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Program Progress Performance Report #3

Missouri University of Science and Technology. INSPIRE - University Transportation Center

PROGRAM PROGRESS
PERFORMANCE REPORT #3

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Inspecting and Preserving Infrastructure through Robotic Exploration (INSPIRE)

Tier 1 University Transportation Center Sponsored by the Office of the Assistant Secretary for Research and Technology (OST-R)



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MISSOURI S&T · The City College of New York · Georgia Tech · UNLV · EAST CENTRAL COLLEGE · LINCOLN · OZARKS TECHNICAL COMMUNITY COLLEGE · St. Louis Community College

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1. ACCOMPLISHMENTS

1.A - What Are the Major Goals and Objectives of the Program?

Center's Mission and Goal

The mission of the INSPIRE center is to make an impactful contribution to the overall University Transportation Center Program authorized under the Fixing America's Surface Transportation (FAST) Act by providing leadership in research, education, workforce development, and technology transfer aimed at infrastructure inspection and preservation solutions with advanced sensing and robotic technologies for a sustainable and resilient transportation system. This mission becomes increasingly important in addressing greater needs for condition assessment and maintenance of bridges as natural disaster risks increase and approximately 50% of bridges in the National Bridge Inventory approach their design life.

The overarching goals of the center in five years are to transform in at least two demonstration cases from manual to automated inspection and preservation of bridges with sensors, nondestructive evaluation (NDE) devices, multi-modal unmanned vehicles, and data logistics, thus providing cost-effective, consistent, and reliable solutions in bridge condition assessment and maintenance, and to develop diverse transportation workforces mastering the advanced technologies.

Research Objectives

To meet the above goals, three research objectives of the center are set:

1. To explore, develop, validate, and demonstrate standardized-integrated measurement technologies, decision-making tools, data logistics, and autonomous systems to facilitate the field inspection and maintenance of bridges;
2. To develop, validate, and demonstrate methods of robot-enabled resilience analysis and intervention technologies (retrofit and repair) of bridges; and
3. To develop innovative tools and methods for the next-generation transportation workforce training and the general public education.

Education Objectives

To achieve the center's goals, three education objectives are set and achieved through degree-granting programs with transportation components, transportation non-degree programs, and seminars/workshops/short courses:

1. To develop new education materials related to advanced sensing and robotic technologies, such as real-world examples and cases that can reinforce the learning objectives of current curriculums, and interdisciplinary topics for senior design/capstone projects that can promote cooperative learning among students from various disciplines;
2. To create new opportunities for knowledge expansion and skill training on non-traditional civil engineering subjects, such as sensing, NDE, and bridge inspection and maintenance with robotics, which can enrich existing civil engineering programs or non-degree certificate programs; and
3. To connect students with transportation industries and professionals through center meetings, annual transportation research board (TRB) meetings, an international conference, and the external advisory committee.

Workforce Development Objectives

To achieve the center's goals, two workforce development objectives are set and achieved through various outreach activities and close collaborations with professional organizations such as the Missouri Local Technical Assistance Program (LTAP) and the Center for Worker Education (CWE), New York:

1. To raise the public awareness of changes from adopting advanced technologies and attract new entrants from varying pipelines into transportation-related majors; and
2. To apply the robot simulator and video games developed as part of the research portfolio for a rapid and innovative workforce training of both current and prospective transportation workforces.

Technology Transfer Objectives

To achieve the center's goals, three technology transfer objectives are set:

1. To work in partnership with end users to facilitate technology transfer, including state and local governments, non-profit entities, and private enterprises, and assist them in mastering and implementing the developed technologies such as sensors, robots, and image analysis tools;
2. To protect intellectual properties with patent applications through the technology transfer and economic development offices and actively seek their licensing with small businesses such as InnovBot LLC; and
3. To disseminate research results through high quality peer-reviewed journals, conference proceedings, and exhibitions at TRB annual meetings and other national/international conferences.

Diversity Objectives

To achieve the center's goals, two diversity objectives are set:

1. To broaden underrepresented minority participation through direct involvement of two minority institutions; and
2. To recruit and retain female and traditionally underrepresented minority students in close collaboration with special programs such as the activities of the Student Diversity, Outreach and Women's Programs office at Missouri S&T.

1.B - What Was Accomplished Under These Goals?

Research Accomplishments

Twelve research projects were awarded in Year 2 based on the results of the external proposal review described in PPPR-2. One new project began on January 1, 2018 and the remaining projects represented Phase 2 studies of the Year 1 projects which ended July 31, 2018, and are continuing with a new end date of December 31, 2018.

Bi-monthly meetings are scheduled with Principal Investigators (PIs) to provide open lines of communication within the Center, and to share important news and announcements with the research team. PIs provide research progress updates during monthly meetings, and submit written quarterly reports to the Center. The INSPIRE UTC held its annual meeting August 14-15, 2018. INSPIRE PIs provided research updates at the meeting.

Table 1 summarizes the progress made in each of the research topics: sensing and nondestructive evaluation (SN), autonomous systems (AS), inspection and maintenance (IM), retrofit and resilience (RR), and workforce development (WD). Progress evaluation is done in terms of major activities, specific objectives, significant results and key outcomes/achievements.

Table 1 A summary of research progress

Topic	Major Activities	Specific Objectives	Significant Results	Key Outcomes
SN	1. Develop a localization algorithm for more than one smart rocks deployed in	1. Develop a UAV platform for magnetic field measurement and	1. No interference between two smart rocks 3 m apart.	1. Localization algorithm for two smart rocks.

