedestrian Bridge

- **Visual Inspection on Mid-span of the Bridge with Severe Deterioration**

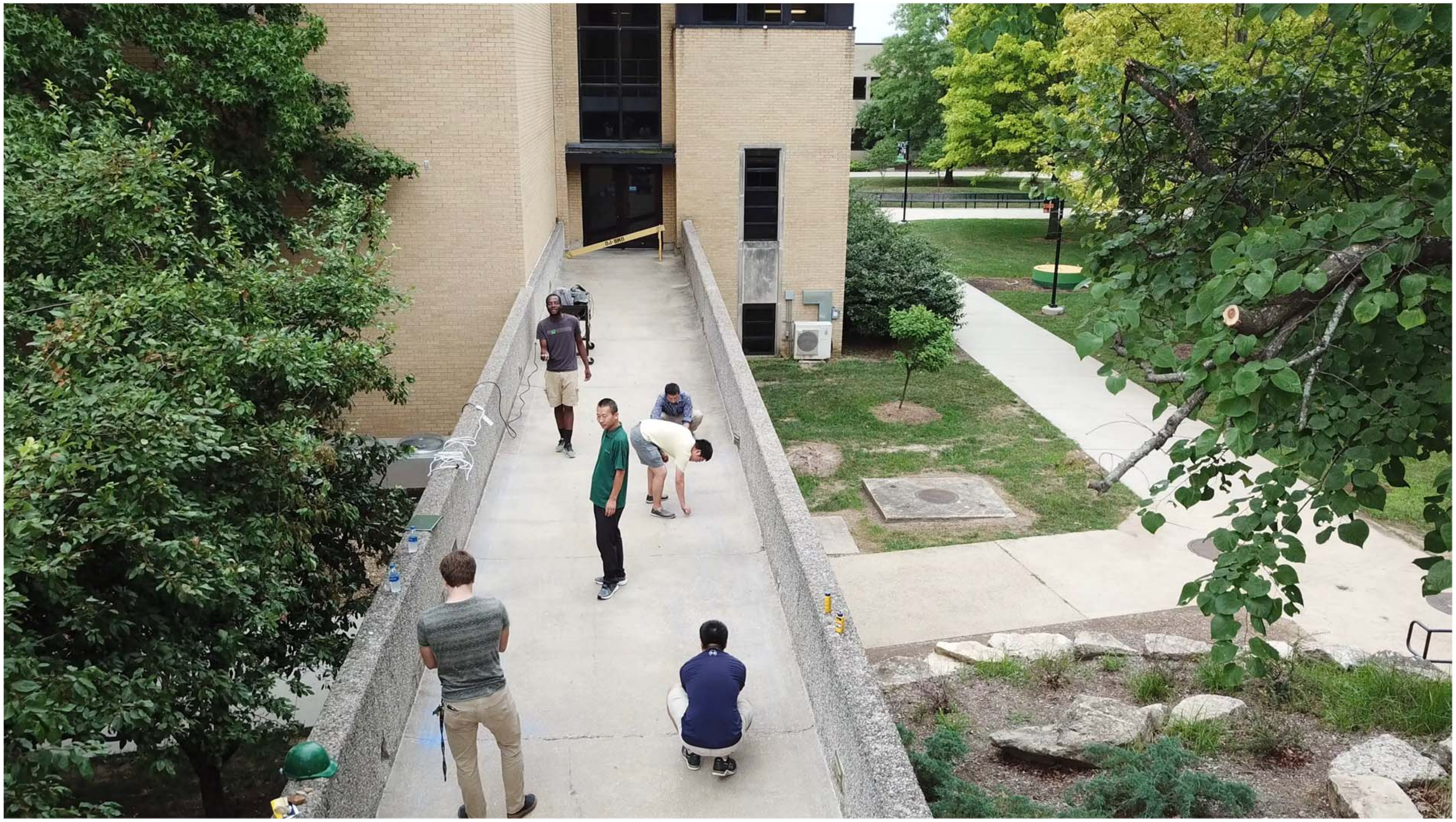




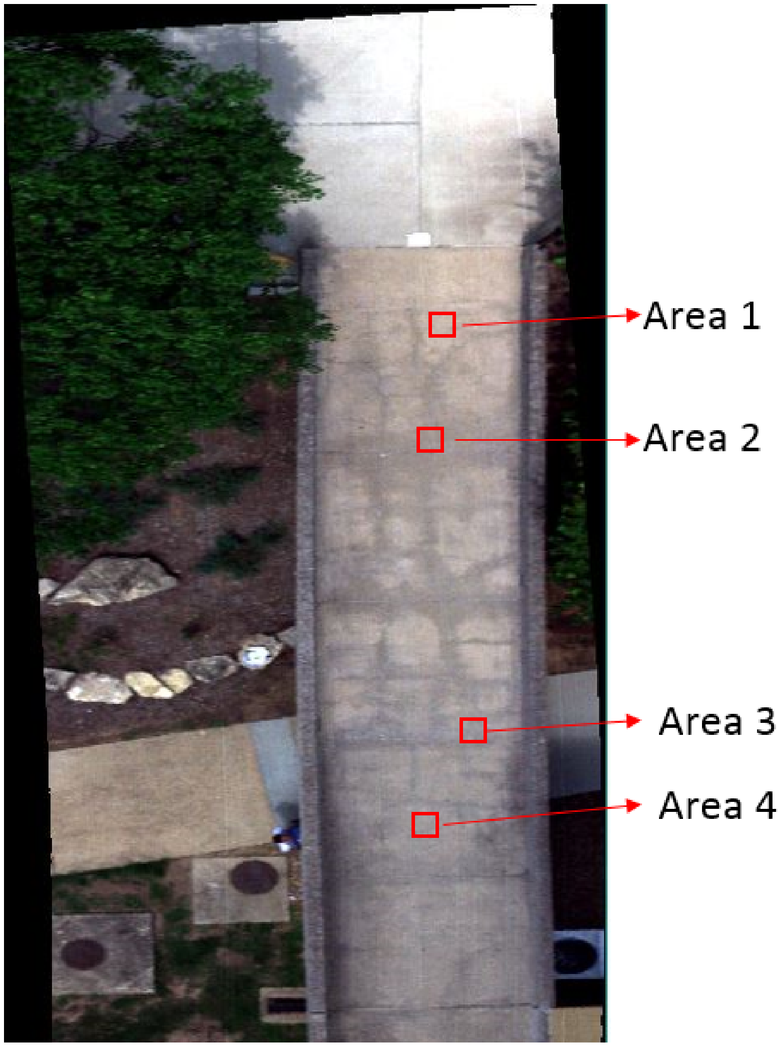
Bottom-up view

