INSPIRE University Transportation Center
2020 Annual Meeting | August 3-4, 2020
Teleconference

MONDAY, AUGUST 3	
Time	**Event**
9:20 am – 9:30 am	**Welcome**
9:30 am – 11:30 am	**Technical Presentations: Sensing and Nondestructive Evaluation**
Dr. Chuanrui Guo	SN-3: IN-LINE LONG PERIOD GRATING AND BRILLOUIN SCATTERING FIBER OPTIC SENSORS FOR STRAIN, TEMPERATURE, CHLORIDE CONCENTRATION, AND STEEL MASS LOSS MEASUREMENT IN BRIDGE APPLICATIONS
Dr. Reza Zoughi	SN-4: 3D MICROWAVE CAMERA FOR CONCRETE DELAMINATION AND STEEL CORROSION DETECTION
Dr. Genda Chen	SN-5: HYPERSPECTRAL IMAGE ANALYSIS FOR MECHANICAL AND CHEMICAL PROPERTIES OF CONCRETE AND STEEL SURFACES
Dr. Yang Wang	SN-6: AUTONOMOUS ULTRASONIC THICKNESS MEASUREMENT BY A MAGNET-WHEELED ROBOT
11:30 am – 12:00 pm	**Technical Presentations: Inspection and Maintenance**
Dr. Anil Agrawal	IM-2: QUANTITATIVE BRIDGE INSPECTION RATINGS USING AUTONOMOUS ROBOTIC SYSTEMS
12:00 pm – 1:00 pm	**Technical Presentations: Workforce Development**
Dr. Ruwen Qin	WD-1: A TRAINING FRAMEWORK OF ROBOTIC OPERATION AND IMAGE ANALYSIS FOR DECISION-MAKING IN BRIDGE INSPECTION AND PRESERVATION
Dr. Sushil Louis	WD-2: DEVELOPING A ROBOTIC SIMULATOR AND VIDEO GAMES FOR PROFESSIONAL AND PUBLIC TRAINING
1:00 pm – 2:00 pm	**Graduate Student Poster Session**
2:00 pm – 4:00 pm	**Technical Presentations: Autonomous Systems**
Dr. Paul Oh	AS-1: MOBILE-MANIPULATING UAVS FOR SENSOR INSTALLATION, BRIDGE INSPECTION AND MAINTENANCE
Dr. Hung La	AS-2: CLIMBING ROBOTS WITH AUTOMATED DEPLOYMENT OF SENSORS AND NDE DEVICES FOR STEEL BRIDGE INSPECTION
Dr. Jizhong Xiao	AS-3: AUTONOMOUS WALL-CLIMBING ROBOTS FOR INSPECTION AND MAINTENANCE OF CONCRETE BRIDGES
Dr. Bo Shang	AS-4: BRIDGE INSPECTION ROBOT DEPLOYMENT SYSTEMS (BIRDS)
4:00 pm – 4:30 pm	**Technical Presentation: Retrofit and Resilience**
Dr. Iris Tien	RR-1: BRIDGE RESILIENCE ASSESSMENT WITH INSPIRE DATA

TUESDAY, AUGUST 4	
Time	**Event**
9:30 am – 11:00 am	**Graduate Student Poster Session**
11:00 am – 12:00 pm	Pooled-Fund Study
12:00 pm – 12:30 pm	Poster Awards Ceremony
12:30 pm – 1:00 pm	Semi-Annual Executive Meeting with DOT Members
1:00 pm	Closing Remarks

TECHNICAL PROGRAM

Monday, August 3

9:20 am WELCOME

Dr. Genda Chen
Professor and Robert W. Abbett Distinguished Chair, Director INSPIRE University Transportation Center, Missouri S&T

9:30 am TECHNICAL PRESENTATIONS: SENSING AND NONDESTRUCTIVE EVALUATION

9:30-10:00 am
In-line Long Period Grating and Brillouin Scattering Fiber Optic Sensors for Strain, Temperature, Chloride Concentration, and Steel Mass Loss Measurement in Bridge Applications, Dr. Chuanrui Guo, Missouri S&T

Corrosion is the main reason for costly maintenance of aging transportation infrastructure in the U.S. Since 2008, the PI's group has developed long period fiber grating (LPFG) sensors for point strain and steel mass loss measurements. When attached on a steel bar, a LPFG sensor doped with nano iron/silica particles and polyurethane can monitor the corrosion process of steel. However, the coating of particles with polyurethane was not robust. In addition, chloride concentration is important for the prediction of early corrosion in practice. Compared to grating sensors, Brillouin scattering based sensors have lower spatial resolution but offer a cost-effective solution to the monitoring of large-scale civil infrastructure. Therefore, integrating LPFG sensors into a distributed sensing system for multiple parameter measurements is important in bridge applications. Unlike fiber Bragg grating (FBG) sensors that have been recently applied to civil infrastructure, LPFG sensors and distributed sensing systems are still tested in laboratory. Their packaging is critical in field applications.