Topic	Major Activities	Specific Objectives	Significant Results	Key Outcomes
	close distance and continue with field validation tests. 2. Compare the performance of two antenna sensors with RT/duroid®6202 and 5880 substrates and conduct the multi-physics simulation of antenna sensors. 3. Develop a parameter discrimination method using one LPFG sensor with different cladding modes and evaluate the performance of distributed fiber optic sensors in large-scale composite beams. 4. Prepare a new test setup with controllable uniform corrosion of reinforcing bars in concrete specimens, and microwave scan specimens with corroded bars. 5. Set up a dual VNIR-SWIR hyperspectral camera with vendor to ensure it is fully operational and test the camera function with copper sheets retrieved from a national park.	characterize field performance of smart rocks for bridge scour monitoring. 2. Develop and validate a light antenna sensor that can be interrogated over 30 m distance. 3. Develop a Fe-C coated LPFG sensor for simultaneous strain and mass loss measurement and inscribe it along an optical fiber as distributed sensor. 4. Develop and optimize a linear array of microwave probes for bridge inspection on a UAV platform. 5. Ensure that the dual VNIR-SWIR camera meet required technical specifications.	2. Accurate measurement of a milli-inch crack width with antenna sensors with a RT/duroid®6202 substrate. 3. 6th and 7th cladding modes appropriate for discrimination of two measured parameters, and temperature measurement from a distributed fiber optic sensor affected by the friction between the fiber and its coating over long distances. 4. Clear microwave images of corroded bars with scanning in X-band. 5. Clear sign of spectral features of the copper sheets.	2. Antenna sensors on RT/duroid® 6202 substrate for both strain and temperature measurements. 3. Two mode measurements of LPFG sensors for measurands discrimination, acceptable accuracy for strain and temperature measurements in concrete with embedded optical fibers.
AS	1. Simulate air spraying, test vehicle reaction to spraying and test a gripper and manipulator design mimicking lizard tongue motion. 2. Design, simulate and preliminarily test the 2nd prototype of climbing robots that overcome the difficulty in climbing around a curve surface. 3. Develop a multi-chamber rover for rough surface climbing and impact sounding mechanism for subsurface detection using a concrete slab with embedded delamination.	1. Design and use hyper-redundant serpentine-like limbs for dexterous manipulation such as air spraying for bearing cleansing and epoxy injection for crack sealing. 2. Develop and prototype automated climbing robotic platforms for steel bridge inspection with NDE devices. 3. Design a multi-chamber rover with 3 sets of impact mechanisms to overcome climbing obstacles on concrete surfaces and detect subsurface defects with impact sounding.	1. Reaction to spraying action relatively small, and a critical component of the end-effector of drone arm and gripper. 2. Improved versatility of magnetic roller-chain based design for robots to climb along curved surface of steel members. 3. Improved mobility from one to another surface without falling and over small obstacles and creation of impact sounding mechanism.	1. Bio-inspired gripper and manipulator design with lizard tongue movement. 2. Second prototype of climbing robot for steel structures. 3. Prototype multi-chamber rover with a RGB-D camera and impact sounding with software for the detection of surface/subsurface defects.
IM	1. Develop impact sounding systems for subsurface defect detection and algorithms for delamination detection, and evaluate their	1. Develop new fusion strategies of data collected from multiple NDE devices for improved POD based on	1. Potential use of aerodynamic noise itself from a crawler as a sounding source for the	1. Three impact sounding systems developed and tested, and empirical mode

Topic	Major Activities	Specific Objectives	Significant Results	Key Outcomes
	accuracy with a concrete slab specimen with defect holes.	further understanding and modeling of damage detection mechanisms.	detection of subsurface defects.	decomposition used to reduce noise effect on impact sounding.
RR	1. Assess the fragility of bridge systems, including deck, bearings, shear keys, columns and abutments, and study the effect of corrosion induced mass loss of steel on the failure modes of bridge elements.	1. Develop and validate a framework of bridge condition assessment and prioritizing structures for repair after an extreme event.	1. More brittle failure and more difficulty in failure prediction of shear-critical columns and columns with short lap splices than those of flexure-critical columns.	1. Fragility curves of bridge systems and various failure modes of columns different in aspect ratio and lap splice length, including corrosion effect.
WD	1. Develop algorithms for data processing and pattern recognition, and create tools for assisting and training users on visual image data analysis. 2. Refine user interaction and user interface designs, finalize two-way communication between the simulator and robots, and search for genetic algorithms for optimal or near optimal inspection route.	1. Develop a framework of robotic operation and image analysis trainings for inspection and preservation of bridges. 2. Build a Simulation Training and Control System (STACS) within a game-like 3D simulation environment and develop a realistic training tool for civil engineers and college graduates.	1. Improve image retrieval algorithms from transfer learning to reduce false positive detection but show over-fitting due to limited new data. 2. Visualize a variety of data sources from multiples sensors on a few inspecting robots on STACS over the wireless network in real time.	1. A hierarchical feature representation developed to match regions of interest with different scales in the image. 2. Genetic algorithms introduced to optimize route planning over multiple robots for bridge inspection.

Note: to address the 1st research objective; the 2nd objective; and the 3rd objective.

Education Accomplishments

In June 2018, a summer research exchange program was implemented by INSPIRE consortium members, University of Nevada, Las Vegas (UNLV) and University of Nevada, Reno (UNR). Stacey Cubos, a junior in Electrical Engineering at UNLV, was deployed to UNR for a 10 week summer research experience from June – August 2018. At UNR, Stacey worked with Dr. Hung La, INSPIRE PI and Director of the UNR Advanced Robotics and Automation (ARA) Laboratory on the project, *Eddy Current Flaw Detector Inspection Robot Simulation in Virtual Reality.* This project aims to prevent the percent of human casualties in manual bridge inspections through the use of virtual reality system simulation. The project was part of UNR's Research Experience for Undergraduates (REU) program which focuses on collaborative human-robot Interaction. For more information about UNR's REU program, visit: https://www.unr.edu/cse/research/intelligent-and-autonomous-systems/reu.

In August 2018, the INSPIRE UTC implemented course sharing among partner institutions. 8 graduate students are currently enrolled for Missouri S&T's Structural Health Monitoring course (CIV/ARCH ENG 6001) taught by INSPIRE UTC Director, Dr. Genda Chen, including 6 Missouri S&T students, 1 student from The City College of New York and 1 student from Georgia Institute of Technology.

In August 2018, the INSPIRE UTC implemented a new Undergraduate Research Program. One undergraduate student is currently participating in the program. Ashely-Ann Davis, a sophomore pursuing a double major in Civil and Architectural Engineering at Missouri S&T, is working with Dr. Genda Chen and his research team on the project, *Hyperspectral Image Analysis for Mechanical and*

*Chemical Properties of Concrete and Steel Surface*s. Her role in the project is to help prepare test samples (concrete and steel), characterize and categorize them, and prepare documentation for data curation in Scholars' Mine. At Missouri S&T, Ashley-Ann is the President of the National Society of Black Engineers, and is also involved with Engineers without Borders and works as a peer mentor.

In January 2018, 20 graduate students were enrolled in the Engineering Risk Analysis course taught by Dr. Iris Tien at Georgia Institute of Technology. Dr. Tien used part of the research results from the INSPIRE project as a case study in this course.

In January and August 2018, Dr. Hung La at UNR introduced automated infrastructure inspection concepts using robots into the current robotics courses: CPE470/670-Autonomous Mobile Robots; CS791-Special Topics on Robotics, and CS455/655-Mobile Sensor Networks. Dr. La is also developing a new advanced robotics course: CPE471/671 Advanced Robotics, and its curriculum has been submitted and under review by the UNR Curriculum Committee.