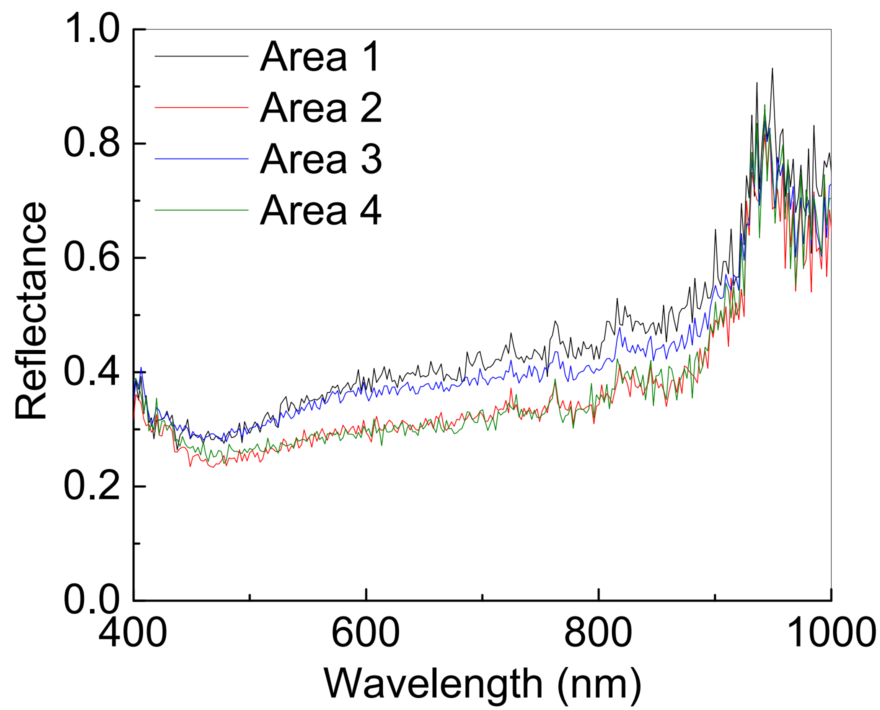
Three-span Pedestrian Bridge

- **Bridge Deck Markup for Nondestructive Tests**



Preliminary Tests of the Bridge





The pixel size is approximately 15 cm.