This project aims to: (1) Develop a physically and optically protected LPFG strain sensor that is hermetically packaged in a fused silica capillary tube, (2) Develop a Fe-C coated LPFG sensor for life-cycle corrosion monitoring (chloride ion and mass loss) of nearby steel members, (3) Understand how many LPFG sensors of different types and wavelengths can be multiplexed to measure multiple parameters for the monitoring of large-scale bridges, and (4) Understand potential interference between the LPFG sensor interrogation and the pulse pre-pump Brillouin optical time domain analysis (PPP-BOTDA) measurement.

10:00-10:30 am
3D Microwave Camera for Concrete Delamination and Steel Corrosion Detection, Dr. Reza Zoughi, Iowa State University

Corrosion of embedded steel reinforcement in concrete leads to concrete cracking and delamination, followed by increased salt and moisture permeation and further damage. Invisibility of the embedded rebar in combination with physical inaccessibility in elevated bridges presents a challenge in the assessment of RC bridge elements. Wideband (3D) microwave synthetic aperture radar (SAR) imaging techniques that can be integrated into a UAV offer a practical solution to overcome this challenge.

This project aims to develop and optimize a 3D microwave camera for bridge inspection on a UAV platform, quantify its performance for steel corrosion evaluation and concrete delamination detection in reinforced concrete (RC) bridge elements, and build a microwave camera prototype that can be installed on a UAV for field applications.

10:30-11:00 am
Hyperspectral Image Analysis for Mechanical and Chemical Properties of Concrete and Steel Surfaces, Dr. Genda Chen, Missouri S&T

A typical human eye will respond to wavelengths from approximately 400 to 700 nm. A hyperspectral camera can extend the wavelength to as high as 2500 nm. This extension will allow engineers to find objects, identify materials, and detect processes on structural surface, which cannot be done with visual inspection.

This project aims to develop an open-source catalogue of concrete and steel surfaces and their spectral/spatial features (discoloration, characteristic wavelength, roughness, texture, shape, etc.), extract spatial/spectral features of hyperspectral images, and develop/train a multi-class classification or regression classifier through machine learnings (supervised and/or semi-supervised), and 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 bridges.

11:00-11:30 am
Autonomous Ultrasonic Thickness Measurement By a Magnet-Wheeled Robot, Dr. Yang Wang, Georgia Institute of Technology

A wireless sensing device recently developed by PI Wang's group has demonstrated various structural sensing capabilities for bridge applications. In the meantime, a latest robot platform developed by Dr. La's group at the University of Nevada, Reno (UNR) demonstrates promising performance navigating on steel bridge members. Marrying the two state-of-the-art developments, this project will produce a magnet-wheeled robot capable of autonomous nondestructive measurement on steel bridge structures. Both laboratory and field validations will be performed.

This project will integrate advanced wireless sensing technologies to the UNR robot platform. At first, the functionality of ultrasonic thickness measurement will be developed on the mobile platform. The ultrasonic thickness measurement only requires access to one side of an object, and can achieve sub-millimeter accuracy. The technique can be used for corrosion and defect detection, e.g. on the web and flanges of an I-beam. In addition, vibration measurements will be added to the robotic platform as well; potential applications include tension estimation in steel strands of cable-supported structures.

11:30 am TECHNICAL PRESENTATION: INSPECTION AND MAINTENANCE

11:30 am-12:00 pm
Quantitative Bridge Inspection Ratings Using Autonomous Robotic Systems, Dr. Anil Agrawal, The City College of New York

The 2001 study sponsored by FHWA raised serious concern on the consistency and reliability of visual inspection. Although consistent ratings can be obtained with a good QA/QC program, based on a recent study by the PI, the concern for reliability of defect detection remains. With the adoption of the recent AASHTO Manuel for Bridge Element Inspection, the new inspection approach not only requires rating for bridge elements, but also the location and extent of deterioration. Since autonomous robotic systems generate an enormous amount of inspection data, deducing from the data to a simple rating along with the location and extent of deterioration is a significant challenge. For example, RABITTM has been used to inspect concrete bridge decks with six devices, including ground penetrating radar (GPR), impact-echo and ultrasonic surface wave. However, the probability of detection (POD) for damage has not been fully demonstrated to be significantly improved using multiple devices.