Workforce Development Accomplishments

On April 11, 2018, Dr. Paul Oh of UNLV hosted 15 students from the Robert O. Gibson Middle School robotics team for a visit to the UNLV Drones and Autonomous Systems Lab (DASL). Dongbin Kim, DASL Manager and mechanical engineering Ph.D student at UNLV, directed the students through various robotics demonstrations highlighting the work of the laboratory. Read the full article at https://www.unlv.edu/news-story/gibson-ms-robotics-team-meet-their-unlv-counterparts, or watch a video of this outreach activity at https://www.youtube.com/watch?v=bvTv_Upj67k.

On June 1, 2018, Dr. Hung La and his students at UNR organized and hosted a lab tour and robotics demonstration for visitors of the NSF REU Site event at UNR's ARA Lab. Participants included 30 students from California, New Hampshire, Oklahoma and Nevada.

On July 17, 2018, the INSPIRE UTC hosted a one-day MoDOT Transportation Camp on the Missouri S&T campus as part of MoDOT's annual Youth Transportation Conference. Each summer, MoDOT selects 30 students from across the state of Missouri to participate in the camp, exposing them to numerous career opportunities in the field of transportation. Attendees spent a full day visiting S&T and explored a variety of topics related to transportation.

On August 7, 2018, Dr. Hung La and his students at UNR organized 2 lab tours for robot and virtual reality demonstration at UNR's ARA Lab. Participants included 43 visitors of the Emissions Measurement and Testing Committee.

Technology Transfer Accomplishments

Quarterly Webinars - The INSPIRE UTC hosts quarterly webinars. Overall, 5 INSPIRE webinars have engaged a total of 292 people from 42 US States and 12 different countries, including Australia, Canada, China, Germany, India, Italy, Portugal, Serbia, Sweden, Taiwan, United Kingdom and the USA. On average, 51% of participants are from academia, 23% are from industry, 19% are from Government, and 7% are unknown.

Two webinars were presented in this reporting period, and engaged 106 participants:

1. *Toward Autonomous Wall-climbing Robots for Inspection of Concrete Bridges and Tunnels* was presented on September 19, 2018 by Dr. Jizhong Xiao, Professor, Electrical Engineering Department, The City College of New York (CCNY).

2. *Climbing Robots for Steel Bridge Inspection and Evaluation* was presented on June 21, 2018 by Dr. Hung La, Assistant Professor, Computer Science and Engineering Department, University of Nevada, Reno.

Five professional certificates were issued to attendees (upon request). All quarterly webinars are archived and can be viewed at: http://scholarsmine.mst.edu/inspire_webinars.

2018 Annual Meeting - The INSPIRE UTC held its first Annual Meeting on the Missouri S&T campus August 14-15, 2018. Activities included technical research presentations by the INSPIRE UTC faculty, an executive meeting and panel discussion with the INSPIRE UTC External Advisory Committee, a Graduate Student Poster Session and awards ceremony, and a Pedestrian Bridge Test Demonstration. For more information, visit https://inspire-utc.mst.edu/annualmeeting/.

INSPIRE Newsletters - The INSPIRE UTC publishes a biannual newsletter that has been subscribed by over 3,500 readers. One (1) newsletter was published in this reporting period and posted on the Center's website at: http://inspire-utc.mst.edu/news/. **Volume 2, Issue 1**- Spring 2018- featured 3 technical articles highlighting INSPIRE robotics research:

1. *Aerial Manipulation Drones*, Dr. Paul Oh, Lincy Professor of Unmanned Aerial Systems, UNLV
2. *A Climbing Robot for Steel Bridge Inspection,* Dr. Hung La, Assistant Professor of Computer Science and Engineering, Director, Advanced Robotics Automation (ARA) Laboratory, UNR
3. *Autonomous Wall-climbing Robots to Inspect Concreate Bridges,* Dr. Jizhong Xiao, Professor of Electrical Engineering, and Director, CCNY Robotics Lab, CCNY

Visiting Scholars Seminars – In April 2018, the INSPIRE UTC co-hosted 2 Visiting Scholars Seminars with the Missouri S&T Civil, Architectural and Environmental Engineering Department.

1. *The Impact of Human Behavior During Emergencies on Civil Infrastructures*, presented April 25, 2018 by Dr. Gian Paolo Cimellaro, Associate Professor of Structural Engineering, Politecnico di Torino, Italy.
2. *Reuse of Foundations of Existing Bridges,* presented April 19, 2018 by Dr. Anil Agrawal, Associate Director, INSPIRE UTC, and Herbert G. Kayser Professor of Structural/Bridge Engineering, The City College of New York.

Keynote/Invited Presentations/Distinguished Lectures -

- On May 31 – June 2, 2018, Dr. Jizhong Xiao, INSPIRE UTC PI, delivered a distinguished lecture on *Mobile Robots against Gravity for Non-destructive Inspection of Infrastructures* at the 13th IEEE Conference on Industrial Electronics and Applications (ICIEA 2018), Wuhan, China.
- On June 22, 2018, Dr. Jizhong Xiao, INSPIRE UTC PI, and his associates made an invited presentation on *Semantic Metric 3D Reconstruction for Concrete Inspection* at the International Workshop on Visual Odometry and Computer Vision Applications Based on Location Clues in conjunction with Computer Vision and Pattern Recognition (CVPR2018), Salt Lake City, UT.
- In July 2018, INSPIRE UTC Director, Dr. Genda Chen, and INSPIRE UTC Associate Director, Dr. Anil Agrawal participated by invitation in the 31st US-Japan Bridge Engineering Workshop in Los Angeles, CA. Sponsored by the Federal Highway Administration, the workshop series brings together bridge engineers from the US and Japan to discuss common issues in bridge engineering.
- On July 8-13, 2018, INSPIRE UTC Associate Director, Dr. Hung La, and INSPIRE UTC PI, Dr. Sushil Louis made an invited presentation on *A Genetic Algorithm for Convolutional Network Structure Optimization for Concrete Crack Detection* at the 2018 IEEE Congress on Evolutionary Computation (IEEE CEC), Rio de Janeiro, Brazil.