Experimental Plan

- **Influence of Key Operation Parameters**
  - Determine the pixel sizes corresponding to various measurement distances and the optimal exposure time and frame rate.
  - Evaluate the detection precision and sensitivity using standard samples with known material composition and grain sizes.
  - Compare reflectance spectra from various samples to understand the influence of the parameters under investigation.

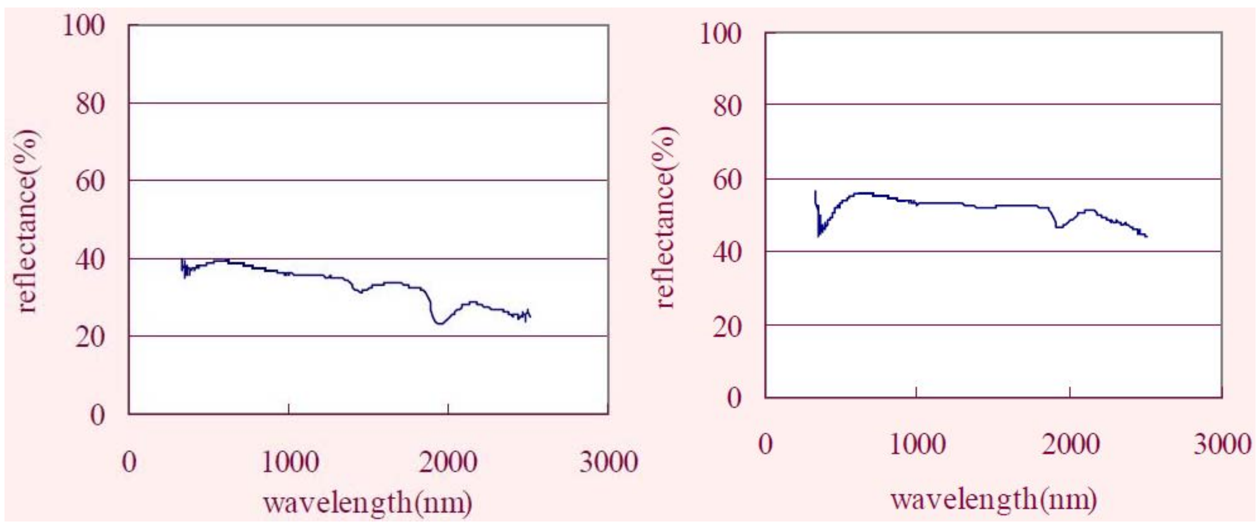
Experimental Plan

- 1st Set of Tests
  - Small plain concrete slabs with various water-to-cement ratios of 0.4, 0.5, and 0.6 will be cast and cured for 28 days, and subjected to carbonation for various exposure periods (thus carbonation depths).
  - Hyperspectral image will be taken, and the depth of carbonation will be determined by phenolphthalein.
  - The surface reflectance spectra at each pixel of an image will be related to the extent of carbonation.

Experimental Plan

- **Concrete Degradation due to Carbonation**
  - **Normal concrete contains 25% of calcium hydroxide ($Ca(OH)_2$), while carbonated concrete generates calcium dioxide ($CaCO_3$).**
  - **Absorption peak around 1450 nm in normal concrete is hardly seen in degraded concrete.**