This project aims to develop new fusion strategies of data collected from multiple NDE devices for improved POD based on further understanding and modeling of damage detection mechanisms, and to develop algorithms for the derivation of bridge ratings from identified damage and visual inspection findings.

12:00 pm TECHNICAL PRESENTATIONS: WORKFORCE DEVELOPMENT

12:00-12:30 pm
A Training Framework of Robotic Operation and Image Analysis for Decision-Making in Bridge Inspection and Preservation, Dr. Ruwen Qin, Missouri S&T

Inspection and preservation of existing transportation infrastructure to extend their service life is an effective way of mitigating the pressure of steadily growing transportation demands on the aging infrastructure. Their current practice, though, represents one of the most costly operations in state departments of transportation.

The INSPIRE University Transportation Center will develop a remotely-controlled robotic platform that helps with these labor-intensive tasks and allows engineers to focus on decision-making processes. An important mission of INSPIRE is to leverage users' capability of implementing, and interacting with, the robotic platform. Therefore, a long-term plan has been made to create a framework of training engineers and policy makers as well as new workforce on robotic operation and image analysis for the inspection and maintenance of transportation infrastructure. The proposed project, as a component of the plan, involves the prototyping of such a framework based on camera-based bridge inspection and robot-based maintenance.

The overall goal of the project is to create a framework of training engineers and policy makers on robotic operation and image analysis for the inspection and preservation of transportation infrastructure. Specifically, the project aims to (1) provide the method for collecting camera-based bridge inspection data and the algorithms for data processing and pattern recognitions; and (2) create tools for assisting and training users on visually analyzing the processed image data and recognized patterns for inspection and preservation decision-making.

12:30-1:00 pm
Developing a Robotic Simulator and Video Games for Professional and Public Training, Dr. Sushil Louis, University of Nevada, Reno

Civil engineers are not educated with robotics. They need to be trained on the job with effective tools. The most recent simulation trainer that the PI has built is currently being used by the United States Navy to train surface warfare officers in decision making under stress. In a crowded in-port environment, the crew on a ship's bridge is trained to probe and identify suspicious boat behavior within the port's traffic pattern. Officers in charge of the simulation training lesson use software for high-level control of dozens of other ships, boats, and aircrafts that quickly react and adapt to the crewed ship's actions based

on lower-level programmed autonomy and game-like user interaction. Without this virtual "experience," improperly trained crews put lives in danger. Scenarios that would be catastrophic in reality can also be simulated and, without this training, especially for recovering from error states, operators may inadvertently lose valuable hardware, produce erroneous results, and compromise system and human safety.

This project aims to build a Simulation Training And Control System (STACS) prototype within a 3D simulation game-like environment and develop a realistic training environment. Specific objectives include: (1) Investigate and optimize the design of user interaction and user interfaces within a full 3D game-like environment for training and control, (2) Investigate and optimize the tradeoff between manual and autonomous control of multi-robot teams for bridge inspection, (3) Train bridge inspectors in the use of the proposed multi-robot system, and (4) Provide human operators with complete situational awareness and operational control during an ongoing inspection.

1:00 pm GRADUATE STUDENT POSTER SESSION

1:00-2:00 pm

The Graduate Student Research Poster Session will showcase INSPIRE UTC research projects and highlight the students supporting research efforts by communicating results to other students, faculty and staff, representatives from the transportation industry and facilitate work by exchanging knowledge and ideas between individuals from multiple disciplines. An award ceremony will be held at the closure of the annual meeting for 1st, 2nd, and 3rd place participants.

2:00 pm TECHNICAL PRESENTATIONS: AUTONOMOUS SYSTEMS

2:00-2:30 pm
Mobile-manipulating UAVs for Sensor Installation, Bridge Inspection and Maintenance, Dr. Paul Oh, University of Nevada, Las Vegas

Mobile manipulating UAVs have great potential for bridge inspection and maintenance. Since 2002, the PI has developed UAVs that could fly through in-and-around buildings and tunnels. Collision avoidance in such cluttered near-Earth environments has been a key challenge. The advent of light-weight, computationally powerful cameras led to breakthroughs in SLAM even though SLAM-based autonomous aerial navigation around bridges remains an unsolved problem.