- On July 22-25, 2018, INSPIRE UTC Director, Dr. Genda Chen, made an invited presentation on *Identification of Nonlinear Oscillators with Multiple Analytical Mode Decompositions* at the 7th World Conference on Structural Control and Monitoring, Qingdao, China.
- On August 23-35, 2018, INSPIRE UTC Director, Dr. Genda Chen, made a keynote presentation on *Enamel Coating for Steel Rebar in Concrete: Corrosion Barrier and Bond Enhancer* at the World Congress of Materials Science and Engineering, Amsterdam, Netherlands.

Publications/Conference Presentations - INSPIRE UTC faculty disseminate research results and information through numerous publications, presentations and technical reports. A list of publications for this reporting period is included in Sections 1.D and 2.A.

Scholars' Mine Certification - In June 2018, Scholars' Mine, Missouri S&T's online repository of research papers, creative works and other documents, received CoreTrustSeal certification which signifies that Scholars' Mine is a trusted and certified repository for research data. To view the Scholars' Mine certification, visit https://www.coretrustseal.org/wp-content/uploads/2018/04/Scholars-Mine-.pdf . For more information about CoreTrustSeal, visit https://www.coretrustseal.org/.

Diversity Accomplishments

The INSPIRE UTC broadens underrepresented minority participation through direct involvement with three minority institutions. UNLV and CCNY are major consortium members leading research, education, workforce development and technology transfer initiatives for the Center. Lincoln University, a minor consortium member, encourages student participation in INSPIRE UTC workforce development activities.

Through its education, outreach and workforce development efforts, Missouri S&T has implemented multiple outreach and education initiatives to introduce underrepresented students to the field of transportation, and opportunities to participate in transportation-related research through Center activities and programs. In this reporting period, the INSPIRE UTC reached more than 30 underrepresented students.

- In June 2018, a summer research exchange program was implemented by INSPIRE consortium members, UNLV and UNR. 1 female, minority UNLV undergraduate student, Stacey Cubos, was deployed to UNR for a 10 week summer research experience.
- In July 2018, Missouri S&T engaged 30 underrepresented high school students from Missouri in a hand-on bridge engineering competition and other interactive activities and lab tours during a one-day Missouri Department of Transportation Camp on the Missouri S&T campus.
- In August 2018, 1 female, minority undergraduate student, Ashley-Ann Davis, at Missouri S&T was selected and awarded the Opportunities for Undergraduate Research Experience and co-supported by the INSPIRE UTC's Undergraduate Research Program. Ashley is currently performing research with Dr. Genda Chen on the INSPIRE UTC project entitled *Hyperspectral Image Analysis for Mechanical and Chemical Properties of Concrete and Steel Surfaces*.
- In August 2018, 1 female graduate student, Xi Liu, began to perform transportation-related research with Dr. Yang Wang at Georgia Institute of Technology.

1.C - What Opportunities for Training and Professional Development Has the Program Provided?

- The INSPIRE UTC hosts quarterly webinars, as described in the technology transfer accomplishments section above.
- 19 graduate students and 22 undergraduates are trained in interdisciplinary team environments through various activities in 13 research projects.

1.D - How Have the Results Been Disseminated?

Publications/Presentations

See Section 2.A for journal publications, conference papers and presentations.

Newsletters

- A. Gillman, and G.D. Chen. *INSPIRE UTC Newsletter*, 2(1), April 2018 (http://inspire-utc.mst.edu/news/) with the following three feature articles:
    - *Aerial Manipulation Drones*, Dr. Paul Oh, Lincy Professor of Unmanned Aerial Systems, UNLV
    - *A Climbing Robot for Steel Bridge Inspection,* Dr. Hung La, Assistant Professor of Computer Science and Engineering, Director, ARA Laboratory, UNR
    - *Autonomous Wall-climbing Robots to Inspect Concreate Bridges,* Dr. Jizhong Xiao, Professor of Electrical Engineering, and Director, CCNY Robotics Lab, CCNY

Poster Presentations

- On August 14-15, 2018, graduate students from all INSPIRE consortium institutions attended the INSPIRE UTC 2018 Annual Meeting on the Missouri S&T campus in Rolla, Missouri. Participating students interacted with transportation professionals from government and industry transportation sectors. A *Graduate Student Poster Session* was held to offer students the opportunity to showcase their research, communicate results to other students, faculty and staff, engage with representatives from the transportation industry, and facilitate interdisciplinary work by exchanging knowledge and ideas between individuals from multiple disciplines. **10 research posters were presented**. First, second and third place awards were given to the following students:
    - 1st Place- Chuanrui Guo, Missouri S&T- *Integrated Fiber Optic Sensors for Strain, Temperature and Corrosion-induced Mass Loss Measurement*
    - 2nd Place- Dan Li, Georgia Institute of Technology- *Thermally-Stable Passive Antenna Sensor for Strain and Crack Monitoring*
    - 3rd Place- Liang Yang, The City College of New York- *Deep Semantic 3D Visual Metric Reconstruction Using Wall-climbing Robot*

Other

- On August 14, 2018, 13 technical presentations were made by the INSPIRE UTC PIs at the INSPIRE Annual Meeting. To view the technical program and presentations, visit: https://inspire-utc.mst.edu/annualmeeting/.

1.E - What Do You Plan to Do During the Next Reporting Period to Accomplish the Goals and Objectives?

Research Plan

Research projects will continue in the five research topics described in 1.B above. No Change will be made to the approved plan. Planned research activities are summarized in Table 2 for each of the 12 active research projects awarded by INSPIRE UTC.