Normal concrete

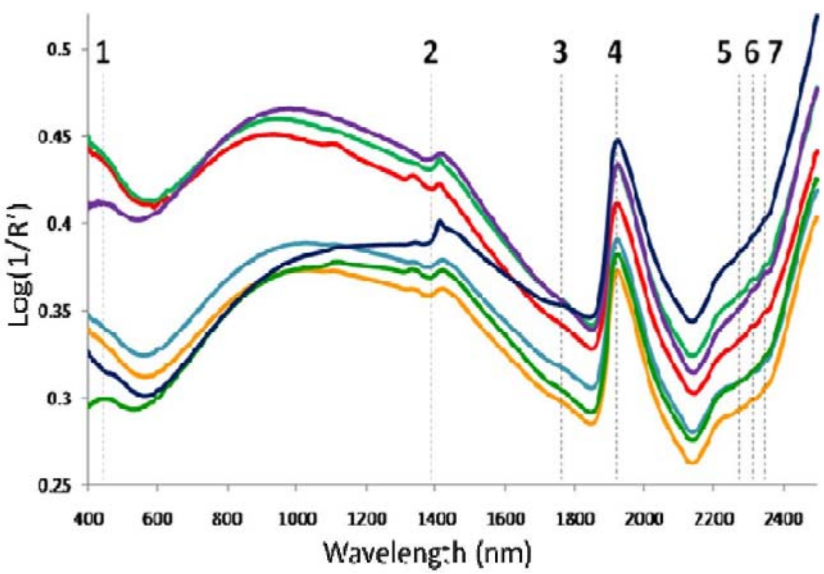


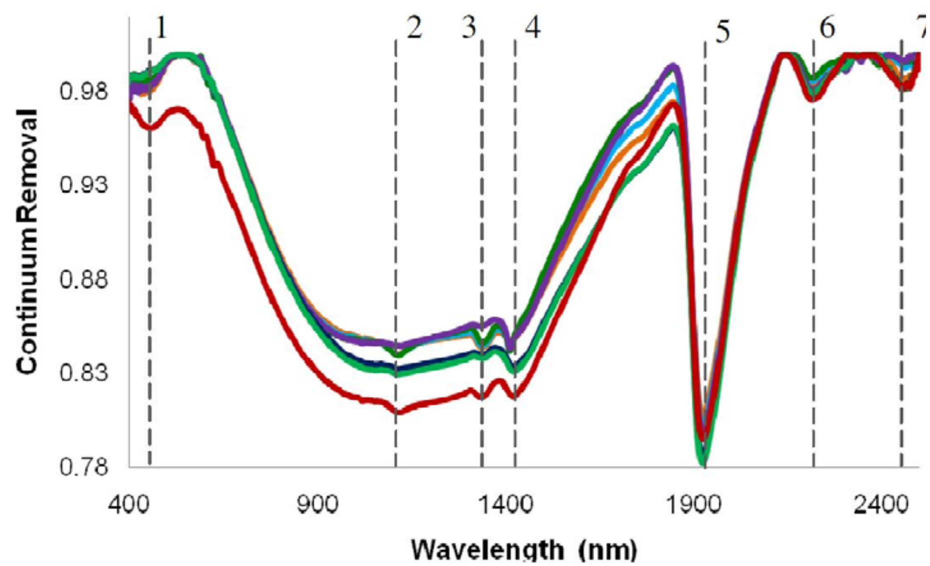
Concrete degraded by CO_2

Arita, Jun, et al. "Assessment of concrete degradation with hyperspectral remote sensing." 22nd Asian Conference on Remote Sensing, Vol. 5. 2001.

Experimental Plan

- **Concrete Ingredients**
  - **Processed with different algorithms at various curing ages (0,1, 3, 5, 7, 14, and 28 days):**
    - ✓ ***1: 460 nm-iron oxide; 2: 1400 nm – hygroscopic water***
    - ✓ ***3: 1780 nm – hardener; 4: 1930 nm – liquid water***
    - ✓ ***5: 2225 nm – clay; 6: 2309 nm – calcium***
    - ✓ ***7: 2395 nm – hardener***





Experimental Plan

- 2nd Set of Tests
  - Steel reinforcing bars embedded in slab specimens will be impressed with electrical current to attain various levels of corrosion.
  - The reflectance spectra will be obtained during the whole accelerated corrosion tests.
  - The reflectance spectra obtained on the surface of the slabs will be related to the degree of steel corrosion (chemical change on the surface of the specimens).

Experimental Plan

- Main spatial and spectral features will be extracted from the obtained images. The imagery will be divided into a large training set and a small validation set.
- Hyperspectral imaging classification models will be built based on the training set and verified by the validation set.

Concluding Remarks

- **Hyperspectral imaging obtains a reflectance spectrum of each pixel to characterize physical defects or chemical features of structural degradation.**
- **Preliminary tests indicated different characteristic wavelengths at location of wet/dry concrete, corrosion rust, and crack.**
- **The characteristic features can be mapped over the entire area of an image to understand the degradation extent of specimens.**
- **Classification models can be built to predict the degree of concrete degradation.**

Acknowledgement

- Financial support for this INSPIRE UTC project is provided by the U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology (USDOT/OST-R) under Grant No. 69A3551747126 through INSPIRE University Transportation Center (http://inspire-utc.mst.edu) at Missouri University of Science and Technology. The views, opinions, findings and conclusions reflected in this publication are solely those of the authors and do not represent the official policy or position of the USDOT/OST-R, or any State or other entity.