In 2007, the PI integrated a mobile manipulation function into UAVs, greatly extending the capabilities of UAVs from passive survey of environments with cameras to active interaction with environments using limbs. Mobile-manipulating UAVs have since been demonstrated to successfully turn valves, install sensors, open doors, and drag ropes. Their research and development face

several challenges. First, limbs add weight to aircraft. Second, rotorcraft, like a quadcopter, is an under-actuated system whose stability can be easily affected by limb motions. Third, when performing a task like turning a valve, limbs demand compensation for torque-force interactions. Thus, even if battery technologies afford the additional payload of limbs, current knowledge for manipulation with under-actuated systems remains sparse.

This project aims to develop and prototype a mobile-manipulating UAV for bridge maintenance and disaster cleanup through further study on SLAM technology for robust navigation, impedance controllers to ensure UAV's stability with limb motion, and coordinated and cooperative motions of multiple limbs to perform simple tasks like bearings cleaning and crack sealing in concrete bridges. Two strategies will be explored for bridge maintenance: (a) A UAV brings and uses a can of compressed air for bridge cleaning, and (2) Two UAVs airlift, position, and operate hoses from ground, and clean bridges with air or water. The latter can be potentially implemented by including a station-keeping, lighter-than-air UAV like blimp that can airlift a hose and remain airborne for extended periods. The mobile-limbed UAVs can then pull-and-drag the hose into areas that need to be cleaned. The blimp-based approach is attractive because it is easier for a UAV to drop hose lengths rather than pull the hose up in air.

2:30-3:00 pm
Climbing Robots with Automated Deployment of Sensors and NDE Devices for Steel Bridge Inspection, Dr. Hung La, University of Nevada, Reno

The PI was a research scientist/faculty at Rutgers University who successfully developed in 2014 a Robotic Assisted Bridge Inspection Tool (RABIT) for bridge deck inspections. Other bridge elements, such as girders and columns, or even underside of bridge decks are difficult to access and remain a challenge for efficient inspection. Like visual inspection, current practices for bridge maintenance are equally time consuming and expensive. Automation of simple maintenance actions such as bearing cleaning and concrete sealing with robots will lead to a leap forward to the next-generation strategy of bridge maintenance.

This project aims to develop and prototype automated climbing robotic platforms for steel bridge inspection and evaluation with support of visual and 3D LiDAR for navigation in global positioning system (GPS)-denied environments, develop a nondestructive evaluation (NDE) device or sensors deployment strategy with a mechanical limb, and evaluate the condition of steel bridges based on data collected from the device or sensors.

3:00-3:30 pm
Autonomous Wall-climbing Robots for Inspection and Maintenance of Concrete Bridges, Dr. Jizhong Xiao, The City College of New York

Since 2002, the PI's group has developed four generations of wall-climbing robots for NDE inspection of civil infrastructure. These robots combine the advantages of aerodynamic attraction and suction to achieve a desirable balance of strong adhesion and high mobility. They don't require perfect sealing and can thus move on smooth and rough surfaces, such as brick, concrete, stucco, wood, glass, and metal. For example, Rise-Rover uses two drive modules to carry their middle compartment with payload up to 450 N. Ground penetrating radar (GPR)-Rover and Mini GPR-Rover are custom designed to carry a GSSI's GPR antenna for subsurface defect detection and utility survey on concrete structures such as bridges and tunnels. The robots can also carry other devices such as impact echo and ultrasonic flaw detectors for bridge evaluation. To date, all the robots are remotely controlled to scan concrete surfaces.

This project aims to develop motion control and localization methods to make wall-climbing robots a fully autonomous system with automated inspection process using various NDE devices and sensors, and design innovative mechanisms and tools and integrate them into the robots for maintenance actions.