Table 2 A summary of planned research activities

Topic	Project Title	Planned Activities
	UAV-enabled Measurement for Spatial Magnetic Field of Smart Rocks in Bridge Scour Monitoring	• Continue to validate the field performance of smart rocks in bridge scour monitoring and characterize the effects of various influence factors. • Continue to validate the field test procedure with two or three smart rocks for repeatability of test results.
	Battery-free Antenna Sensors for Strain and Crack Monitoring of Bridge Structures	• Increase the interrogation distance of antenna sensors with the active operation mode of RFID chips with solar power. • Conduct fatigue tests of an aluminum to verify the performance of the new antenna sensor made of RT/duroid® 6202. • Conduct multi-physics simulation of the new antenna sensor using updated mechanical and dielectric parameters under loading and thermal effects.
	In-line Long Period Grating and Brillouin Scattering Fiber Optic Sensors for Strain, Steel Mass Loss, and Temperature Measurement in Bridge Applications	• Identify the areas for improvement in deployment of distributed fiber optic sensors for strain and temperature measurements in large specimens. • Monitor the life-cycle performance of metallic structures and steel reinforcement with Fe-C coated LPFG sensors when enclosed in multiple coaxial thin-walled steel tubes so that the times when corrosion rate is measured can be controlled by the wall thicknesses of the tubes.
	3D Microwave Camera for Concrete Delamination and Steel Corrosion Detection	• Optimize antenna properties and image a portion of a pedestrian bridge on top and bottom surfaces, respectively, both manually and automatically with an automated scanner. • Investigate the detectability of delamination pre-embedded in reinforced concrete plates using the large automated scanner. • Develop a new dielectric constant estimation technique that allows the estimate of corrosion level using Green's function-based SAR imaging models.
	Hyperspectral Image Analysis for Mechanical and Chemical Properties of Concrete and Steel Surfaces	• Set up and calibrate a dual VNIR-SWIR hyperspectral camera to verify its technical specifications in application setting. • Cast and test concrete specimens based on the developed metric to understand their surface characteristics. • Collect and establish a library of hyperspectral images of the specimens.
	Mobile-manipulating UAVs for Sensor Installation, Bridge Inspection and Maintenance	• Apply Kalman filter analysis on drone for position hold (i.e., station keeping). • Apply drone gripper end-effector controller for insertion tasks.
	Climbing Robots with Automated Deployment of Sensors and NDE Devices for Steel Bridge Inspection	• Conduct tests and evaluations of the second climbing design. • Continue to improve the second design of the climbing robot.
	Autonomous Wall-climbing Robots for Inspection and Maintenance of Concrete Bridges	• Design a new impact-Rover integrated with 2 sets of impacting mechanisms to collect sounding data. • Develop analysis software of sounding data.
	Re-Inventing the Bridge Inspection Program	• Secure off-campus non-federal matching funds to meet the center requirements and get this project started.
	Quantitative Bridge Inspection Ratings using Autonomous Robotic Systems	• Collect sounding data from the running crawler and investigate the frequency and energy component of noise signals recorded from the delaminated and good-bonding areas. • Develop a software module in MATLAB for quick analysis of the impact sounding data, which will be implemented in the future autonomous platforms of inspection.
RR	Bridge Resilience Assessment with INSPIRE Data	• Increase the computational efficiency for the fragility curves of a bridge system so that the impact of collected bridge inspection data on bridge performance and resilience can be evaluated in practice.

Topic	Project Title	Planned Activities
WD	A Training Framework of Robotic Operation and Image Analysis for Decision-Making in Bridge Inspection and Preservation	• Expand the training data set to include some true and false positive regions of interest from a video. • Update the convolutional neural networks through iterative approach from one-shot through iterative one-shot to k-shot learning so that the false positive and false negative detections can be reduced significantly.
	Developing a Robotic Simulator and Video Games for Professional and Public Training	• Test the performance of genetic algorithms in a searching optimal or near optimal inspection route for up to five climbing robots on a steel bridge.

Note: to address the 1st research objective; the 2nd objective; and the 3rd objective.

Education Plan

1. One new course, CPE471/671-Advanced Robotics, is currently being developed and will be offered in 2019 by Dr. Hung La from UNR.
2. The INSPIRE UTC will host a distinguished lecture during the spring 2019 semester.
3. Missouri S&T is planning to host an 8-week summer research opportunity for Lincoln University undergraduate students.
4. Missouri S&T will continue to offer undergraduate research opportunities through the INSPIRE UTC Undergraduate Research Program- http://inspire-utc.mst.edu/studentprograms/ .
5. Consortium members are exploring course sharing opportunities for the spring 2019 semester, and 2019-2020 academic year.

Workforce Development/Outreach Plan

1. On October 5, 2018 the INSPIRE UTC and Mid America Transportation Center will co-host two hands-on transportation engineering workshops during the Expanding Your Horizons (EYH) Conference on the Missouri S&T campus.
2. On January 12, 2019, The INSPIRE UTC will participate in the Missouri State Future City Competition hosted by the Kaleidoscope Discovery Center in Rolla, MO and Future City Competition- Missouri.
3. February 22-24 2019, the INSPIRE UTC will lead a hands-on bridge engineering competition for the National Society of Black Engineers (NSBE) Pre-College Initiative (PCI) event.
4. On February 24, 2019, the INSPIRE UTC will participate in the FLL Junior Expo hosted by the Kaleidoscope Discovery Center on the Missouri S&T campus in Rolla, MO.

Technology Transfer Plan

1. On October 5-6, 2018, Dr. Genda Chen, INSPIRE UTC Director, will deliver a keynote presentation on "*Sensor-enhanced Analysis and Behavior of Steel Beams in Fire*" at the 5th World Congress and Exhibition on Construction and Steel Structure, Los Angeles, CA.
2. On October 28-31, 2018, Dr. Genda Chen, INSPIRE UTC Director, will deliver a keynote presentation on "*Short-time Continuous Wavelet Transform of the Response of Time-varying Systems*" at the 2018 International Conference on Sensor Networks and Signal Processing, Xi'an, China.
3. Quarterly webinars will be held in December 2018 and March 2019. The next webinar, titled "*Assistive Intelligence (AI): Intelligent Data Analytics Algorithms to Assist Human Experts*" will be presented on December 10, 2018 by Dr. Zhaozheng Yin, Associate Professor and St. Clair Fellow, Department of Computer Science, Missouri S&T. For more information, or to register for the webinar, visit: http://inspire-utc.mst.edu/webinars/

2. PRODUCTS

2.A - Publications, Conference Papers, and Presentations

Journal Publications

1. Yizheng Chen, Fujian Tang, Zhaochao Li, **Genda Chen**, and Yan Tang. "Bridge Scour Monitoring Using Smart Rocks Based on Magnetic Field Interference," Smart Materials and Structure, 27(8), July 10, 2018.
2. Liang Fan, Fujian Tang, Signo T. Reis, **Genda Chen**, and Michael L. Koenigstein. "Corrosion Resistances of Steel Pipe Internally Coated with Enamel," Corrosion, 73(11): 1335-1345, July 3, 2018.
3. Liang Fan, Signo Reis, **Genda Chen**, and Michael L. Koenigstein. "Corrosion Resistance of Pipeline Steel with Damaged Enamel Coating and Cathodic Protection," Coatings, 8(5): 1-12, DOI: 10.3390/coatings8050185, May 14, 2018.
4. S. Gibb, **H. M. La**, T. Le, L. Nguyen, R. Schmid, and H. Pham. "Non-Destructive Evaluation Sensor Fusion with Autonomous Robotic System for Civil Infrastructure Inspection," Journal of Field Robotics, 35(6): 988-1004, September 2018, DOI:10.1002/rob.21791.
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8. Haohan Li, **Zhaozheng Yin**, Paul Manley, Joel Burken, Nadia Shakoor, Noah Fahlgren, and Todd Mockler. "Early Drought Stress Detection with Bidirectional Long Short-Term Memory Networks," Journal Photogrammetric Engineering & Remote Sensing. 84(7): 459-468, July 2018
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10. Hongya Qu, Tiantian Li, and **Genda Chen**. "Synchro-squeezed Adaptive Wavelet Transform with Optimum Parameters for Arbitrary Time Series," Mechanical Systems and Signal Processing, 114: 366-377, doi.org/10.1016/j.ymssp.2018.05.020, May 11, 2018.
11. Fujian Tang, Yizheng Chen, Zhaochao Li, **Genda Chen**, and Yan Tang. "Application of Fe-C Coated LPFG Sensor for Early Stage Corrosion Monitoring of Steel Bar in RC Structures," Construction and Building Materials, 175, DOI: 10.1016/j.conbuildmat.2018.04.187, June 2018.

Conference Papers/Presentations

1. R. Dubey, J. Ghantous, **S. Louis**, S. Liu. "Evolutionary Multi-objective Optimization of Real-Time Strategy Micro," IEEE Conference on Computational Intelligence and Games (CIG), August 14-17, 2018, Maastricht, The Netherlands.
2. Liang Fan, Signo T. Reis, **Genda Chen** and Michael L. Koenigstein. "Impedance Models and Water Transport Behaviors of Steel Pipes Coated with Cathodically Polarized Enamel." Proceedings of the CORROSION Conference and Exposition, National Association of Corrosion Engineers, Phoenix, AZ, April 15-19, 2018.

3. A. Gajurel, **S. Louis**, D. Mendez, S. Liu. "Neuroevolution for RTS Micro," IEEE Conference on Computational Intelligence and Games (CIG), August 14-17, 2018, Maastricht, The Netherlands.
4. S. Gibb, **H. M. La**, **S. Louis**. "A Genetic Algorithm for Convolutional Network Structure Optimization for Concrete Crack Detection," Proceedings of the 2018 IEEE Congress on Evolutionary Computation (IEEE CEC), July 8-13, 2018, Rio de Janeiro, Brazil.
5. Pranav Godse, MD Al-Amin, **Ruwen Qin**, and **Suzanna Long**. "An Analysis of Human Involved Incident Data for Enhancing the Safety of Hazardous Material Transportation," Proceedings of the 2018 IISE Annual Conference, K. Barker, D. Berry, C. Rainwater, eds., Orlando, FL, May 2018.
6. Jacob Hale, Pranav Godse, and **Suzanna Long**. "Shifting the Energy Market: A Case for Microgrids," Proceedings of the 2018 IISE Annual Conference, K. Barker, D. Berry, C. Rainwater, eds., Orlando, FL, May 2018.
7. Bhanu Kanwar, Steven M. Corns, **Suzanna Long**, and Tom Shoberg. "Mapping Influential Nodes for Transportation Network Post-Disaster Restoration Planning Using Real-World Data," Proceedings of the AAG, New Orleans, LA, April 2018.
8. **Sushil J. Louis**, Tianyi Jiang, and Siming Liu. "Real-time Strategy Game Micro for Tactical Training Simulations," Proceedings of the Genetic and Evolutionary Computation Conference Companion (GECCO '18), Hernan Aguirre (Ed.). ACM, New York, NY, USA, 1656-1663. DOI: https://doi.org/10.1145/3205651.3208288.
9. Akhilesh Ojha, **Suzanna Long**, Tom Shoberg, and Steven M. Corns. "Improving the Efficiency of Vital Supply Distribution after an Extreme Event," Proceedings of the AAG, New Orleans, LA, April 2018.
10. Lizzette Perez-Lespier, **Suzanna Long**, and Tom Shoberg. "Post-Disaster Diagnostics of Sustainable, Resilient Decision-Making for Maritime Transportation Systems," Proceedings of the 2018 IISE Annual Conference, K. Barker, D. Berry, C. Rainwater, eds., Orlando, FL, May 2018.
11. Samareh Moradpour, Brian Smith, **Suzanna Long**, and Paul Robin. "Multinomial Logistic Regression Analysis for Work Zone Safety," Proceedings of the 2018 IISE Annual Conference, K. Barker, D. Berry, C. Rainwater, eds., Orlando, FL, May 2018.
12. L. Nguyen, S. Gibb, H. X. Pham, and **H. M. La**." A Mobile Robot for Automated Civil Infrastructure Inspection and Evaluation," Proceedings of the 16th IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR), August 6-8, 2018, Philadelphia, PA, USA. (Best paper finalist)
13. Akhilesh Ojha, **Suzanna Long**, Tom Shoberg, and Steven M. Corns. "A Mathematical Programming Approach to Minimizing Post-Disaster Transportation Indirect Costs," Proceedings of the 2018 IISE Annual Conference, K. Barker, D. Berry, C. Rainwater, eds., Orlando, FL, May 2018.
14. Fujian Tang, Lushuai Bai, Gang Li, and **Genda Chen**. "Probabilistic Modeling of Corrosion-induced Crack Width in Reinforced Concrete," Proceedings of the EUROCORR 2018 Congress, Cracow, Poland, September 9-13, 2018.
15. **Iris Tien**. "Fragility Assessment Results for Columns and Bridges with Measured Cracking or Corrosion," Engineering Mechanics Institute Conference, American Society of Civil Engineers, Boston, MA, May 29 – June 1, 2018.
16. Shuang Wu, Wenjin Tao, Ming Leu, and **Suzanna Long**. "Engine Sound Simulation and Generation in Driving Simulator," Proceedings of the 2018 IISE Annual Conference, K. Barker, D. Berry, C. Rainwater, eds., Orlando, FL, May 2018.
17. **Jizhong Xiao**. "Mobile Robots against Gravity for Non-destructive Inspection of Infrastructures," Distinguished lecture at the 13th IEEE Conference on Industrial Electronics and Applications (ICIEA 2018), Wuhan, China, May 31-June 2, 2018.