3:30-4:00 pm
Bridge Inspection Robot Deployment Systems (BIRDS), Dr. Bo Shang, Missouri S&T

Climbing robots for both concrete and steel bridges and UAVs are being developed to support bridge inspection with advanced evaluation technologies at the INSPIRE University Transportation Center. They are mostly applicable to large open areas with little or no obstacles. For I-shaped beams or girders, climbing along the cross section of these structural members is not a trial task. In particular, a climbing robot may not have a sufficient footprint to make a safe turn from the inner to outer face of a top or bottom flange. In this case, an unmanned vehicle is conceived to facilitate I-girder inspection and deployment of climbing robots on the underside of bridge deck between two adjacent girders. The unmanned vehicle, in combination with the climbing robots and UAVs, will allow the inspection and maintenance of over 90% of the bridges in the National Bridge Inventory and will be relatively easy to be adopted by inspectors due to their familiarity with the concept of inspection platforms. It must be able to fly in air and traverse along a girder with an effective vehicle-bridge engagement mechanism for smooth transition from the flying to traversing mode as designed with support of limited stress analysis, prototyped, tested, modified with expanded functionality, and re-tested in laboratory and field conditions.

This project aims to develop and build a solar-powered mobile test facility based on a ground vehicle (e.g., recreational vehicle) to support field tests at bridge sites and provide wireless communication, such as satellite services, between no cell service bridge sites and the INSPIRE University Transportation Center. The mobile test facility is hereafter referred to as Bridge Inspection Robot Deployment Systems (BIRDS) that include climbing robots, UAVs, multimodal vehicles, sensors, nondestructive evaluation devices, data acquisition units, batteries, and miscellaneous tools to support field tests and wireless communication.

The BIRDS serve as a field station for data collection and transmission to the base station at the INSPIRE University Transportation Center, and as a means of transportation for a crew of two or three inspectors.

4:00 pm TECHNICAL PRESENTATION: RETROFIT AND RESILIENCE

4:00-4:30 pm
Bridge Resilience Assessment with INSPIRE Data, Dr. Iris Tien, Georgia Institute of Technology

Robotic data collection, both automated and remote, will enable post-disaster assessment of bridge components where it would normally be difficult and potentially dangerous for manual inspection by field workers to do so.

This project aims to develop and validate a new framework that uses the data collected from the robotic exploration of infrastructure, particularly after a disaster, to assess the condition of bridges and prioritize these structures for repair. This will improve the resilience of the transportation system to disasters by targeting bridge repairs and enabling resources to be distributed more effectively across the system for more rapid recovery after a disaster.

4:30 pm ADJOURN

Tuesday, August 4

9:30 am GRADUATE STUDENT POSTER SESSION

9:30-11:00 am

The Graduate Student Research Poster Session will showcase INSPIRE UTC research projects and highlight the students supporting research efforts by communicating results to other students, faculty and staff, representatives from the transportation industry and facilitate work by exchanging knowledge and ideas between individuals from multiple disciplines. An award ceremony will be held at the closure of the annual meeting for 1st, 2nd, and 3rd place participants.

11:00 am POOLED-FUND STUDY DISCUSSION

11:00 am-12:00 pm

The goals of the pooled-fund initiative are to engage closely with several state Departments of Transportation (DOTs) in the early stage of technology development at the INSPIRE University Transportation Center, and leverage the center resources to develop case studies, protocols, and guidelines that can be adopted by state DOTs for bridge inspection without adversely impacting traffic. The initiative involves the integration, field demonstration and documentation of a robotic system of structural crawlers, unmanned aerial vehicles, a multimodal unmanned vehicle, nondestructive devices, sensors, and data analytics. Depending on the interest of participating DOTs, the objectives of this initiative include, but are not limited to:

- Development of inspection/operation protocols for various types of bridges with the robotic system integrated into current practice.
- Comparison and correlation of bridge deck inspections from the top and bottom sides of decks to understand the reliability of traffic disruption-free bridge inspection from the underside of decks.
- Design and technical guidelines of measurement devices on a robotic platform for the detection of surface and internal damage/deterioration in structural elements, and for the change in lateral support of foundations.
- Data fusion and analytics of measurements taken from various imaging and sensing systems for consistency and reliability.
- Development of best practices on bridge inspection using the robotic system.

12:00 pm **POSTER AWARDS CEREMONY**

Dr. Lesley Sneed
Professor, Missouri S&T
Department of Civil, Architectural & Environmental Engineering
Chair of the Judging Committee

12:30 pm **SEMI-ANNUAL EXECUTIVE MEETING**

Closed meeting with center-only members (INSPIRE UTC Directors, Associate Directors, External Advisory Committee and Pooled-Fund Study Members)

1:00 pm **CLOSING REMARKS**

Dr. Genda Chen
Director, INSPIRE University Transportation Center
Missouri S&T