18. Liang Yang, Bing Li, Wei Li, Biao Jiang, and **Jizhong Xiao**. "Semantic Metric 3D Reconstruction for Concrete Inspection," International Workshop on Visual Odometry and Computer Vision Applications Based on Location Clues in Conjunction with CVPR2018, Computer Vision and Pattern Recognition (CVPR2018), Salt Lake City, June 22, 2018.
19. Liang Yang, Guoyong Yang, Zhaoming Liu, Yong Chang, Biao Jiang, Youssef Awad, and **Jizhong Xiao**. "Wall-Climbing Robot for Visual and GPR Inspection," Proceedings of the 13th IEEE International Conference on Industrial Electronics and Applications (ICIEA 2018), Wuhan, May 31-June 2, 2018.
20. Xinzhe Yuan and **Genda Chen**. "An Adaptive SMART Shear Key and its Mechanical Properties for Earthquake/Tsunami Mitigation," Proceedings of the 7th World Conference on Structural Control and Monitoring (7WCSCM), Qingdao, China, July 22-25, 2018.

Books and Other One-Time Publications

1. Book Chapter: Akhilesh Ojha, Steven Corns, Tom Shoberg, **Ruwen Qin**, and **Suzanna Long**. "Modeling and Simulation of Emergent Behavior in Transportation Infrastructure Restoration" in Emergent Behavior in Complex Systems Engineering: A Modeling and Simulation Approach. Wiley Press, 2018.
2. INSPIRE UTC Newsletter Articles-See Section 1.D for a list of technical articles included in Volume 2, Issue 1 of the INSPIRE UTC Newsletter.

2.B - Website(s) or Other Internet Site(s)

A website is maintained for the INSPIRE UTC at http://inspire-utc.mst.edu. This website serves as an information clearinghouse for all activities related to the grant and a gateway to transportation agencies, end users, technical communities, and the general public. The website is updated weekly, and in this reporting period, the following NEW webpage was added to the site:

- 2018 Annual Meeting- http://inspire-utc.mst.edu/annualmeeting/

PPPRs are posted to the site as they are submitted and approved. http://inspire-utc.mst.edu/pppr/.

In addition to the main website, INSPIRE recently established a YouTube Channel at https://www.youtube.com/channel/UCi3KZfYuQok7ON3xdvbmYpQ?view_as=subscriber. This channel will be populated with some initial content in the next reporting period.

INSPIRE webinars are archived and made available through the Missouri S&T Scholars' Mine site at http://scholarsmine.mst.edu/inspire_webinars/. Webinar videos are available for viewing and webinar content may be downloaded.

Affiliated research facility websites include:

- Advanced Robotics and Automation Lab (ARA Lab)- https://ara.cse.unr.edu
- Applied Microwave Nondestructive Testing Laboratory *(amntl)*- http://amntl.mst.edu/
- Computer Vision and Biomedical Imaging Laboratory (CVBI Lab)- http://cs.mst.edu/research/researchlabs/computervisionandbiomedicalimaginglaboratory/
- Drones and Autonomous Systems Laboratory (DASL)- http://www.daslhub.org
- Evolutionary Computing Systems Laboratory (ECSL Lab)- https://ecsl.cse.unr.edu/projects/bridge_inspection/index.html, http://cse.unr.edu/~ecsl/
- Highbay Structural Engineering Research Laboratory (HSERL)- https://care.mst.edu/research/facilities/high-baystructureslab/
- Laboratory for Smart Structural Systems (LSSS)- http://wang.ce.gatech.edu/

- CCNY Robotics Laboratory- http://robotics.ccny.cuny.edu/
- System and Process Assessment Research Laboratory (SPAR Lab)- http://spar.mst.edu

2.C - Technologies or Techniques

Affiliated research faculty developed the following technologies during the reporting period:

- Dr. Genda Chen's team developed an algorithm for locating two smart rocks 3 m apart.
- Dr. Genda Chen's team developed a two-cladding-mode algorithm of a long period fiber gratings sensors for simultaneous measurement of strain and corrosion-induced mass loss.
- Dr. Hung La and Sushil Louis's team developed genetic algorithms to optimize route planning over multiple robots for bridge inspection.
- Dr. Hung La developed a second generation climbing robot on steel bridges.
- Dr. Paul Oh's team developed a bio-inspired gripper and manipulator with lizard tongue movement.
- Dr. Ruwen Qin's team developed a hierarchical feature representation to match regions of interest with different scales in the image.
- Dr. Yang Wang's team developed antenna sensors on RT/duroid® 6202 substrate for both strain and crack measurements.
- Dr. Jizhong Xiao and Anil Agrawal's team developed an impacting mechanism to generate sounding for nondestructive evaluation of delamination. The two chambers used enabled a climbing rover to cross over a deep grove.

2.D - Inventions, Patent Applications, and/or Licenses

- **H. M. La**, *A Magnetic Roller-chain Climbing Robot for Steel Bridge and Steel Structure Inspection and Evaluation*. Submitted to UNR's Innovation Office for filling *US Provisional patent*: DIS19-05, September 19, 2018. Will be submitted to iEdison by 11/20/18.
- **H. M. La**, Multi-functional Robotic System for Civil Infrastructure Inspection. *US Provisional Patent*: UNR 18-005. Filed May 25, 2018. Reported to NSF & DOT via iEdison, IR No. 0829903-17-0004, and to NASA, e-NTR no. 1511825964, Case no. HQN-11512-1.
- **H. M. La**, *A Universal Convolution Neural Network (U-CNN) for Highly Accurate Defect Detection in Civil Infrastructure Inspection*. Submitted to UNR's Innovation Office for filling *US Provisional patent*: UNR18-018, April 6, 2018. Reported to DOT & NSF via iEdison, IR No. 0829903-18-0008, and to NASA, e-NTR no. 1537978999.

2.E - Other Products, Such as Data or Databases, Physical Collections, Audio or Video Products, Software or Netware, Models, Educational Aids or Curricula, Instruments, or Equipment.

Video Products

- The INSPIRE UTC webinars were video recorded. (See Section 2.B)
- INSPIRE recently established a YouTube Channel at https://www.youtube.com/channel/UCi3KZfYuQok7ON3xdvbmYpQ?view_as=subscriber. INSPIRE posted one video related to the climbing robot research being conducted by UNR, and is developing additional video content for Center's 5 research areas.

Equipment

- PI 85L SEM PicoIndenter was purchased with non-federal match funds to enable nanomechanical characterization of fiber optic sensors and thin film coatings.
- DASnova™ Series Optical Fiber Distributed Acoustic Sensing System was purchased with non-federal match funds to enable a cost-effective detection of cracks in large-scale bridge structures.

3. PARTICIPANTS & COLLABORATING ORGANIZATIONS

3.A - What Organizations Have Been Involved as Partners?

Participants:
The consortium members of this University Transportation Center remain the same as proposed originally, including:

- Missouri University of Science and Technology - Rolla, MO (lead institution)
- City College of New York - New York, NY
- Georgia Institute of Technology - Atlanta, GA
- University of Colorado at Boulder - Boulder, CO
- University of Nevada-Las Vegas - Las Vegas, NV
- University of Nevada at Reno - Reno, NV
- East Central College - Union, MO
- Lincoln University - Jefferson City, MO
- Ozarks Technical College - Springfield, MO
- St. Louis Community College - St. Louis, MO

External Collaborators:

- Jacobs Engineering Group http://www.jacobs.com/
- Kaleidoscope Discovery Center https://thekaleidoscope.org
- Koch Industries http://www.kochind.com
- McClure Engineering Co. http://www.mcclureeng.com/
- Missouri Department of Transportation http://www.modot.org/
- Rich Robotics Corp http://richrobotics.com
- Dr. Reginald DesRoches, Rice University
- Northeastern University
- Honeywell, Nevada

Internal Partners at Missouri S&T:

- Department of Civil, Architectural and Environmental Engineering http://care.mst.edu/
- MinerFly https://itrss.mst.edu/minerfly/
- Student Diversity Initiatives http://sdi.mst.edu/
- Educational Technology http://edtech.mst.edu/
- Curtis Law Wilson Library/Scholars' Mine http://scholarsmine.mst.edu/

3.B - Have Other Collaborators Or Contacts Been Involved?

Members of the INSPIRE External Advisory Committee attended the 2018 Annual Meeting in August 2018, and served as judges for the Graduate Student Poster Competition.

Tony Wu, Missouri S&T alumnus attended the Annual Meeting to interact with INSPIRE faculty and learn more about the research and possible future collaborations.

Dr. Tong of the Xiamen University in China provided several sets of impact sounding data at the preliminary phase of CCNY's project to assist Dr. Agrawal with testing algorithms.

4. IMPACT

4.A - What Is the Impact on the Development of the Principal Discipline(s) of the Program?

- The framework developed in Dr. Ruwen Qin's project will facilitate engineers' and college graduates' trainings in bridge inspection with advanced technologies. In particular, the region-of-interest identification and grouping from a long video will be completed semi-automatically with limited experts' input and intervention. In doing so, engineers will spend minimum time in reviewing recorded videos and inspecting target problem areas.
- The optimal dispatch path of multiple climbing robots developed in Dr. Sushil Louis' project will help engineers to plan for an efficient inspection task of significant or long-span bridges. Once integrated in a 3D bridge inspection simulation system, the optimization algorithms allow engineers to get trained for not only robot operation in simulation but also control of a robot team in a realistic environment during an inspection.

4.B - What Is the Impact on Other Disciplines?

- The convolution neural network with limited experts' input and intervention developed to identify regions of interest from a long video is transferrable from bridge inspection for interested areas to other applications for image analysis in computer science. As a semi-supervised machine learning algorithm, it is particularly useful to find the representative data for human annotations and retrieve similar data for the human analysis in computer vision and machine learning tasks.
- The path optimization algorithms developed to guide the movement of multiple climbing robots for bridge inspection are transferrable to other applications such as the dispatch of robots in battle fields.

4.C - What Is the Impact on the Development of Transportation Workforce Development?

- The training framework with integrated region-of-interest identification and dispatch path optimization of multiple robots will help the workforce development at the INSPIRE center. The former integration provides a toolkit for engineers to analyze imagery and the latter integration allows engineers to get trained in robot operation and control during an inspection scenario.

4.D - What Is the Impact on Physical, Institutional, and Information Resources at The University or Other Partner Institutions?

- The development of convolution neural network to identify regions of interest from a long video promoted the experts' interaction and talent development between the researchers at INSPIRE Center and MinerFly, a Missouri S&T IT support service in the area of unmanned aerial vehicle manufacturing and video recording. In this process, the infrastructure with robotics research

and imaging analysis will be improved, and the recorded data and imagery will eventually be stored in the Scholars' Mine repository for information exchange.
- The 3D simulation and virtual reality technologies developed for automated infrastructure inspection can further strengthen the research infrastructure for effective robot operation training at UNR.
- The climbing robots on steel bridges will add a new automation-assisted inspection device that is nondestructive, comprehensive, rapid, and cost effective for all stages of deteriorations. They are new physical and institutional resources at UNR.

4.E - What Is the Impact on Technology Transfer?

- The computer-based simulations with cutting edge virtual reality and augmented reality technologies developed in Dr. Sushil Louis' project will provide an effective tool to aid in bridge inspector training with advanced robotic and sensing technologies.
- The climbing robots on steel bridges are patentable. Once commercialized, they will likely be transferred into applications in bridge inspection through entrepreneurship.
- The research results on climbing robots for automated infrastructure inspection were introduced to three current robotics courses: CPE470/670-Autonomous Mobile Robots, CS791-Special Topics on Robotics, and CS455/655-Mobile Sensor Networks at UNR.

4.F - What Is the Impact on Society Beyond Science and Technology?

- Once the developed technologies such as climbing robots, robot control and operation algorithms, and video identification for regions of interest are implemented in practice, bridges can potentially be inspected from underside without affecting traffic on the roadway, thus relieving traffic congestion and reducing safety risks for both inspectors and passengers.
- Once the workforce training framework is complete, it can train potential transportation workforces with a wide range of cultural and technical backgrounds. For example, the robotic operation and control training in a game-like realistic environment for bridge inspections not only motivates the interest of young college graduates but also makes senior engineers effectively learn the advanced technologies in an intuitive manner.

5. CHANGES/PROBLEMS

5.A - Changes in Approach and Reasons for Change

No Change to Report.

5.B - Actual or Anticipated Problems or Delays and Actions or Plans to Resolve Them

The University of Colorado, Boulder, encountered difficulty in securing non-federal match funds. Currently, the INSPIRE UTC director is in the process of initiating a pooled-fund study with several State Departments of Transportation and encouraging the Associate Director at the University of Colorado, Boulder, to engage with the Colorado State Department of Transportation and seek its participation in the pooled-fund study. The financial commitment from the Colorado State Department of Transportation can be used as non-federal match funds for the project at the University of Colorado, Boulder.

5.C - Changes That Have a Significant Impact on Expenditures

No Change to Report.

5.D - Significant Changes in Use or Care of Animals, Human Subjects, And/or Biohazards

Nothing to Report.

5.E - Change of Primary Performance Site Location from That Originally Proposed

No Change to Report.

6. SPECIAL REPORTING REQUIREMENTS

Nothing to Report.